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Ambient air quality assessment and modelling across phases of road construction: A case study of the Jalgaon-Bhadgaon state highway, India

Anilkumar Dattatray Shimpi*, Ashok Maruti Datir, Pravin Mukund Nalawade

Department of Environmental Science, K.R.T. Arts, B.H. Commerce and A.M. Science (KTHM) College, Affiliated with Savitribai Phule Pune University, Pune, Nashik, Maharashtra, India

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ABSTRACT

Highway construction, a critical driver of economic growth in developing nations like India, is a significant but understudied source of ambient air pollution. While numerous studies have modelled urban air quality, a gap exists in phase-specific, empirical assessments of pollution from road construction activities. This study presents a detailed assessment of ambient air quality across all construction phases of the Jalgaon-Bhadgaon State Highway (NH-753J), Maharashtra. Monitoring of PM_{10}, $PM_{2.5}$, NO_2, SO_2, and CO was conducted at seven strategic locations (including intersections and straight sections) using High-Volume Samplers following CPCB guidelines. Results indicate that initial phases, Cleaning & Grubbing, Granular Sub-Base, and Wet Mix Macadam, were the most polluting, with PM_{10} and $PM_{2.5}$ concentrations exceeding National Ambient Air Quality Standards (NAAQS) by up to 169%. Major intersections showed 30-45% higher pollution levels compared to straight sections due to vehicular congestion. A significant surge in CO levels (5-7 ppm) was recorded during asphalt-related activities (Base and Top Coat). The study concludes that pollution mitigation efforts, such as mandatory water sprinkling and optimised traffic management, must be phase-specific and focused on high-risk zones like junctions. This research provides a robust dataset for validating air quality models and formulating targeted policies for sustainable infrastructure development.

***Corresponding Author:** Anilkumar Dattatray Shimpi ✉ anilkumarshimpi@yahoo.com

INTRODUCTION

India's ambitious infrastructure development agenda, epitomised by initiatives like the National Infrastructure Pipeline, has led to an unprecedented expansion of its road network (Ministry of Finance, 2021). While vital for economic growth, this construction boom poses significant environmental challenges, particularly to ambient air quality (Guttikunda and Calori, 2019). Road construction is a complex process involving earthworks, material transport, crushing, paving, and asphalt laying, each phase emitting distinct pollutants including particulate matter (PM), nitrogen oxides (NOx), sulfur dioxide (SO_2), and carbon monoxide (CO) (Amarullah *et al.*, 2022; EPA, 2022).

Numerous studies have documented the deterioration of air quality in urban centres (Sharma and Dikshit, 2016), but the transient and dispersed nature of construction activities has made them a less-studied source, despite their significant contribution (Cement Sustainability Initiative, 2019). Existing research often treats "construction" as a single entity, overlooking the nuanced emission profiles of different phases. For instance, earthmoving generates coarse PM, while asphalt laying emits fine PM and hazardous volatile organic compounds (VOCs) and CO (Ehsan *et al.*, 2023; Liu *et al.*, 2023). Furthermore, the interplay between construction emissions and pre-existing traffic pollution at intersections creates critical hotspots that are poorly quantified (Goel *et al.*, 2022).

Previous modelling studies in India have highlighted the need for improved, localised emission inventories to enhance predictive accuracy (Guttikunda and Mohan, 2014). Empirical, phase-specific data are crucial for building these inventories. While international studies have begun this work (Ammann *et al.*, 2023; Nega *et al.*, 2022), a definitive study in the Indian context, with its unique climatic conditions, material usage, and regulatory landscape, is lacking. This study aims to address a critical gap in understanding ambient air pollution during highway construction by quantifying the concentrations of PM_{10}, $PM_{2.5}$, NO_2, SO_2, and CO across each discrete phase of a live highway project. Additionally, it will compare pollution levels between high-traffic intersections and straight road sections to identify any amplification effects that may arise. Furthermore, the study will evaluate compliance with National Ambient Air Quality Standards (NAAQS) and discuss the findings in the context of global literature, ultimately suggesting targeted mitigation strategies to improve air quality during construction activities.

MATERIALS AND METHODS

Study area

The study was conducted on the up-gradation project of NH-753J, connecting Jalgaon to Bhadgaon (Chainage: Km 4+000 to Km 56+200) in Maharashtra, India. This site was selected for its representativeness of typical highway expansion projects in India. Fig. 1 shows the location map of the study area.

Fig. 1. Location map of the study area showing the stretch of Jalgaon-Bhadgaon Highway

Construction phases monitored

The air quality was monitored across eight distinct phases of the highway construction project. The first phase was the Baseline phase, which assessed pre-construction conditions. This was followed by the Clearing and Grubbing phase, where vegetation and topsoil were removed. Next came the Granular Sub-Base (GSB) Preparation phase, during which the foundation layer was laid and compacted. This was succeeded by the Sub-Grade phase, which involved preparing the soil foundation. The Wet Mix Macadam (WMM) phase focused on laying the sub-base layer, followed by the Base Course (BC) phase, during which the bituminous base layer was applied. The final wearing course was added in the Top Coat phase, and the process concluded with the Road Furniture Installation phase, which included marking, signage, and the installation of amenities. Fig. 2 illustrates the cross-sectional layers of the road, and Table 1 provides detailed specifications of each layer.

Table 1. Detailing about the various layers (Cross sections) of road construction

Road construction layers	Activities detailed raw material used
Cleaning and grubbing	Clearing means the removal of all vegetation, while grubbing is the removal of roots that may remain in the soil. This includes the removal of all logs, brush, and debris, further as grinding and removal of stumps
Granular base preparing	The granular subbase forms the lowest (bottom) layer of the pavement structure, and acts as the principal foundation for the subsequent road profile, provides drainage for the pavement structure, and protects the structure from frost.
Sub-grade	Subgrade is that portion of the earth roadbed which after having been constructed to reasonably close conformance with the lines, grades, and cross-sections indicated on the plans, receives the base or surface material. In a fill section, the subgrade is the top of the embankment or the fill
Sub base	Subbase is the layer of aggregate material laid on the subgrade, on which the base course layer is located. It may be omitted when there will be only foot traffic on the pavement, but it is necessary for surfaces used by vehicles.
Base course	Base Course. The layer immediately beneath the surface course. It provides additional load distribution and contributes to drainage. Base courses are usually constructed out of crushed aggregate or HMA.
Binder course	The binder course is an intermediate, bitumen bound aggregate layer placed between the base layer and the surfacing of asphalt pavement, sometimes referred to as a levelling course. The binder course's function is to distribute the load from the surfacing into the base course, strengthening the pavement.
Surface coat	Surface Dressing is a mixture of polymer modified bitumen emulsion and a layer of chippings. It will seal the surface, improve surface texture and prolong the life of the road by many years.
Top coat	In the construction of a pavement, three coats are applied depending on the situation of existing surface. They are prime coat, tack coat and seal coat. Basically, these are types of bituminous road according to construction
Road furniture (Road marking, cat-eyes, highway lighting etc.)	Street furniture is a collective term for items and structures that are installed on Road such the Road Marking, Cat-eyes, High lighting. or placed in public areas and other outdoor public spaces for various purposes

Table 2. Monitoring locations along Jalgaon–Badgaon National Highway (NH-7753J)

# Location name / Village / Town	Latitude (N)	Longitude (E)	Distance from Jalgaon (Km)
1 Icchwa Devi Chowk	20°59″42.54′	75°33″57.21′	4.000
2 Shirsoli	20°55″11.91′	75°31″36.31′	9.500
3 Wavadada Road Chowk	20°51″24.12′	75°30″1.85′	17.900
4 Pathari Village	20°49″29.93′	75°28″2.97′	22.850
5 Near Bahula Dam	20°41″52.53′	75°24″29.40′	39.750
6 Jalgaon–Chowk Pachora	20°39″57.61′	75°21″49.21′	46.590
7 Maharanapratap Chowk Pachora	20°39″50.08′	75°20″4.94′	50.050

Monitoring locations

Seven strategic monitoring locations were selected along the highway stretch, including major intersections and straight rural sections. Table 2 lists the monitoring locations with chainage and site characteristics.

Fig. 2. Various layers (Cross sections) of road construction

Sampling and analysis

Ambient air sampling was conducted as per CPCB guidelines (CPCB, 2019). Particulate matter (PM_{10} and $PM_{2.5}$) was collected using an Envirotech APM 460 NL High-Volume Sampler operating at a flow rate of 1.1-1.4 m^3/min for 24-hour durations. Gravimetric analysis was performed after conditioning the filters in a desiccator. Gaseous pollutants (SO_2, NO_2) were absorbed in appropriate solutions ($NaOH/NaAsO_2$ for SO_2; TCM/NaOH for NO_2) and analysed spectrophotometrically. CO was measured using a non-dispersive infrared (NDIR) sensor-based portable analyser.

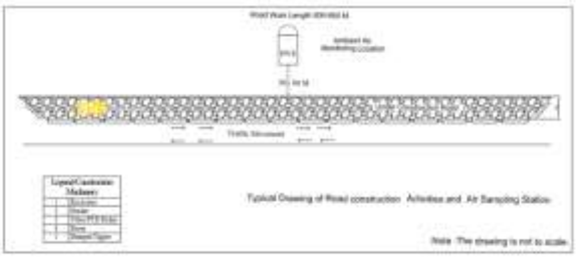

Fig. 3. Locations of HVS monitoring during road construction activity

Quality Assurance and Quality Control (QA/QC) protocols were rigorously implemented throughout the monitoring program to ensure the accuracy, precision, and reliability of the measured data. These procedures included the use of field blanks, routine flow rate calibration, and instrument zeroing before each sampling event. Pollutant concentrations were calculated using standard analytical formulae and evaluated against the 24-hour National Ambient Air Quality Standards (NAAQS), namely 100 µg/m^3 for PM_{10}, 60 µg/m^3 for $PM_{2.5}$, 80 µg/m^3 for NO_2, 80 µg/m^3 for SO_2, and 2 ppm for CO. Fig. 3 illustrates the deployment of high-volume samplers (HVS) used during the air quality monitoring campaign.

Ethics approval and consent to participate

The study complied with ethical guidelines set by Savitribai Phule Pune University. As it involved environmental monitoring without human or animal subjects, no specific ethics approval or participant consent was required.

RESULTS AND DISCUSSION

Particulate matter (PM_{10} and $PM_{2.5}$)

The highest concentrations of both PM_{10} and $PM_{2.5}$ were observed during the initial Clearing and Grubbing phase across all locations. At Icchwa Devi Chowk, PM_{10} peaked at 423 µg/m^3, exceeding the NAAQS by 323%. $PM_{2.5}$ levels showed a similar trend, reaching 188 µg/m^3 at the same location, a 213% exceedance. Table 3 presents PM10 concentrations across all phases and locations. Similarly, Table 4 shows PM2.5 data.

This is consistent with global studies identifying earthmoving and soil disturbance as the primary source of fugitive dust at construction sites (Ammann *et al.*, 2023; Nega *et al.*, 2022). The mechanical action of excavators, bulldozers, and the movement of heavy vehicles on unpaved surfaces suspend large quantities of soil-derived particulates into the atmosphere (EPA, 2022).

A clear spatial gradient was evident, with intersections consistently recording 30-45% higher PM concentrations than straight sections during the same phase. This can be attributed to the "congestion-emission" effect, where vehicles idling, accelerating, and decelerating at junctions resuspend settled construction dust and contribute their own exhaust emissions, creating a compounded pollution hotspot (Goel *et al.*, 2022; Sharma and Dikshit, 2016). As construction progressed to the WMM and BC phases, PM levels showed a marked decline, often falling close to or below baseline levels, as activities became less dust-generative and the surface was progressively sealed.

Table 3. Ambient air parameters-PM 10: Particulate matter (Size less than 10µm): 100 PPM

Ambient air parameters: PM 10							
Particulate matter (Size less than 10µm): 100 PPM							
Road layer details	Icchwa Devi Chowk	Shirsoli	Vadada Road Chowk	Pathri Village	Bahula Dam	Jalgaon Chowk-Pachora	Maharna Chowk Pachora
Baseline reading	234.00	39.07	45.34	47.58	49.00	92.00	86.00
Cleaning and grabbing	423.00	98.81	110.53	120.57	132.00	185.00	168.00
Granular base preparing	380.00	62.94	72.33	66.77	76.00	172.00	166.00
Sub-grade	365.00	76.15	74.17	67.66	88.00	174.00	162.00
Sub base (WMM)	280.00	63.41	46.26	48.49	58.00	98.00	112.00
Base course (BC)	285.00	44.60	46.26	48.15	56.00	84.00	106.00
Top coat	296.00	36.00	37.00	35.65	48.00	89.00	92.00
Road furniture (Road marking, cat-eye)	264.00	31.00	33.20	32.80	42.00	78.00	82.00

Table 4. Ambient air parameters-PM 2.5: Particulate matter (Size less than 2.5 µm):60 ppm

Ambient air parameters: PM 2.5							
Particulate matter (Size less than 2.5 µm): 60 ppm							
Road layer details	Icchwa Devi Chowk	Shirsoli	Vadada Road Chowk	Pathri Village	Bahula Dam	Jalgaon Chowk-Pachora	Maharna Chowk Pachora
Baseline reading	158.00	15.49	15.38	17.80	18.80	68.00	62.00
Cleaning and grabbing	188.00	51.00	52.00	49.86	51.00	89.00	93.00
Granular base preparing	164.00	31.72	38.00	37.35	45.00	91.00	95.00
Sub-grade	160.00	33.00	35.00	34.00	38.00	64.00	62.00
Sub base (WMM)	152.00	20.00	19.00	21.00	23.00	54.00	51.00
Base course (BC)	154.00	16.00	15.40	17.69	20.00	45.00	46.00
Top coat	142.00	12.00	13.23	12.80	15.00	44.00	47.00
Road furniture (Road marking, cat-eye)	132.00	9.20	8.60	8.20	8.30	45.00	45.70

Table 5. Ambient air parameters- Nitrogen dioxide (NO_2)

Ambient air parameters	Nitrogen Dioxide (NO_2)						
National ambient air quality standards (NAAQS) in India	24-hour average is 80 µg/m3, and the annual average is 40 µg/m3						
Road layer details	Icchwa Devi Chowk	Shirsoli	Vadada Road Chowk	Pathri Village	Bahula Dam	Jalgaon Chowk-Pachora	Maharna Chowk Pachora
Bsaeline reading	34.00	24.32	25.00	23.20	20.20	28.45	29.00
Cleaning and grabbing	42.00	27.00	28.00	29.00	24.00	32.00	33.23
Granular base preparing	37.00	25.00	25.78	25.00	22.00	31.00	31.00
Sub-grade	34.00	25.00	25.23	24.00	21.00	27.00	30.00
Sub base (WMM)	34.00	25.00	25.23	24.00	21.00	27.00	30.00
Base course (BC)	32.00	23.00	23.00	22.00	19.00	26.00	28.00
Top coat	31.50	22.00	22.00	21.00	18.10	25.00	26.00
Road furniture (Road marking, cat-eye)	31.50	22.00	22.00	21.00	18.10	25.00	26.00

Gaseous pollutants (NO_2 and SO_2)

NO_2 levels showed a moderate increase (12-25%) during the initial earthwork phases, likely due to the intensive use of diesel-powered construction equipment like excavators, rollers, and trucks, which are significant sources of NOx (Liu *et al.*, 2023). Concentrations, however, remained within NAAQS limits at all times. SO2 levels showed minimal fluctuation throughout the project and were consistently well below the standard. This suggests that the construction machinery and materials used (e.g., diesel, bitumen) were not significant sources of SO_2 emissions for this project, a finding supported by other lifecycle assessments of construction activities (Cement Sustainability Initiative, 2019). Table 5 shows NO_2 trends, while Table 6 presents SO_2 data.

Table 6. Ambient air parameters-sulfur dioxide (SO2)

Ambient air parameters	Sulfur dioxide (SO_2)						
National ambient air quality standards (NAAQS) in India	The 24-hour average is 80 µg/m3, and the annual average is 50 µg/m3.						
Road layer details	Icchwa Devi chowk	Shirsoli	Vadada road chowk	Pathri village	Bahula dam	Jalgaon chowk-pachora	Maharna chowk pachora
Baseline reading	22.00	15.00	14.00	14.00	14.00	18.00	17.00
Cleaning and grabbing	24.00	17.00	17.00	17.00	17.00	20.00	20.00
Granular base preparing	20.00	15.00	15.00	15.00	15.00	19.00	19.00
Sub-grade	20.00	15.00	15.00	15.00	15.00	19.00	19.00
Sub base (WMM)	14.00	12.00	12.00	13.00	12.45	14.00	14.00
Base course (BC)	30.00	18.00	17.00	17.00	17.00	22.00	24.00
Top coat	31.00	18.00	18.00	18.00	18.00	23.00	25.00
Road furniture (Road marking, cat-eye)	20.00	12.00	12.00	8.00	10.00	14.00	15.00

Table 7. Ambient air parameters- Carbon monoxide (CO)

Ambient air parameters	Carbon monoxide (CO)						
National ambient air quality standards (NAAQS) in India	For CO, the 8-hour average is 2 ppm (parts per million)						
Road layer details	Icchwa Devi chowk	Shirsoli	Vadada road chowk	Pathri village	Bahula dam	Jalgaon chowk-pachora	Maharna chowk pachora
Baseline reading	5.00	2.00	1.50	2.00	2.00	3.00	3.00
Cleaning and Grabbing	3.00	2.00	2.00	2.00	2.00	2.00	2.00
Granular base preparing	3.00	3.00	2.00	2.00	2.00	2.00	2.00
Sub-grade	2.00	2.00	1.00	1.00	1.00	1.00	1.00
Sub base (WMM)	2.00	2.00	1.00	1.00	1.00	1.00	1.00
Base course (BC)	9.00	7.00	7.00	7.00	7.00	6.00	7.00
Top coat	9.00	7.00	7.00	7.00	7.00	6.00	7.00
Road furniture (Road marking, cat-eye)	3.00	1.00	1.00	2.00	1.00	2.00	2.00

Table 8. Ambient air pollution comparison at urban area and rural area (At Time WMM & BC Layer)

Area	Location	PM10 (µg/m³)	PM2.5 (µg/m³)	Remarks
Urban area	Icchaw Devi Chowk, Jalgaon	320	165	Icchaw Devi Chowk is connecting road Chalisgoan, Nagapur and Mumbai
Village area	Shirsoli village (During WMM)	64	42	Single straight road
	Shirsoli village (During BC)	41	15	Single straight road

Carbon monoxide (CO)

A significant and concerning finding was the sharp increase in CO levels during the BC and Top Coat phases. Concentrations rose to 6-9 ppm, exceeding the NAAQS (2 ppm) by 300-450% (Table 7). This is directly linked to the operation of hot-mix asphalt plants and the on-site application machinery (pavers, rollers). The heating of asphalt releases a complex mixture of emissions, including CO and VOCs (Ehsan *et al.*, 2023). This phase-specific spike is often overlooked in general construction impact assessments but poses a significant health risk to workers and nearby residents, requiring specific mitigation measures like proper PPE and ensuring good ventilation downwind of the paving activity.

Urban vs. Rural comparison

The data unequivocally showed that the urban intersection (Icchwa Devi Chowk) had significantly higher pollution levels (PM_{10}: 320 µg/m³; $PM_{2.5}$: 165 µg/m³ during WMM) compared to the rural straight section (Shirsoli Village: PM_{10}: 64 µg/m³; $PM_{2.5}$: 42

μg/m³ during WMM) (Table 8). This underscores the synergistic effect of construction activities with high background traffic volumes (PCU count ~20,500 at the junction vs. ~5,500 on the straight section), amplifying the overall pollution burden in urban corridors (Guttikunda and Calori, 2019).

CONCLUSION

This study analyses air pollution from highway construction in India, highlighting significant findings. The initial earthwork phases (Clearing, Grubbing, Earthwork) are major contributors to particulate matter pollution, frequently exceeding NAAQS. Traffic intersections intensify dust concentrations due to vehicular turbulence, while asphalt laying (Base and Top Coat) emerges as a key source of carbon monoxide, leading to localised exceedances. The urban environment worsens air quality effects due to existing pollution and congestion. The study calls for phase-specific pollution control measures such as mandatory water sprinkling and dust suppression systems for PM control, alongside enhanced machinery maintenance and traffic management plans to mitigate congestion. This research provides critical data for developing accurate emission factors for Indian construction, aiming to improve air quality models. Future efforts should focus on real-time monitoring and health impact assessments to better understand the public health implications of infrastructure projects.

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