Proceedings of the 9th World Congress on Civil, Structural, and Environmental Engineering (CSEE 2024)
London, United Kingdom – April 14-16, 2024
Paper No. ICEPTP 118
DOI: 10.11159/iceptp24.118

NH-16 Traffic and Meteorology Impact on Ozone Pollution in Kharagpur, India

Samrat Santra[1,]*, Aditya Kumar Patra[2], Arpan Chakraborty[3], Abhishek Penchala[4]
[1]School of Environmental Science and Engineering, Indian Institute of Technology Kharagpur, Kharagpur, West Bengal India, 721302
santra127samrat@kgpian.iitkgp.ac.in
[2]Department of Mining Engineering, Indian Institute of Technology Kharagpur, Kharagpur, West Bengal India, 721302
akpatra@mining.iitkgp.ac.in
[3]Department of Humanities and Social Sciences, Indian Institute of Technology Kharagpur, Kharagpur, West Bengal India, 721302
arpan.ms97@kgpian.iitkgp.ac.in
[4]Department of Mining Engineering, Indian Institute of Technology Kharagpur, Kharagpur, West Bengal India, 721302
abhishekpenchala@kgpian.iitkgp.ac.in

***Abstract* -** This study focuses on ozone (O_3) pollution resulting from road traffic in India (special focus on National Highways), where diesel and petrol are major fuels used for transportation system which are major contributors to O_3 forming precursors such as NO_x and VOC emissions. Data is collected by using a Serinus 10 ozone analyzer and a portable weather station Kestrel 5500. Using Multiple Linear Regression (MLR), O_3 concentration levels are predicted along NH-16 in Kharagpur, West Bengal, India. The MLR model performance is assessed by R-squared, and F-test, along with AIC and BIC tests which are evidencing that MLR is the most suitable model, accurately predicting O_3 pollution levels. The study reveals that the 8-h average O_3 concentrations (117.24 µg m^{-3}) exceed NAAQS 2009 (100 µg m^{-3}) and WHO 2021 (100 µg m^{-3}) standards. Higher traffic volume correlates negatively ($r = -0.87$) with lower O_3 levels. Moderate south-east winds elevate O_3 levels and transport pollutants away from the traffic area. Urgent action is needed, including comprehensive O_3 pollution assessment on India's national highways and policy measures to mitigate it.

***Keywords*:** Ozone, Pollution, Correlation, Meteorology, Traffic, Regression, NH-16

1. Introduction

Ozone (O_3) acts as a strong oxidizing agent in the lower atmosphere (troposphere) [1], generated through chemical reactions involving oxides of nitrogen (NO_x) and volatile organic compounds (VOCs) [2]. The rapid pace of urbanization has exposed many individuals to elevated O_3 levels, increasing the risk of both immediate and long-term health consequences [3]. Numerous epidemiological studies have unearthed a connection between ozone concentrations and hospital admissions for a range of medical ailments such as pregnancy complications [4], conjunctivitis [5], influenza [6], mortality risks [7] including various respiratory issues [8]. The road traffic emerges as the predominant source of emissions for photochemical precursors like NO_x and VOCs [9]. In India, road transportation predominantly relies on diesel and petrol as fuel sources [10]. Fuels such as diesel, petrol, kerosene, and LPG (liquefied petroleum gas) significantly contribute to NO_x and VOC emissions in traffic [11]. Additionally, meteorological factors such as temperature and humidity influence O_3 formation, while wind speed aids in dispersing O_3 molecules and their precursors from their source regions to more distant areas [12]. Typically, O_3 levels tend to be higher in rural regions or areas distant from urban centres and heavy traffic locations [13].

A very few research studies conducted on the adjacent areas of Indian national highways and consistently reported elevated levels of O_3 concentration attributed to vehicular emissions [14], [15], [16]. No significant study has been done on ozone pollution by denoting a particular national highway in India. Furthermore, considering the significant consequences for both public health and the environment, it becomes imperative to cultivate a comprehensive understanding of the mechanisms and variables contributing to O_3 formation along India's national highways, as well as its dispersion into neighbouring areas.

In the realm of modelling ozone levels, the Multiple Linear Regression (MLR) model, a well-proven method, has been shown to be highly effective in predicting ozone concentrations by uncovering correlations with other relevant parameters [17]. In the context of this study, a multiple linear regression method is used for to predict O_3 concentration along NH-16, utilizing meteorological variables such as temperature (T), relative humidity (RH), wind speed (WS) and wind direction (WD).

Despite extensive research on ground-level ozone variations and their potential causes in urban areas, there is a notable research gap regarding this issue in open-traffic settings. The central aim of our investigation is to quantitatively assess how traffic volume data and meteorological variables impact variations in O_3 concentration levels along the NH-16 of India. To assess the model's performance, R-squared and F-test were evaluated. To check the model's goodness of fit, Akaike Information Criterion (AIC) test and Bayesian Information Criterion (BIC) test were conducted. The subsequent section outlines the study site and data collection method. Section 3 delves into the results and discussion, while the final section offers a summary and conclusions.

2. Methods

2.1 Study site

On-site measurements were conducted at a traffic location situated at Kanchdiha (22.382144°N, 87.403331°E) along the National Highway 16 (NH-16) in Kharagpur, West Bengal, India. NH-16 is commonly known as Chennai-Kolkata Highway which is one of the major and important national highways in India. NH-16 acts as a crucial transportation route connecting major cities along India's eastern coast. The study area lacks any structural or residential development and primarily serves as a thoroughfare for vehicular traffic along the Chennai-Kolkata Highway.

2.2 Sampling protocol

The O_3 concentrations were measured using an USEPA-approved method applied instrument (Model: Serinus 10, Make: Acoem, Australia) that utilizes ultraviolet (UV) absorption technology at a wavelength of 254 nm. Data collection took place from February 14th to February 24th, 2023, with observations made from 07:00 to 19:00 each day. To complement the O_3 measurements, a portable weather station (Model: Kestrel 5500, Make: KestrelInstruments, USA), was utilized for the measurement of T, RH, WS and WD. These instruments were positioned at a height of 1.5 meters above the ground surface on the south side of the road, situated 6.7 meters (22 feet) away from the road's edge (Fig. 1). To monitor traffic levels, manual traffic counts were conducted. This involved recording the number of vehicles passing through the study area for a 15-minute duration every hour [18], throughout the entire study duration.

2.3 Multiple linear regression

In this context, the dependent variable that denoted as y_i represents the concentration of O_3. The independent variables that denoted as x_{ip} encompass factors such as T, RH, WS and WD. We introduce an error term ϵ_i to account for any unexplained variability in the model. Consequently, the linear regression model can be expressed as follows

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + \beta_4 x_{i4} + \epsilon_i; \quad i = 1(1)n$$

Or,

$$y_i = \beta_0 + \sum_{p=1}^{4} \beta_p x_{ip} + \epsilon_i; \quad i = 1(1)n$$

Where, p =1,2,3,4 denotes four regressors, and n denotes the number of observations respectively.

Fig. 1: Data collection on NH-16 in Kharagpur, India

3. Results and Discussion

3.1 Traffic volume impacts on O_3 concentration

The vehicle composition at the study site consisted of several categories, which included motorbikes (2 wheelers), autos (3 wheelers), cars/jeeps/vans (4 wheelers), buses (6 wheelers), light commercial vehicles or LCVs (4 - 6 wheelers), and heavy commercial vehicles or HCVs (6 wheelers or more). These categories represented 32.4%, 1.7%, 25.1%, 2.3%, 13.2%, and 25.3% of the total fleet, respectively (Fig. 3b). Motorbikes and HCVs were the most prevalent vehicle types, whereas autos and buses were comparatively less abundant. Throughout the day, there were fluctuations in traffic volume, with the highest levels occurring in the morning and evening and the lowest levels in the afternoon. There was a strong negative correlation (r = -0.87) between traffic volume (TV) and O_3 concentration (Fig. 3a).

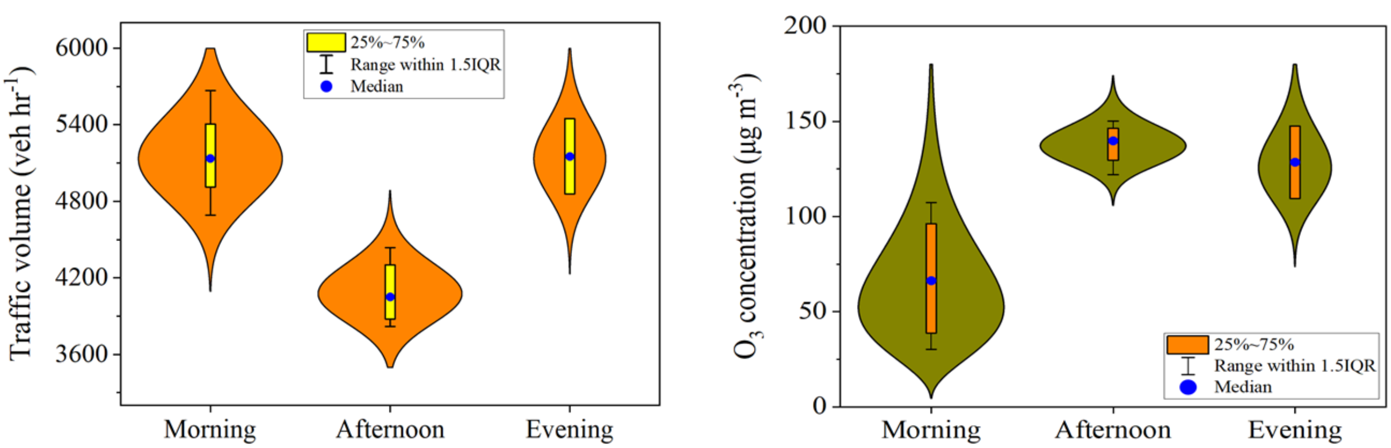
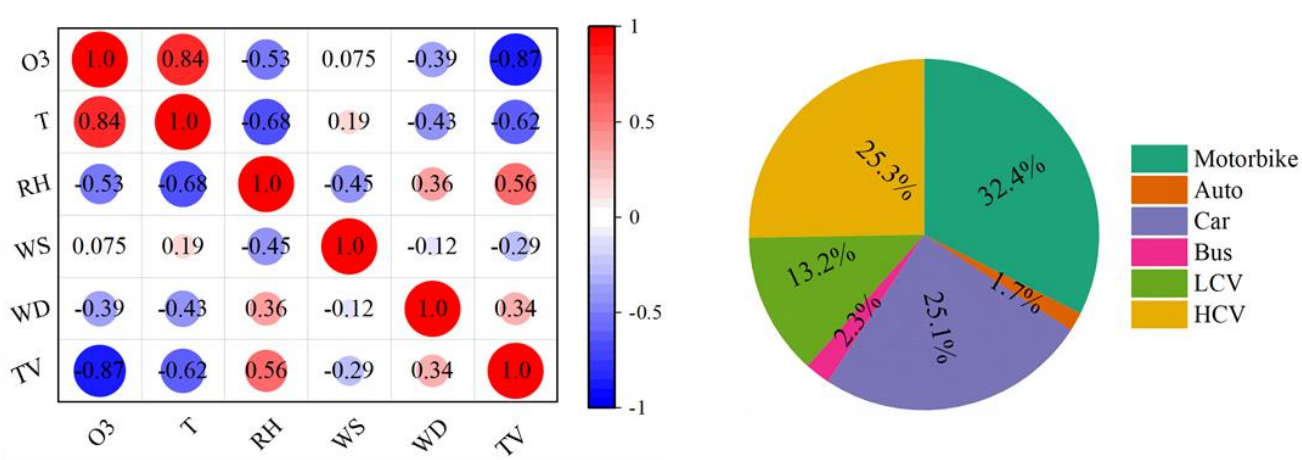


Fig. 2: Variation across the day: (a) Traffic volume (b) O_3 concentration

Figure 2 illustrates a relationship wherein an increased number of vehicles (mixed traffic flow) leads to decreased O_3 concentration during morning and evening hours at the traffic site. This decrease in O_3 concentration is primarily attributed to high vehicle volume, which serves as a major contributor to elevated emissions of NO_x, particularly nitric oxide (NO) [19]. These newly emitted NO molecules rapidly react with ozone O_3 molecules [20], [21] leading to the formation of nitrogen dioxide (NO_2) and molecular oxygen (O_2). As a result, this chemical transformation results in a noticeable decrease in the concentration of ground-level ozone (GLO) [22] during the morning and evening at the traffic site. This phenomenon highlights the significant role of vehicular emissions in influencing GLO chemistry [23], and air quality dynamics in traffic areas [24], [25]. But during afternoon, increased O_3 concentration was observed due to decreased number of vehicles at the traffic site. This increase in O_3 concentration is primarily attributed to the low vehicle volume, so lower emission of fresh NO thus lower destruction of O_3 molecules and high photochemistry of NO_2 to O_3 formation due to high solar insolation.

3.2 Meteorological impacts on O_3 concentration

Meteorology played an important role in O_3 concentration variation at the traffic site where temperature exhibited a strong positive correlation (r = 0.84) with O_3 concentration, while relative humidity displayed a negative correlation (r = -0.53) (Fig. 3a). When the wind was blowing from the south-east (SE) to the north-west (NW) at a relatively low to moderate speed (0.5 to 1.25 m s^{-1}), the concentration of O_3 in the air was high (Fig. 4). It is evident that wind speed played a pivotal role in carrying O_3 molecules and their precursors away from the traffic site [26]. The wind was dispersing O_3 molecules and ozone forming precursors (NO_x and VOC) towards the adjacent rural areas located on both the sides of NH-16. When the wind direction shifts, it is likely that other rural areas in close proximity to NH-16 will also be affected by these pollutants.



(a) (b)

Fig. 3: (a) Correlation analysis of the variables (b) Composition of traffic fleet

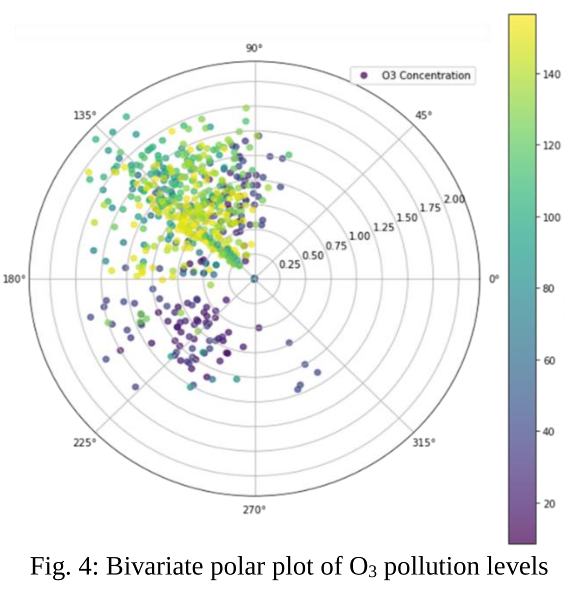


Fig. 4: Bivariate polar plot of O_3 pollution levels

3.3 Variability in O_3 concentration and its prediction

The average 8-hour GLO concentrations, measured from 09:00 to 17:00, were recorded at 117.22 μg m^{-3}. These measurements revealed that the maximum daily average 8-hour (MDA8) GLO concentration exceeded both the NAAQS 2009 and WHO 2021 standards of 100 μg m^{-3}. This variation can be attributed to the presence of precursors such as NO_x and VOCs originating from traffic emissions. These precursors exhibit rapid changes in line with the photo-stationary state of the NO-NO_2-O_3 chemical system [27]. Additionally, the study observed lower O_3 concentrations during the morning and evening hours, while higher ozone concentrations were observed during the afternoon at the study site (Fig. 5). Table 1 provides a comprehensive descriptive analysis of all the essential variables examined in the study.

A multiple linear regression model is an advanced version of the simple linear regression model designed to analyse data with more than one predictor variable while still predicting a single outcome variable [28], [29]. Our analysis revealed the significance of all four chosen regressors T, RH, WS and WD in influencing O_3 concentration. This implied that each of these variables played a role in affecting ozone levels. Specifically, we found that temperature had the most substantial impact on O_3 concentration, with a coefficient of 20.95 and a high level of statistical significance at 99%. This suggests that for every 1°C increase in temperature, we observed a corresponding increase in O_3 concentration by 20.95 units. Furthermore, wind speed demonstrated a strong negative influence on O_3 concentration, with a coefficient of -8.85 and a high statistical significance at 99%. This indicates that a one-unit increase in wind speed leads to an 8.85-unit decrease in GLO concentration. In contrast, both wind direction and relative humidity are statistically significant, but their coefficients have comparatively smaller magnitudes in relation to O_3 concentration. These variables still contribute to influencing O_3 levels, though to a lesser extent compared to temperature and wind speed. To evaluate the goodness of fit of our model, we considered several metrics: AIC (Akaike Information Criterion), BIC (Bayesian Information Criterion), and the R-squared. Our model yielded values of 4291.42 for AIC, 4312.30 for BIC, and an R-squared of 0.64. Lower AIC and BIC values, along with a higher R-squared, indicate a strong fit for our model. For detailed results, please refer to Table 2, which provides a comprehensive overview of our findings. Figure 6 portrays a comparative assessment of measured ozone concentrations in relation to their corresponding predicted values.

Table 1: Descriptive statistics of variables at the traffic site and rural site

Study sites	**O_3 (μg m^{-3}) (Min-Max) Avg ± SD**	**T (°C) (Min-Max) Avg ± SD**	**RH (%) (Min-Max) Avg ± SD**	**WS (m s^{-1}) (Min-Max) Avg ± SD**
Traffic	(8.53-156.46) 98.45 ± 45.12	(18.65-30.33) 26.96 ± 2.63	(22.75-93.6) 64.45 ± 15.50	(0-2.1) 0.86 ± 0.47
Rural	(19.50-150.64) 98.60 ± 37.69	(24.3-36.3) 29.91 ± 3.07	(50.4-91.3) 70.52 ± 10.72	(0-2.5) 0.42 ± 0.52

Table 2: Multiple linear regression of O_3 concentration

O_3	Coef.	St.Err.	t-value	p-value	95% Confi	Interval	Sig
Temperature	20.954	.827	25.35	0	19.329	22.578	***
Relative humidity	.614	.092	6.70	0	.434	.795	***
Wind speed	-8.848	2.808	-3.15	.002	-14.365	-3.33	***
Wind direction	.101	.035	2.88	.004	.032	.171	***
Constant	-514.793	28.906	-17.81	0	-571.592	-457.994	***

Mean dependent var	117.246	SD dependent var	34.658
R-squared	0.641	Number of obs	481
F-test	212.926	Prob > F	0.000
Akaike crit. (AIC)	4291.419	Bayesian crit. (BIC)	4312.299
*** p<.01, ** p<.05, *p<.1			

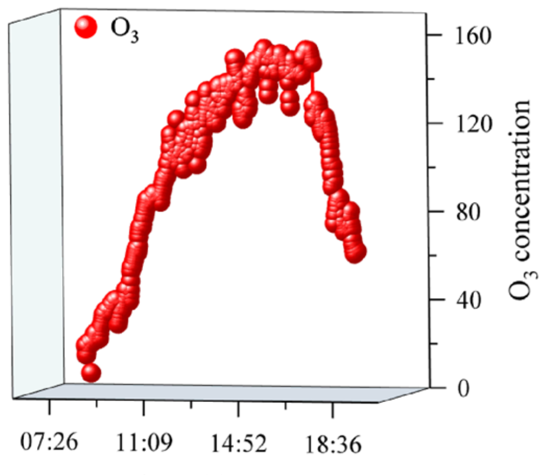


Fig. 5: O_3 concentration variation

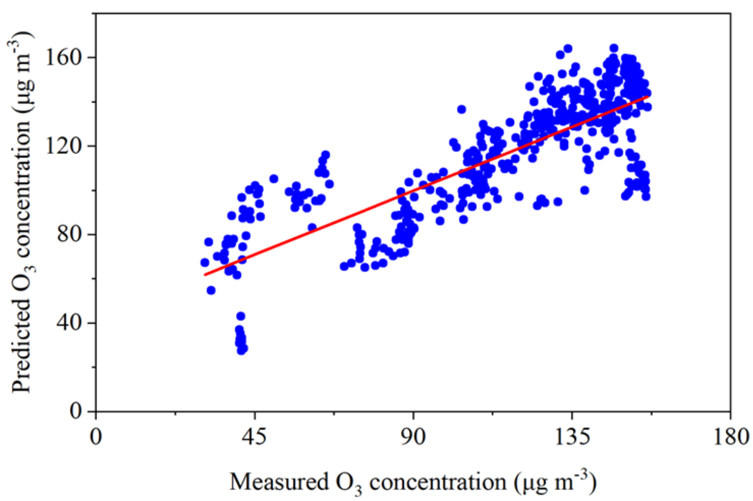


Fig. 6: Predicted vs measured values of O_3 concentration

4. Conclusion

The concentration of O_3 over an 8-hour period has been found to exceed the prescribed standards for both NAAQS 2009 and WHO 2021 along NH-16 in Kharagpur, India. Interestingly, there is a significant negative correlation (r = -0.87) between traffic volume and O_3 concentration, indicating that high traffic volume is associated with lower O_3 levels. Temperature shows a positive correlation, while relative humidity is negatively correlated with O_3 concentration. Moderate SE winds play a role in elevating O_3 levels at the study site and carrying O_3 molecules and their precursors away from the traffic area. When wind direction changes, it is likely that nearby rural areas along NH-16 will also be affected by these pollutants. The most suitable model for predicting O_3 concentration is multiple linear regression, as supported by the R-squared, AIC, and BIC analyses. This model successfully predicts O_3 pollution levels along NH-16 in Kharagpur, with the highest predicted concentration at 164.14 μg m^{-3}, closely matching the highest measured value of 156.46 μg m^{-3}. In light of these findings, urgent action is required to establish a comprehensive screening process for assessing O_3 pollution levels along all national highways in India. Furthermore, it is imperative to conduct further investigations and formulate policy measures aimed at effectively addressing and mitigating O_3 pollution levels along the national highways in India.

Acknowledgements

We express our gratitude to the esteemed School of Environmental Science and Engineering and the Department of Mining Engineering at IIT Kharagpur for their invaluable support in providing us with necessary instruments and facilitating seamless data collection at the study site. This work is supported by IIT Kharagpur, India.

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