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Assessment of the relationship between ground level ozone and meteorological parameters in Aizawl, Mizoram

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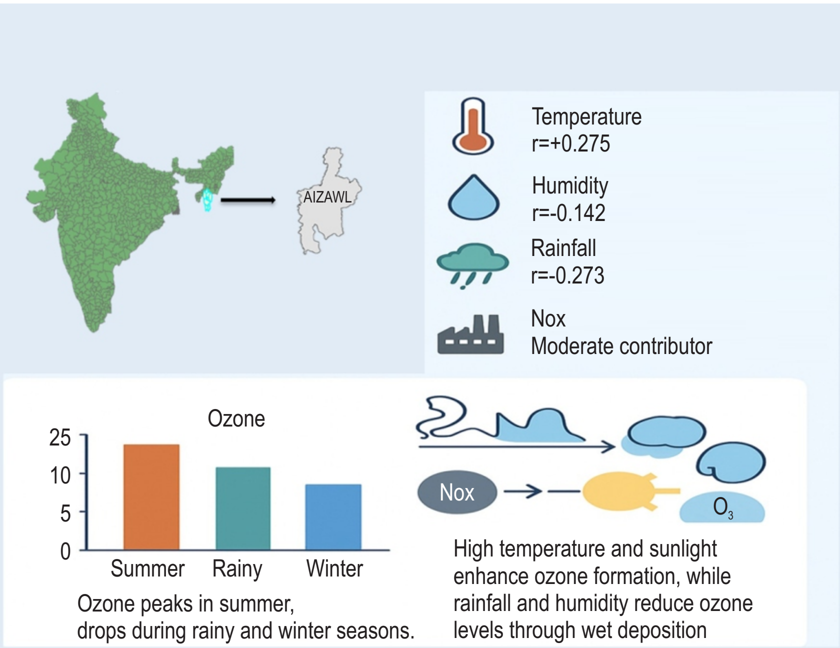
Abstract

Aim: This study explores the relationship between ground-level ozone and key meteorological parameters in Aizawl, Mizoram over a period from March 2022 to February 2023.

Methodology: Secondary data on ozone concentrations and meteorological parameters were analysed using SPSS tool and Excel to investigate the seasonal variability of ground-level ozone concentrations, and to examine diurnal variations to identify peak ozone levels occurring at specific time intervals within 24 hours. It also analysed the correlation between ground-level ozone concentrations and key meteorological parameters such as temperature, humidity, and wind speed.

Results: Seasonal and diurnal variations showed that ozone concentrations were highest in summer (33.34 μg m^{-3}) and lowest in winter (7.04 μg m^{-3}), with peak levels during morning hours (06:00 am to 11:59 am). Correlation analysis and multiple linear regression models were employed to determine the impact of these variables on ozone levels. Temperature had a weak positive correlation with ozone ($r = 0.275$, $p = 0.214$), while rainfall ($r = -0.273$, $p = 0.024$) and humidity ($r = -0.142$, $p = 0.018$) exhibited significant negative correlations.



Interpretation: Ground-level ozone is a secondary pollutant produced due to human activity and has the potential to influence meteorological parameters, as well as climate change.

Key words: Ground level ozone, Humidity, Rainfall, Temperature

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Introduction

Ground-level ozone, also known as tropospheric ozone, is a secondary pollutant formed through photochemical reactions involving nitrogen oxides (NOx) and volatile organic compounds (VOCs) in the presence of sunlight (Zulkifli *et al.,* 2022; Madruga, 2021). It is a significant photooxidant generated from photochemical reactions in urban areas (Zhang *et al.,* 2020). Ground level ozone (O_3) present in the troposphere is a key air pollutant and may have a stratospheric origin (Butler *et al.,* 2020; Lu *et al.,* 2019), although it depends on the characteristics of an area and their climate (Wang *et al.,* 2020). The remaining ozone is a secondary pollutant formed through a photochemical reaction between volatile organic compound and nitrogen oxides and CO in the presence of sunlight appear in the troposphere layer to form an ozone layer (Derwent, 2020).

The ozone level is at peak during day time and lowers during night due to NO titration (Akimoto and Tanimoto, 2022). It is also important to control NOx concentration in order to reduce the ozone level in the troposphere as it can recycle and live longer (Li *et al.,* 2021). Changes in the meteorological conditions can have an impact on ozone layer (Yang *et al.,* 2019), also temperature can influence the ozone level by increasing other chemical reaction occurring in the atmosphere (Boleti *et al.,* 2020). While ozone in the stratosphere protects life on Earth by absorbing ultraviolet radiation, ground-level ozone poses severe environmental and health risks (Goudarzi *et al.,* 2015). Elevated concentrations of ground-level ozone can adversely affect human respiratory health, crop yields and ecosystems, making it a significant concern for public health and environmental sustainability (Dewan *et al.,* 2023; Feng *et al.,* 2021). Recent studies in India have shown increasing trends in ozone concentrations attributed to rising vehicular and industrial operations (Sharma *et al.,* 2021).The formation and concentration of ground-level ozone are influenced by meteorological factors such as temperature, humidity, wind speed, and solar radiation (Chen *et al.,* 2020; Gorai *et al.,* 2015). Ozone levels tend to be higher under hot, bright conditions, encouraging photochemical ozone generation (Lu *et al.,* 2019).

Various linear and nonlinear regression models have been applied to examine the impact of climatic fluctuations on ozone concentrations (Thompson *et al.,* 2003). For instance, studies have employed the probabilistic approach (Cox and Chu, 1993), multi-variable additive model (Flaum *et al.,* 1996; Holland *et al.,* 1999), multilayer neural network (Gardner and Dorling, 2000; Lu and Chang, 2005), and generalized additive model (Zheng *et al.,* 2007) to explore the influence of temperature, wind speed, sunshine hours, and relative humidity on ozone concentration. Tong *et al.* (2017) discovered positive connections between ozone concentrations, solar radiation and air temperature, while relative humidity and heavy precipitation showed negative correlations. In another study, Chu *et al.* (2012) reported that temperature, wind speed, VOCs, and NOx are key variables that cause ozone fluctuations. They discovered a strong link between temperature, wind speed, and ozone levels, suggesting these meteorological parameters significantly impact ozone variability. Further, wind speed affects pollution transfer, influencing ozone concentrations in downwind sites. Wang *et al.* (2017) reported that bright sunshine and low wind speed increased ozone synthesis and accumulation, resulting in high concentrations. Tong *et al.* (2017) also discovered a non-linear positive relationship between ozone concentrations and wind speed. Temperature is one of the most critical meteorological characteristics that governs and influences the speed and amount of photochemical generation of ozone. It significantly impact ozone levels during most seasons of the year, except in winter, when wind speed, humidity, and duration of sunlight exposure plays a significant role in affecting ozone concentrations. Chen *et al.* (2019) found that temperature and humidity consistently affected ozone concentrations, while other components demonstrated higher fluctuations. Punithavathy *et al.* (2015) discovered a substantial reliance of ozone levels on temperature, indicating a considerable impact of temperature on ambient air ozone levels.

Seasonal fluctuations demonstrated the most significant ozone levels during summer and pre-monsoon periods whereas minimum levels occurred during the North-east monsoon and winter seasons. Areas with complex topography, such as valleys, can experience different ozone formation processes due to limited vertical and horizontal air movement, further complicating ozone dispersion and accumulation (Kang *et al.,* 2012).

Due to its geographical and topographical characteristics, Aizawl offers a distinctive case for studying such interactions. In this study, the relationship between ground-level ozone and meteorological parameters was assessed in the Aizawl city of Mizoram, India. The study was conducted to investigate the seasonal variability of ground-level ozone concentrations during winter, summer and rainy seasons, as well as to examine the diurnal variations to identify peak ozone levels occurring at specific time intervals within 24 hours. Furthermore, this research analyzed the correlation between ground-level ozone concentrations and key meteorological parameters such as temperature, humidity, and wind speed.

Materials and Methods

Study area: Aizawl, the capital city of Mizoram is situated 3715 feet above sea level, surrounded by hills and lush greenery, lending it a picturesque charm. Aizawl's economy is primarily based on government services, trade, and small-scale industries. Agriculture plays an important role, with shifting agriculture being the most common practices. The infrastructure of the city consists of narrow winding roads that traverse the hilly terrain, as well as limited public transportation options. Aizawl is linked to other parts of Mizoram and neighbouring states via roadways and a small airport, facilitating domestic air travel. The data used in this research was collected from the websites of Central Ambient Air Quality Monitoring Stations (CAAQMS), provided information on ground-level ozone concentrations, while Directorate of Science and Technology provided temperature, humidity, and wind speed data. These datasets were collected from March 2022 to February 2023 to allow for a comprehensive analysis of atmospheric conditions in the study area.

Data analysis: Meteorological parameters (temperature, humidity, and rainfall) were presented in descriptive statistics. The Mean ± SD, median, minimum and maximum values for each parameter was analyzed. A box plot and error bar graphs were plotted to represent variations in various metrological parameters. Pearson Correlation Coefficient was evaluated to assess the relationship between ground-level ozone and metrological parameters. Linear regression model was applied to find significant metrological parameters affecting the ozone level.

Seasonal variation in ozone levels and trends of nitrogen oxides (NOx) were analyzed using descriptive statistics the and presented as line graphs and seasonal categorization. Significant monthly variation in humidity percent was recorded in 2021 at Aizawl (Table 1). The average minimum and maximum humidity % in all months were analysed, and the overall significant variation in humidity was recorded at Aizawl, primarily attributable to the seasonal shift between months across Aizawl.

Results and Discussion

Rainfall variation during three-year time period in Fig. 1 indicates a clear seasonal, as monsoon months recorded the highest rainfall value of 365 mm in July 2021, 342 mm in August 2022, and 358 mm in July 2023 whereas winter months reported comparatively rainfall low values of less than 30 mm in December and January. This heterogeneity plays an important role in surface ozone levels, with more monsoon-season rainfall promoting wet deposition of precursors such as NOx and VOCs and thus lowering surface ozone. While during summer and winter months, reduced precipitation results in less atmospheric cleansing that allows ozone and precursors to accumulate more readily. Fluctuation in humidity for the period of 2021, 2022, and 2023 are graphically represented in Fig. 2 a,b,c) where relative humidity possessed significant month-to-month changes, with higher humidity (85–92%) recorded in the months of July and August, while the winter months possessed significantly lower values, predominantly humidity below 45%, rendering the air dry.

This seasonal trend has a direct influence on ozone formation because greater humidity during rainy season strengthens wet deposition of precursors of ozone, which lowers surface ozone concentration. The minimum and maximum temperature in Aizawl for the years 2021, 2022 and 2023 is represented in Fig. 3 (a,b,c). These weather parameters provide essential information for deriving ozone concentration trends in our study. It depicts warmer summer months from March to June with temperature extremes 32.8 °C in May 2021, 33.2 °C in April 2022, and 32.5 °C in May 2023, while lowest winter temperature decreased to 7.5 °C as recorded in January 2023. Fig. 4 shows variation in the ground-level ozone concentrations between March 2022 and February 2023 at different time points. In the first plot, the ozone concentration ranged from 1.30 to 32.1 μg m^{-3}, with a mean value of 5.21 μg m^{-3}. A sharp spike in ozone levels were observed around early December 2022 and late December 2022, indicating a chance of the occurrence of high photochemical activity. The second plot showed a more extended time series, where ozone concentrations ranged from 50 to 0.42 μg m^{-3} with a mean value of 7.30 μg m^{-3}. The fluctuations were more frequent and intense in February and April 2023; a frequent fluctuation was observed which can possibly be due to increased solar radiation and favourably meteorological conditions enhancing ozone formation.

From March 2022 to February 2023, the ground-level ozone concentrations demonstrated a clear seasonal variation (Fig. 5a). The highest ozone levels were observed during summer, particularly in April and June 2022, with the average concentrations of 20.57 and 20.17 μg m^{-3}, respectively, whereas in winter months such as December 2022 and January 2023, the ozone levels were lower as higher sunlight exposure and elevated temperature promote ozone formation from NOx and VOCs. Conversely, cooler temperature and weaker sunlight during winter months can suppress ozone formation. These findings are consistent with the reports of Chen *et al.* (2019), who observed that temperature and solar radiation were the dominant meteorological factors driving higher ozone concentrations

Table 1: Correlation between Ozone level and Meteorological parameters

		Ozone	Temperature maximum	Rainfall
Ozone	Pearson's r	—		
	p-value	—		
Temp max	Pearson's r	0.275	—	
	p-value	0.214	—	
Rainfall	Pearson's r	-0.273	0.1	—
	p-value	0.024	0.091	—
Humidity	Pearson's r	-0.142	-0.068	0.198
	p-value	0.018	0.25	<.001
NOx	Pearson's r	0.270	—	—
	p-value	0.396	—	—

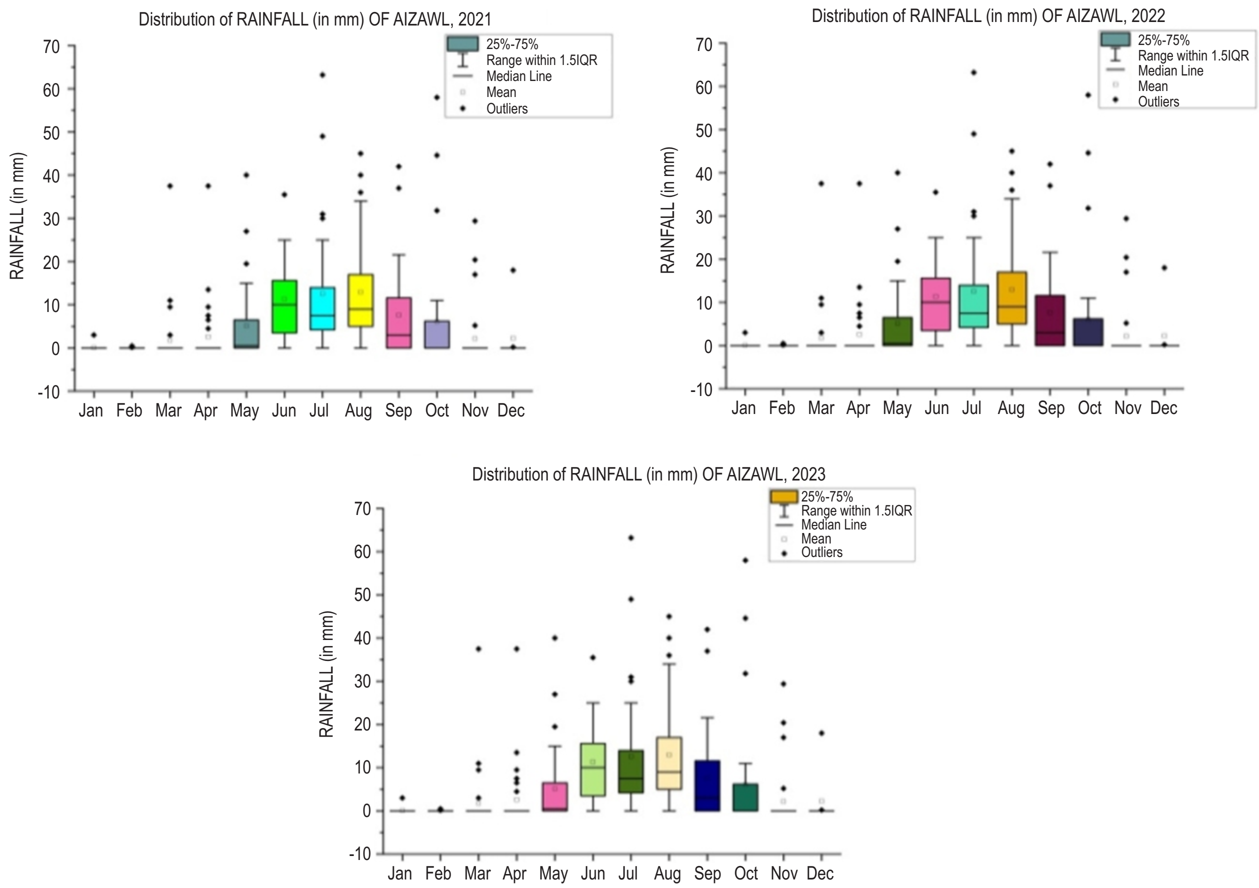

Fig. 1: Distribution of variation of Rainfall in three year.

during warmer months. It revealed that summer time biogenic emissions of VOCs and increased temperatures played a critical role in ozone formation, especially under stable meteorological conditions. They emphasized that summer months provide favorable conditions for ozone production due to long daylight hours and intense solar radiation, both of which catalyze photochemical reactions between NOx and VOCs. Similarly, Ding *et al.* (2013) reported that ozone levels peaked during summer due to strong solar radiation, and the transport of ozone precursors from highly industrialized areas. They observed that synoptic weather systems, such as anticyclones, enhance ozone formation and accumulation by trapping pollutants and promoting photochemical activity. The seasonal cycle observed showed a maximum in summer, with a secondary peak in autumn, similar to what was observed in this study. Their analysis of diurnal variations also revealed that ozone concentrations typically peaked during midday and early afternoon due to increased intensity of sunlight, which is crucial for ozone production.

As shown in Table 1, Spearman's correlation analysis revealed a weak positive relationship between maximum temperature and ground-level ozone ($r = 0.275$, $p = 0.214$) when compared with rainfall and humidity. This suggests that with rise in temperature, the ozone level increased. However, the p-value was non-significant. Higher temperatures can promote ozone formation through acceleration of photochemical reactions involving various atmospheric pollutants, such as NOx. Tong *et al.* (2017) investigated ozone and NOx levels across urban, suburban, and rural sites in Ningbo, China. They found that ozone concentrations were positively correlated with temperature, especially during midday, when both solar radiation and temperature peaked. Their research demonstrated that ozone levels in suburban and rural areas were less affected by the titration process, where NO depletes ozone, compared to urban areas. This insight highlights the role of meteorology in influencing ozone concentrations, especially in non-urban areas, where photochemical processes are more pronounced due to lower NOx emissions. Similarly, Lu and Chang (2005) assessed meteorologically adjusted trends of daily maximum ozone concentrations in Taipei, Taiwan, showing that higher temperatures were strongly correlated with increase in ozone levels. Conversely, it was observed that the ground-level ozone had a significant weak negative correlation ($r = -0.273$, $p = 0.024$), which indicates that increased rainfall was correlated with a slight

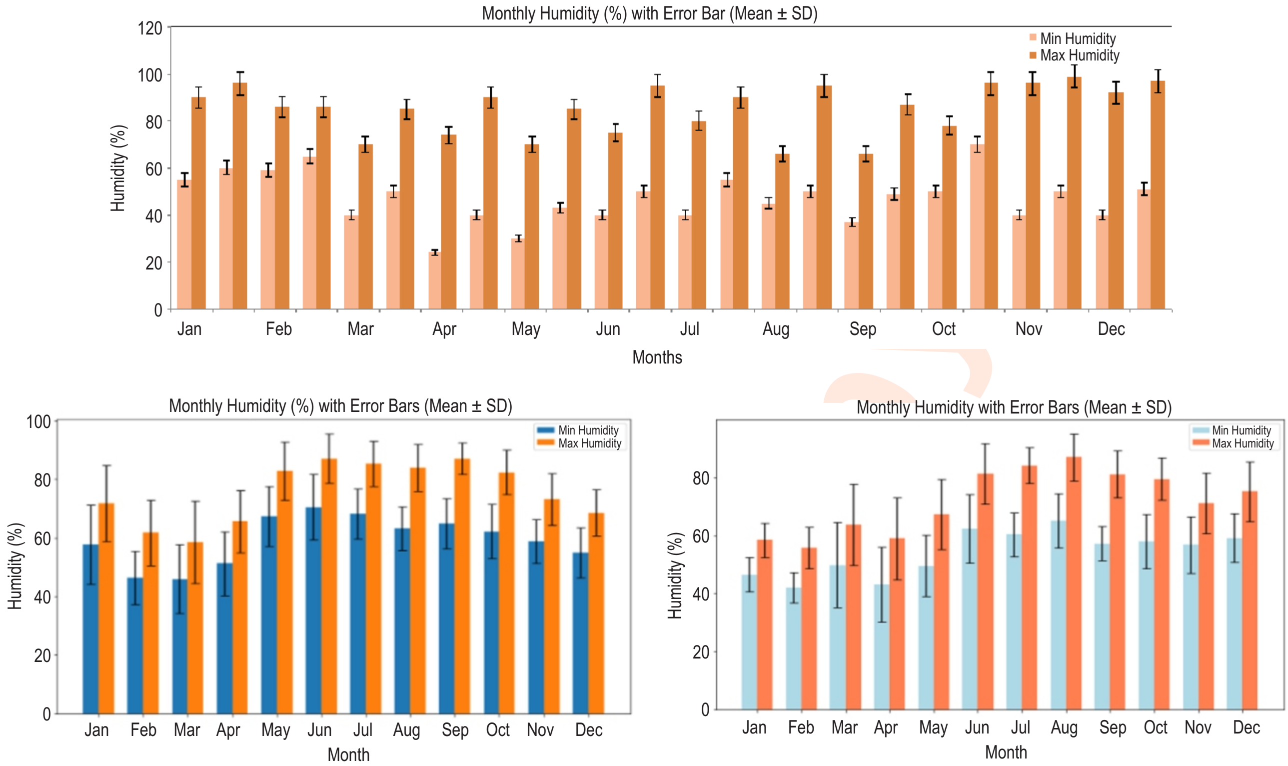

Fig. 2: Distribution of variation of humidity (in %) of Aizawl in (a) 2021, (b) 2022 and (c) 2023.

decrease in ozone levels, and this relationship was statistically significant ($p < 0.05$). Similarly, the analysis revealed that a weak negative correlation existed between the ground-level ozone and humidity ($r = -0.142$, $p = 0.018$), which suggests that higher humidity may reduce ozone concentrations, with statistical significance ($p < 0.05$). In this study, it was observed that maximum temperature showed a weak correlation with rainfall ($r = 0.100$, $p = 0.091$), but p-value was not significant ($p > 0.05$). From the analysis, it was observed that humidity showed a weak correlation with temperature ($r = -0.068$, $p = 0.25$) and rainfall ($r = 0.198$, $p < 0.001$), indicating that humidity is positively correlated with rainfall. There was a weak positive correlation between nitrogen oxides and ozone ($r = 0.270$) and no significant linear relationship was observed between them ($p=0.396$). Overall, from the analysis, it can be inferred that temperature and rainfall have some effect on ozone levels. Humidity showed a weak negative relationship with ground-level ozone. These results reflect typical atmospheric behaviour, where high temperatures induce ozone formation, and rainfall or increased humidity tends to reduce ozone levels due to atmospheric cleansing.The observed significant negative correlation between rainfall and humidity with ozone levels align with the previous findings of Tarasova *et al.* (2003), who reported that rainfall and high humidity facilitate the removal of ozone precursors through wet deposition. It highlights that rainy weather, particularly high humidity, is typically associated with low ozone levels due to less intensive photochemical production and ozone deposition on water droplets. Their study also indicated that these meteorological conditions are more pronounced in colder seasons and regions with significant rainfall, where large-scale atmospheric dynamics govern surface ozone variability rather than local photochemical reactions.

Seasonal variations in ground-Level ozone concentrations were analyzed using data collected from two dates of each month (Fig. 5a). The data was categorized into three seasons: Summer (March to June), Rainy (July to October) and Winter (November to February). Ozone showed a fluctuating change with a mixture of high and low level over time for the past years. In all three years, a positive relationship ($r= 0.76$) was found with a statistically significant relationship ($p=0.005$). However, this comprehensive view clearly showed that the highest average concentration of ground-level ozone was observed during summer season and lowest in average of ground-level ozone during winter season. The NOx level presented in Fig. 5 (b) showed a decline in NOx level. Month wise, the highest NOx level was observed in January and gradually decreased when the weather was warm and hot. The figure showed that the NOx level was high with the arrival of winter season and gradually decreased during summer and rainy seasons. The main reason of the increase in NOx level in winter season can be due to low temperature and humidity in the study area, as stable atmospheric conditions and temperature inversion during this period tend to trap pollutants near the

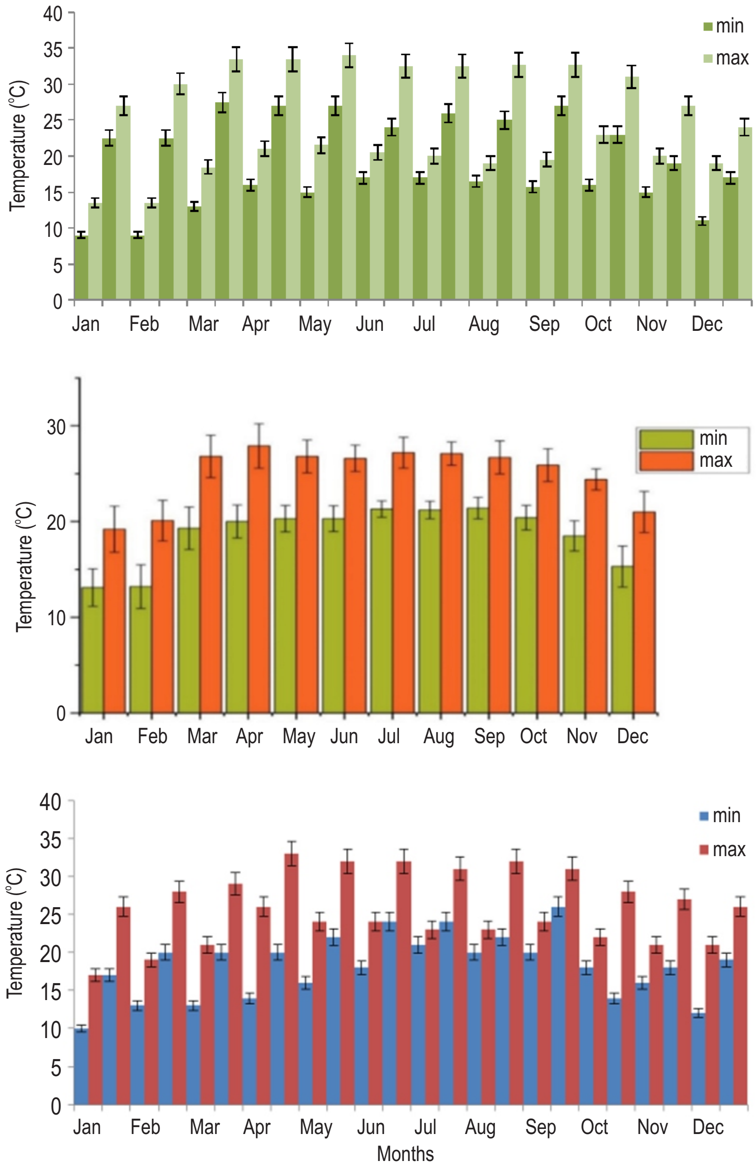

Fig. 3: Distribution of minimum and maximum temperature and its variation at Aizawl in (a) 2021 (b) 2022 and (c) 2023.

surface (Cichowicz *et al.,* 2017; Sadheesh and Jeyanthi, 2023). A multiple linear regression model was introduced to identify the significant predictors of ground-level ozone (Table 2). The analysis observed the average relationship between ground-level ozone, temperature, rainfall, and humidity. The R^2 value of the model was 0.45, which indicates that the predictors explained 45% variation. The model's intercept was significant (Estimate = 13.37, SE = 3.06, $p < 0.001$). The model indicated that maximum temperature showed a positive but non-significant association with the ground-level ozone (β = 0.1304, p = 0.178), which indicates temperature does not have much more influence on ozone level. Similarly, rainfall had a negative effect on the ozone level (β = 0.0277, p = 0.033), which indicates that higher rainfall might have a significant negative association with the ozone level. Similarly, from the analysis, it was observed that humidity had a significant negative association with ozone (β = 0.0576, p = 0.022), which suggests that when humidity increases, the ground-level ozone decreases. The linear regression analysis exhibits an atmospheric association between ozone level, rainfall, humidity, and temperature (Wang *et al.,* 2017).

Multiple linear regression and multilayer perceptron (MLP) models demonstrated that long-term trends in ozone concentrations are significantly influenced by temperature,

Table 2: Linear Regression analysis for factors influencing ground-level Ozone

			95% Confidence Interval			
Predictor	Estimate	SE	Lower	Upper	t	p
Intercept	13.3707	3.0613	7.344	19.39742	4.368	<.001
Temp max	0.1304	0.0965	0.32	0.5954	-1.352	0.178
Rainfall	-0.0277	0.0443	-0.115	0.05963	-0.624	0.033
Humidity	-0.0576	0.0249	-0.107	-0.00852	-2.311	0.022

Table 3: Omnibus ANOVA Test for variation effect on ground-level Ozone

	Sum of Squares	Mean Square	F	p
Temp max	53.7	53.7	1.827	0.178
Rainfall	11.5	11.5	0.39	0.033
Humidity	157	157	5.339	0.022
Residuals	8025.9	29.4		

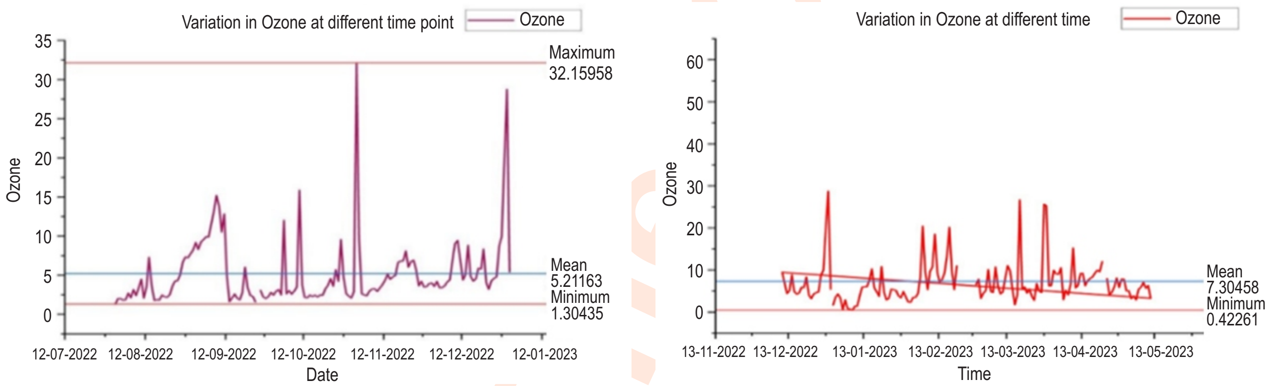

Fig. 4: Variation in Ozone at different time points.

emphasizing that meteorological conditions, especially temperature, mask the underlying trends of precursor emissions (Fiore *et al.,* 2015; Jacob and Winner, 2009). The MLP model outperformed linear regression in their work by capturing the complex, non-linear relationships between ozone and meteorological variables. Both studies indicated the positive influence of temperature on ozone formation, consistent with the behaviour observed in this study, particularly in regions where seasonal and diurnal variations influence photochemical activity. The Omnibus ANOVA test assessed the significance of ozone level's temperature, rainfall, and humidity predictors (Table 3). The analysis indicated that these factors contribute varying amounts to the overall variance in ozone. The sum of the square of the maximum temperature was 53.7. Still, its effect on ozone was insignificant ($F = 1.827$, $p = 0.178$), suggesting temperature had no significant impact on the ozone level in the model. Rainfall had a sum of squares of 11.5, which showed a statistically significant impact on ozone ($F = 0.39$, $p = 0.033$), indicating that rainfall changes have a modest but significant negative impact on the ozone levels. Humidity showed a sum of the square of 157, which had the most significant effect on ozone ($F = 5.339$, $p = 0.022$). While the general trends in temperature and humidity align with the existing literature, the non-significant relationship between temperature and ozone concentrations in our regression analysis ($p = 0.178$) presents a notable discrepancy.

Elminir (2005) observed that meteorological conditions such as temperature inversions, wind speed, and the topographical features of a region could play a substantial role in influencing the concentration of air pollutants, including ozone. Elminir's study in Greater Cairo highlighted that temperature was among the most influential factors forming secondary pollutants like ozone. However, the study also emphasized these temperature inversions where a layer of warm air traps cooler air near the ground can prevent pollutants from dispersing, leading to lower ozone formation in some cases. This is particularly relevant

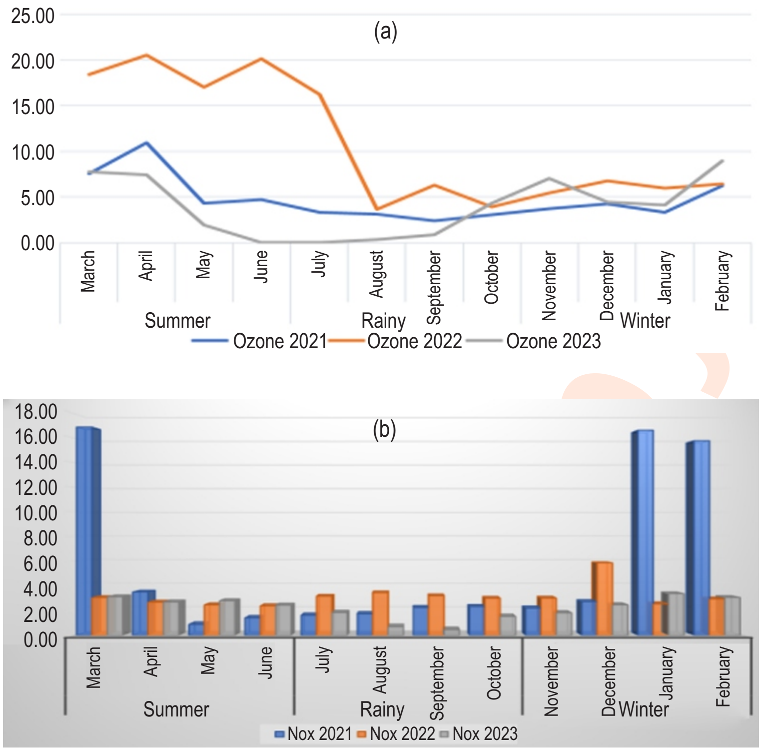

Fig. 5: (a) Seasonal variation of Ground-Level Ozone of all three seasons and (b) Trends analysis of NOx over the years.

in areas with complex topography, such as Aizawl, where ridges and valleys could trap pollutants at night and hinder the expected rise in ozone levels during warmer periods. Further, Elminir's work suggests that localized geographical and meteorological conditions must be considered when interpreting ozone-temperature relationships, as these factors can significantly alter pollutant dispersion and concentration.

Moreover, the significant negative correlations between rainfall, humidity, and ozone suggest that these meteorological factors could be leveraged to predict and manage ozone levels, particularly during rainy season. Effective forecasting models incorporating these factors could help mitigate the health risks associated with high ozone levels during dry periods. Furthermore, a weak positive correlation between temperature and ozone concentrations indicate that global warming may exacerbate ozone pollution in future, reinforcing the need for proactive climate adaptation strategies. While this study focuses on the influence of meteorological condition, future research should aim to study the relationship with primary air pollutants and volatile organic compounds which are key precursors to ozone formation. Thus, including VOC data would provide a more comprehensive understanding of the factors influencing ozone levels in Aizawl. Additionally, the study's reliance on secondary data from monitoring stations may have introduced inconsistencies, particularly regarding the measurement of meteorological parameters. Additionally, the study did not directly measure solar radiation, which is another important factor in ozone formation. Future research should focus on expanding the dataset to include longer time frames and additional variables like VOCs and solar radiation. Given Aizawl's unique topography, more localized models should be developed better to understand the interplay between meteorological parameters and ozone formation.

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