Assessment of Weekday and Weekend Variations on Ground Level Ozone and Nitrogen Dioxide Concentration in Jeli, Kelantan

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Abstract

This study examines the variations in ground-level ozone (O_3) and nitrogen dioxide (NO_2) concentrations between weekdays and weekends in Jeli and their relationship with traffic volume. Data were collected over two weeks in August 2024 using the Aeroqual S500 device and manual traffic counting. The results showed that NO_2 concentrations were lower on weekends, with median values ranging from 20 to 40 parts per billion (ppb), while O_3 concentrations were higher (15–30 ppb) compared to weekdays (10–20 ppb). This trend was attributed to reduced nitrogen monoxide emissions and enhanced photochemical reactions under lower NO_2 conditions. Traffic volume was significantly higher on weekdays, peaking during morning (7–9 a.m.) and evening (4–6 p.m.) rush hours, with Class 1 vehicles averaging 400 vehicles/hour on weekdays and 300 vehicles/hour on weekends. Consequently, NO_2 concentrations were higher on weekdays (60–80 ppb median values, peaking at 140 ppb). Statistical analyses, including T-tests, indicated no significant differences in mean concentrations between weekdays and weekends. Pearson correlation analysis confirmed a moderate positive relationship between traffic volume and NO_2 (0.410), while O_3 levels were influenced by sunlight intensity and atmospheric chemistry. These findings highlight the impact of traffic emissions on NO_2 and the importance of photochemical processes in O_3 variations, emphasising the need for effective air quality management strategies.

1. Introduction

The atmosphere is a dynamic and complex system essential for climate regulation and life support. Comprising multiple layers, including the troposphere, stratosphere, mesosphere, thermosphere, and exosphere, these layers serve as protective barriers regulating temperature and shielding the Earth from harmful solar radiation [1,2]. However, human activities, particularly industrialization, transportation, agriculture, and energy production, have significantly altered atmospheric composition, contributing to air pollution [3]. Ground-level ozone (O_3) and nitrogen dioxide (NO_2) are among the most critical air pollutants, which impact both environmental and public health. Ozone is a secondary pollutant formed through photochemical reactions involving nitrogen oxides (NOx) and volatile organic compounds (VOCs), while NO_2 is primarily emitted from vehicular and industrial combustion

processes. These pollutants are known to exacerbate respiratory conditions, harm vegetation, and contribute to urban smog [4, 5].

Ground-level ozone, also known as tropospheric ozone, is a trace gas in the lower atmosphere with concentrations typically ranging from 20 to 30 ppb but reaching nearly 100 ppb in polluted regions [4]. It is a secondary pollutant, primarily formed through photochemical reactions involving nitrogen oxides (NOx) and volatile organic compounds (VOCs) in the presence of sunlight during the daytime. Emissions from vehicles, power plants, refineries, and industrial facilities are primary sources of these precursor pollutants. Meteorological conditions such as high temperatures and strong solar radiation further influence ozone formation and transport [5]. A tropospheric climatology study in Peninsular Malaysia found that ozone exhibits marked seasonal peaks during dry months and strong diurnal cycles with afternoon maxima characteristic of photochemical formation [19]. This mechanism explains the elevated O_3 levels observed during midday in Jeli, supporting the interpretation of photochemistry-driven ozone formation in your findings. Elevated ozone levels pose significant health risks, particularly for individuals with respiratory conditions like asthma, and can also harm ecosystems by damaging vegetation and reducing crop yields [4]. Likewise, nitrogen dioxide is a reddish-brown gas formed mainly from combustion activities, with major sources including vehicular emissions and industrial processes [2]. Due to its association with respiratory diseases, NO_2 is a major air quality concern, contributing to smog formation, acid rain, and secondary particulate matter [6].

Jeli, Kelantan, Malaysia, has undergone rapid urbanisation and increased vehicular traffic, raising concerns about air quality deterioration. Despite the well-documented impacts of NO_2 and O_3, studies addressing their variations between weekdays and weekends in Jeli remain limited. Traffic emissions, industrial activity, and meteorological conditions significantly influence pollutant concentrations, yet localised data on their temporal patterns are scarce. Understanding these fluctuations is essential for effective air quality management and mitigating potential health risks. Existing studies highlight the role of human activity patterns in shaping pollution levels. Research in Shanghai, China, has shown that NO_2 concentrations peak on weekdays due to traffic congestion and industrial operations. In contrast, ozone levels tend to rise on weekends due to reduced NO_2 emissions affecting the photochemical balance [2, 7]. Similarly, research in cities such as Phoenix and Atlanta have demonstrated that while NO_2 levels decline over weekends, ozone concentrations can increase due to shifting atmospheric chemistry and reduced NO titration [8]. These findings emphasise the need for localised air quality assessments to develop targeted mitigation strategies. Similar findings have also been reported in Malaysian urban areas, where reduced nitrogen oxide emissions on weekends contribute to elevated ozone concentrations due to weakened ozone titration [16].

The interaction between ozone and nitrogen dioxide is complex, influenced by atmospheric conditions, traffic emissions, and photochemical reactions. Ozone formation depends on the presence of NOx and VOCs under sunlight, while NO_2 plays a dual role in both ozone generation and depletion. Ozone formation involves a photostationary balance between NO_2 photolysis (releasing atomic oxygen) and ozone titration by nitric oxide (NO). A study in Malaysia showed that O_3 levels often increase as NO_2 levels begin to drop after the morning traffic peak, consistent with this photochemical dynamic [20]. Urban and semi-urban regions experience dynamic changes in these pollutants due to differences in emission sources and meteorological conditions. With Jeli's expanding urban landscape and rising traffic volume, a comprehensive investigation into these pollutants' variations is crucial. This study aims to assess ozone and nitrogen dioxide variations during weekdays and weekends in Jeli by analysing air quality data and identifying contributing factors. The objectives include determining traffic volume, measuring ground-level ozone and nitrogen dioxide concentrations, comparing their levels between weekdays and weekends, and analysing their relationships with traffic patterns. The findings will provide valuable insights for air quality management, aiding policymakers in designing effective pollution control measures to safeguard public health and environmental sustainability.

2. Materials and Methods

2.1 Study Area

This study focuses on Jeli, Kelantan, a district located in the northern part of Peninsular Malaysia (Fig. 1). Positioned at coordinates 55°44'42.7"N and 101°51'41.9"E, Jeli encompasses a total area of 13,300 hectares and is classified as a rural region situated in the northwest of Kelantan [9]. The selection of Jeli as the study site is based on its unique geographical and socio-economic characteristics, which reflect a blend of rural and emerging urban elements. The district is predominantly agricultural, surrounded by natural landscapes, and maintains a relatively low population density compared to major urban centres.

Jeli experiences a tropical rainforest climate characterised by high temperatures, humidity, and frequent yearly rainfall. The average temperature in Jeli ranges between 24°C and 32°C, with minimal seasonal variation. Relative humidity typically fluctuates between 75% and 90%, contributing to the persistence of atmospheric moisture, which influences air pollutant dispersion and photochemical reactions. Wind patterns in Jeli are

generally influenced by the monsoonal system, with the northeast monsoon (November–March) bringing increased rainfall and reduced atmospheric dispersion, while the southwest monsoon (May–September) is associated with drier conditions and enhanced pollutant transport. The combination of these meteorological factors plays a crucial role in determining pollutant concentrations, particularly for nitrogen dioxide (NO_2) and ground-level ozone (O_3).

Strategically, Jeli serves as a crucial transit hub along the East-West Highway Route, which connects the northern states of Peninsular Malaysia, namely Kelantan and Terengganu. This 216-kilometre highway extends from Gerik, Perak, to Jeli, Kelantan, facilitating significant vehicular movement. Given its strategic location along this primary route, Jeli experiences substantial traffic, particularly during peak hours, festive seasons, and public events. This increased vehicular activity contributes to elevated emissions of air pollutants, including nitrogen dioxide and ground-level ozone, making it an ideal site for investigating air quality variations between weekdays and weekends. The combination of high humidity and limited wind dispersion during certain periods may further influence pollutant accumulation and transport in the region. Meteorological variables such as temperature, relative humidity, wind, and rainfall play crucial roles in the formation and dispersion of O_3. A study conducted in Tanah Rata, Malaysia, found that ozone concentrations peaked during the southwest monsoon under dry and westerly wind conditions, affirming the role of climate and air mass trajectory in air quality dynamics [21]. A recent study in urban Malaysia reported significant seasonal variations in major air pollutants, including elevated levels of NO_2 and O_3 during dry months due to atmospheric stability and reduced dispersion [24]. This supports the need for multi-seasonal data collection in Jeli to capture potential seasonal influences on pollutant patterns. Additionally, Jeli is transitioning from a predominantly rural area to a semi-urban region, retaining its traditional landscape while gradually integrating urban infrastructure and development. This evolving urbanisation presents an opportunity to examine how increasing human activities and vehicular emissions influence local air quality dynamics. Understanding air quality variations in Jeli is crucial for informing air pollution management strategies in similar rural areas experiencing development and rising traffic volumes.
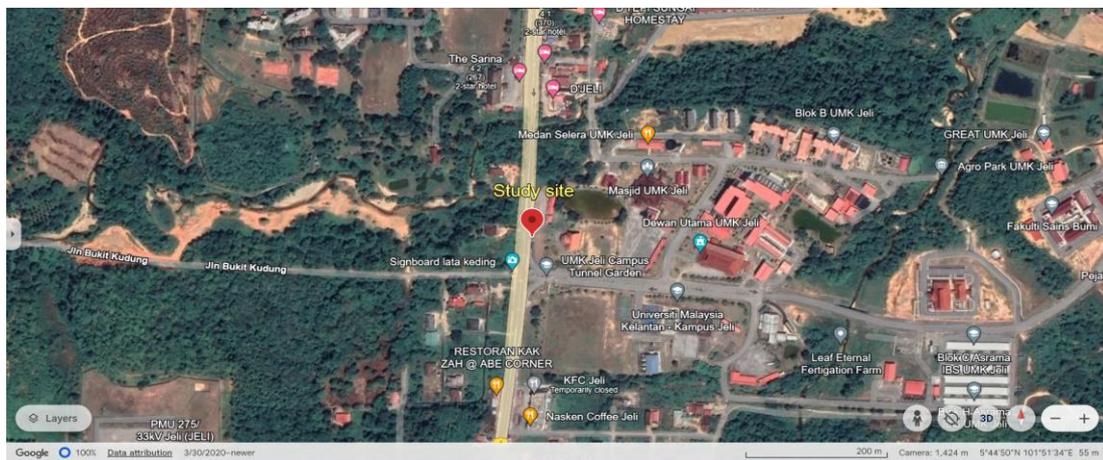

Fig. 1 *The study area of Jeli in Kelantan, Malaysia (Source: Google Earth, 2024)*

2.2 Data Collection

This study collected data over two whole weeks in August 2024 to evaluate the impact of traffic volume on O_3 and NO_2 concentrations in Jeli, Kelantan. Since this were conducted on Kelantan, weekend is defined by Friday and Saturday, while weekdays are the working days from Sunday to Thursdays. This study was conducted over a short two-week period to provide preliminary insights. However, it is acknowledged that the use of a longer-term or seasonal dataset would enhance the robustness and generalisability of the findings. Air quality data was gathered using the Aeroqual S500, a high-precision monitoring device equipped with interchangeable sensor heads for detecting O_3 and NO_2. It was capable of continuous monitoring, allowing for real-time data collection at regular intervals throughout the study period, which was crucial for capturing temporal variations in pollutant concentrations [10]. The device was strategically placed at key locations, considering factors such as traffic density, proximity to industrial activities, and residential areas, ensuring representative data collection. Measurements were taken at three intervals daily (7 a.m. – 9 a.m., 12 p.m. – 2 p.m., and 4 p.m. – 6 p.m.), with real-time data logged at predetermined intervals. To ensure accuracy, the device was calibrated regularly according to the manufacturer's guidelines and preheated before measurements to eliminate residual pollutants.

Meanwhile, traffic volume was determined using manual counting at selected sites, where trained observers recorded the number and type of vehicles (cars, motorcycles, lorries, buses) passing through at designated times. Manual counting was chosen due to the absence of automatic traffic monitoring devices. Each vehicle observed was recorded using tally mark notation on pre-designed data sheets, allowing for quick, organised, and systematic tracking of vehicle flow. This method widely used in short-term traffic studies and has been demonstrated to yield reliable results when performed by trained personnel [18]. The findings contribute to a deeper understanding of how traffic emissions affect air quality, supporting the development of effective air pollution management strategies in Jeli. Additional data, including vehicle speed i.e fast or slow and direction, were recorded where feasible. The data was compiled and analysed to compare traffic volumes between weekdays and weekends, identifying patterns influencing pollutant concentrations. Pearson correlation analysis was applied to explore the relationship between traffic density and air quality, providing valuable insights into pollution trends. Although manual traffic counting is labour-intensive, it offers high accuracy when performed by trained personnel. The findings contribute to a deeper understanding of how traffic emissions affect air quality, supporting the development of effective air pollution management strategies in Jeli.

The sampling period did not include direct recordings of meteorological parameters such as sunlight intensity, ambient temperature, wind direction, and rainfall. This study excludes quantitative analysis regarding the impact of meteorological factors on air pollutant concentrations. The lack of these parameters restricts the capacity to comprehensively elucidate the variations in ozone (O_3) and nitrogen dioxide (NO_2) levels, given that these pollutants exhibit significant sensitivity to environmental factors. This constraint could influence how to understand changes in pollutants, especially concerning photochemical reactions and dispersion trends. Future studies ought to integrate meteorological monitoring to deepen the comprehension of pollutant dynamics and the environmental factors that affect them.

2.3 Data Analysis

The data was analysed using OriginPro 9.1, applying statistical methods such as box and whisker plots, time series plots, diurnal plots, the Mann-Whitney U Test, and Pearson correlation. Environmetric analysis in the northern region of Peninsular Malaysia demonstrated clear seasonal patterns in pollutant concentrations and highlighted the utility of multivariate statistical techniques in assessing spatial and temporal trends [25]. Incorporating such analytical frameworks can enhance the robustness of air quality assessments, particularly when interpreting localised variations as observed in Jeli. Descriptive analysis summarised central tendencies, dispersion, and variability in pollutant concentrations, providing an initial understanding of the dataset. Box and whisker plots visually represented the distribution of pollutant levels, highlighting median values, interquartile ranges, and potential outliers, which helped identify extreme pollution events. Time series plots were generated to observe hourly fluctuations in O_3 and NO_2 concentrations, offering insights into daily and weekly trends, including peak pollution periods corresponding to traffic activity and meteorological conditions. The average daily trend analysis further examined the diurnal variations of pollutants, identifying the highest and lowest concentration periods throughout the day and comparing differences between weekdays and weekends.

An independent t-test was conducted to determine whether the mean pollutant levels differed significantly between weekdays and weekends, with statistical significance evaluated using t-values and p-values at a 95% confidence level ($\alpha = 0.05$). A low p-value (<0.05) indicated a statistically significant difference in pollutant levels, while a high p-value (≥0.05) suggested no significant difference. Pearson correlation analysis was also applied to quantify the linear relationship between traffic volume and pollutant concentrations, producing a correlation coefficient (r) ranging from -1 to 1. A strong positive correlation (r close to 1) indicated that increased traffic volume was directly linked to higher NO_2 and O_3 precursor levels, reinforcing the role of vehicular emissions in air pollution. Conversely, a weak or negative correlation suggested that meteorological factors, chemical interactions, or dispersion effects influenced pollutant concentrations. The combination of these statistical methods provided a robust and detailed assessment of air quality trends, allowing for a more accurate interpretation of how traffic emissions and other environmental factors impact O_3 and NO_2 levels in Jeli. These findings are critical for developing targeted air quality management strategies and policy recommendations.

3. Results and Discussion

3.1 Box and Whisker plot

Box and whisker plots effectively analyse air pollution data by illustrating distribution, stability, and variation. This study examined ground-level ozone and nitrogen dioxide concentrations in Jeli from 9 to 22 August 2024, comparing weekdays and weekends. Figures 2 and 4 showed that NO_2 levels were higher on weekdays, with a median of 60–80 ppb, particularly on 12 and 13 August, due to increased traffic and industrial activities. The interquartile range (IQR) was wide, indicating significant variation, and peak NO_2 levels reached 140 ppb. In

contrast, O_3 levels were lower on weekdays (10–20 ppb median) due to ozone titration, where NO reacts with O_3 [2].

On weekends, in Figs. 3 and 5, NO_2 levels decreased (median: 20–40 ppb) due to reduced traffic, while O_3 concentrations increased slightly (15–30 ppb median) due to enhanced photochemical activity. Notably, higher O3 values were recorded on 10 and 17 August. Traffic volume analysis, based on the Ministry of Works Malaysia classification, revealed that Class 1 vehicles (cars/vans) dominated weekday traffic (median: 400 vehicles, IQR: 300–500), correlating with higher NO_2 emissions. Other categories, such as Class 2 (trucks) and Class 5 (motorcycles), had lower volumes. On weekends, traffic volume declined (Class 1 median: 300 vehicles), reducing NO_2 but increasing O_3 formation due to reduced titration. These findings highlight the impact of traffic on air pollution in Jeli, with higher NO_2 levels on weekdays and increased O_3 formation on weekends. Proper traffic management strategies could help mitigate pollution in developing rural and semi-urban areas.
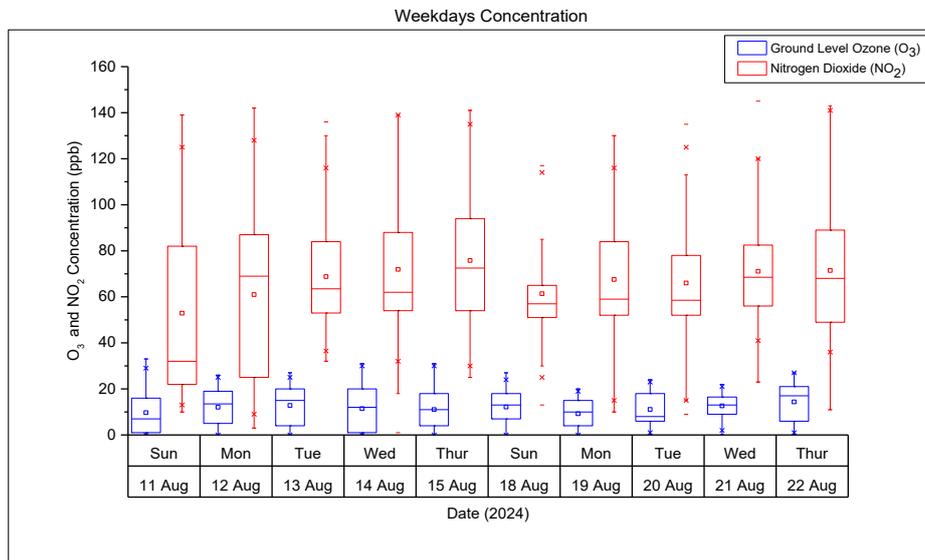

Fig. 2 *Box and whisker plot of ground-level ozone and nitrogen dioxide concentration (ppb) in Jeli during weekdays*
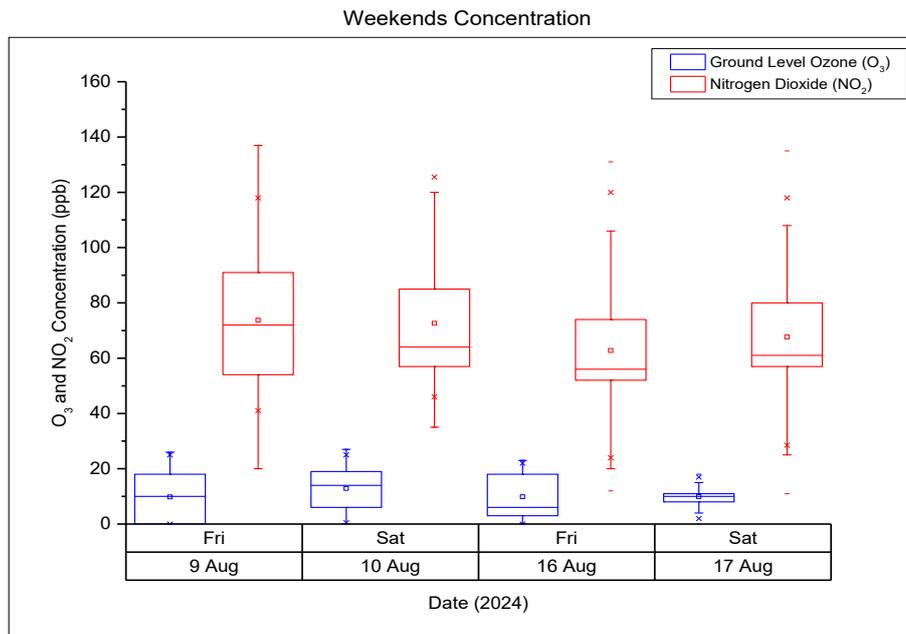

Fig. 3 *Box and whisker plot of ground-level ozone and nitrogen dioxide concentration (ppb) in Jeli during weekends*
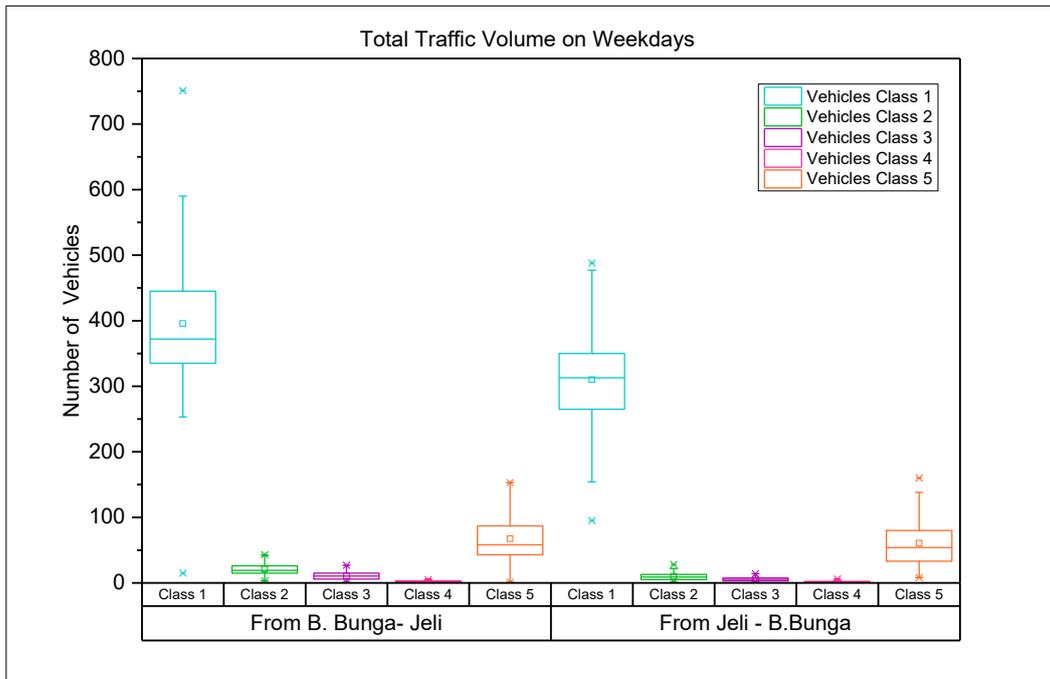
Fig. 4 *Box and whisker plot of total traffic volume (vehicles) in Jeli during weekdays*

Fig. 5 *Box and whisker plot of total traffic volume (vehicles) in Jeli during weekends*

3.2 Time Series Plot

Fig. 6, 7, and 8 illustrate the relationship between traffic activity and air pollutant concentrations from 9 to 22 August 2024, highlighting the impact of human activities and atmospheric processes on air quality in a developing rural area like Jeli. Figure 6 shows traffic patterns that show distinct differences between weekdays and weekends. On weekdays (9, 11–16, and 19–22 August), traffic volume exhibits two clear peaks, one in the morning (7–9 a.m.) and another in the evening (5–7 p.m.), corresponding to work commutes and daily activities. This pattern suggests that traffic emissions significantly influence pollutant concentrations during peak hours. In contrast, weekend traffic (10, 17, and 18 August) is considerably lower, with no pronounced peaks throughout the day. Rainfall on

10 and 17 August at 5 p.m. further reduced traffic flow, emphasising how weather conditions influence human mobility and emissions. This decrease in vehicle activity on weekends correlates with lower NO_2 levels and an altered ozone formation process, as discussed in the following sections.

Fig. 7 shows that O_3 formation is primarily influenced by photochemical reactions involving NO_2 and sunlight. On weekdays, ozone concentrations peak between 12 p.m. and 3 p.m., when sunlight is at its highest, catalysing the reaction between NO_2 and volatile organic compounds (VOCs). For instance, on 9, 15, and 21 August, ozone levels reached nearly 50 ppb during midday, indicating active photochemical ozone formation. On weekends (e.g., 10 and 18 August), NO_2 emissions are lower (30–40 ppb), reducing new ozone formation. However, the lack of vehicle nitrogen monoxide (NO) emissions also weakens the ozone titration process, where NO reacts with O_3 to deplete it. This results in a more stable ozone concentration throughout the day, with moderate peaks in the early afternoon (1–3 p.m.). This trend highlights the dual role of NO_2 in forming and scavenging ozone, making weekend O_3 levels slightly higher than expected despite reduced NO_2 emissions.

Meanwhile, Fig. 8 shows that NO_2 concentrations strongly correlate with traffic volume, peaking during rush hours. On weekdays, NO_2 levels increase sharply at 7:30–9:30 a.m. and 5:30–7:30 p.m., aligning with traffic congestion. For example, on 9 and 14 August, NO_2 concentrations spiked to 40–50 ppb, reflecting high vehicle emissions. The consistency of these peaks across multiple weekdays suggests that traffic is the primary contributor to NO_2 pollution in Jeli. Similarly, in urban areas like Kuala Lumpur, vehicle emissions were identified as the dominant source of air pollutants, including NO_x, where private cars and motorcycles were the major contributors depending on fuel type and usage [22]. This supports the traffic-related emission patterns observed in Jeli. On weekends (e.g., 10 and 17 August), NO_2 levels remain consistently lower, staying below 30 ppb throughout the day due to decreased vehicle activity. The absence of significant NO_2 peaks further confirms the role of traffic as a dominant NO_2 emission source in Jeli. This reduction in NO_2 emissions leads to a shift in the O_3 formation process, reinforcing the weekend ozone patterns observed in Fig. 7.

The time series analysis of traffic volume, NO_2, and O_3 concentrations demonstrates a strong link between human activities and air pollution in Jeli. Higher weekday traffic leads to increased NO_2 emissions, directly impacting ozone formation. However, reduced weekend traffic alters the photochemical balance, leading to relatively stable but slightly higher O_3 levels. This study underscores the importance of traffic management in mitigating air pollution, particularly in growing rural areas where vehicular emissions significantly influence air quality.
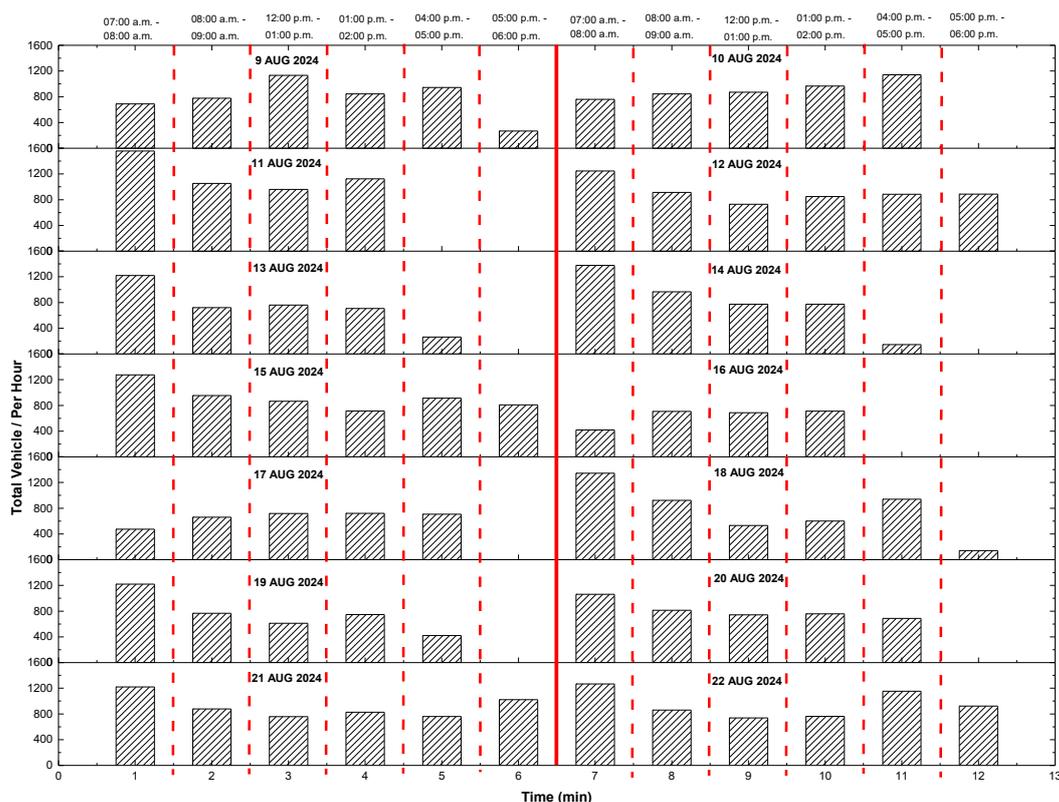

Fig. 6 *Time series plot for traffic volume (vehicles/hours) during weekdays and weekends in Jeli*
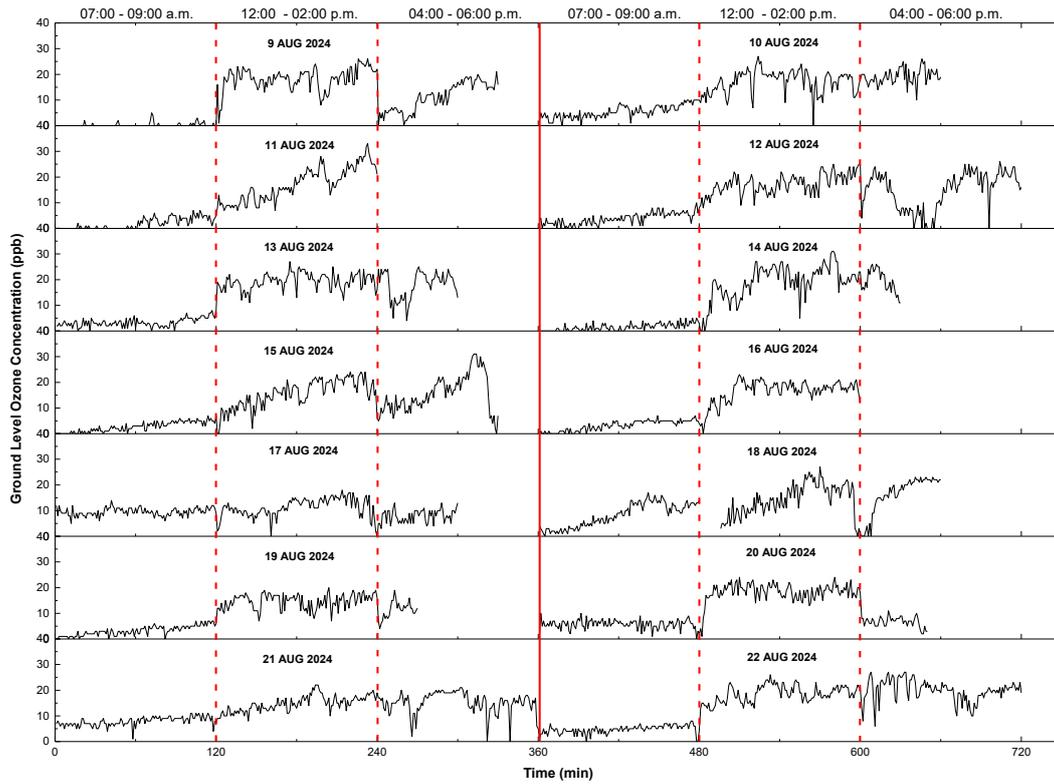
Fig. 7 *Time series plot for ground-level ozone concentration (ppb) during weekdays and weekends in Jeli*
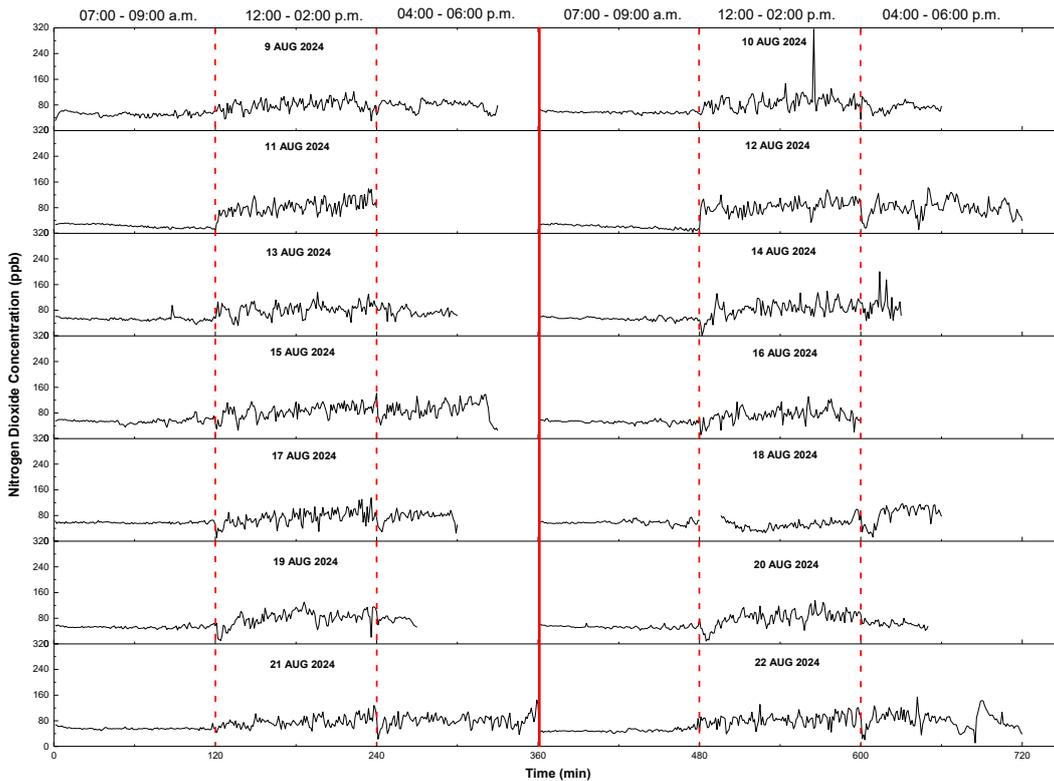

Fig. 8 *Time series plot for nitrogen dioxide concentration (ppb) during weekdays and weekends in Jeli*

3.3 Daily Trend Concentration of O_3, NO_2 and Traffic Volume

Average daily trend plotting is an important method in environmental studies to analyse temporal changes in variables such as ground-level O_3 and NO_2, and total traffic over hours in 2 weeks. It helps visualise temporal patterns and compare differences between scenarios, such as weekdays and weekends. The average daily trend shows temporal patterns for these three parameters, with significant peak times and magnitude variations between weekdays and weekends.

The average daily trend of total traffic is shown in Fig. 9, where NO_2 and ground-level ozone O_3 show significant variation over time, highlighting the relationship between human activities, pollution emissions, and photochemical reactions. Traffic volumes show significant differences between weekdays and weekends. On weekdays, there are two significant traffic peaks, namely in the morning between 7 to 8 a.m., which recorded more than 900 vehicles/hour because the time is the peak time to go to work or send children to school, causing traffic also to increase, and in the afternoon between 12 to 1 p.m., the recorded data is more than 800 vehicles/hour. After 5 p.m., the amount of traffic decreased again due to the rain that occurred then, causing data not to be fully collected, even though it was the peak time when people came home from work. This pattern shows the daily routine of residents in this area, which is directly related to higher pollution emissions during peak hours. On the other hand, weekend traffic is flatter, with a peak of around 700 vehicles/hour at noon from 12 to 1 p.m. due to leisure activities and daily affairs. Low weekend traffic volumes significantly reduced vehicle emissions, contributing to better a air quality, as highlighted in a study on the weekend effect in urban areas or development areas [5].

The ground-level ozone concentration in Fig. 10 shows a clear pattern influenced by photochemical reactions. On weekdays, the lowest concentrations occur in the early morning at 7 a.m., around 5 ppb recorded when nitrogen dioxides dominate, and sunlight is insufficient to drive ozone formation. The concentration of NO_2 increases rapidly as sunlight increases until the recorded data peaks at 95 ppb around 2 p.m. before decreasing in the late afternoon as photochemical activity decreases. On weekends, the O_3 peak is lower at around 80 ppb despite similar sunlight conditions, reflecting reduced emissions of NO_2 precursors and volatile organic compounds due to less reduced traffic or possibly affected by weather factors such as rainfall. This pattern emphasises the important role of sunlight conditions and human activities including traffic emissions in ozone production and the reducing effects of human activities [2, 12].

The average daily trend for nitrogen dioxide levels, closely related to traffic emissions, also shows a link between human activity and air pollution. Weekday NO_2 concentrations peak at 7 a.m. to 9 a.m., with approximately 90 ppb recorded, and again in the late afternoon at 4 p.m. to 5 p.m., around 70 ppb, where traffic emissions increases. This discharge is applied during noon in a photochemical reaction that produces O_3, causing a temporary drop to around 40 ppb. On weekends, NO_2 levels were consistently lower, with a smaller morning peak of only 50 ppb and less significant variations throughout the day, indicating reduced vehicle activity. The inverse relationship between NO_2 and O_3 on weekdays and weekends highlights these areas' complex air quality dynamics.

These observations confirm that traffic is a major driver of NO_2 and O_3 concentrations in urban environments. Daily weekday travel patterns result in higher ozone emissions and formation, while weekend traffic reductions reduce these effects. These findings go hand in hand with extensive studies highlighting the link between human activities, vehicle emissions, and atmospheric chemistry in shaping air quality [13].
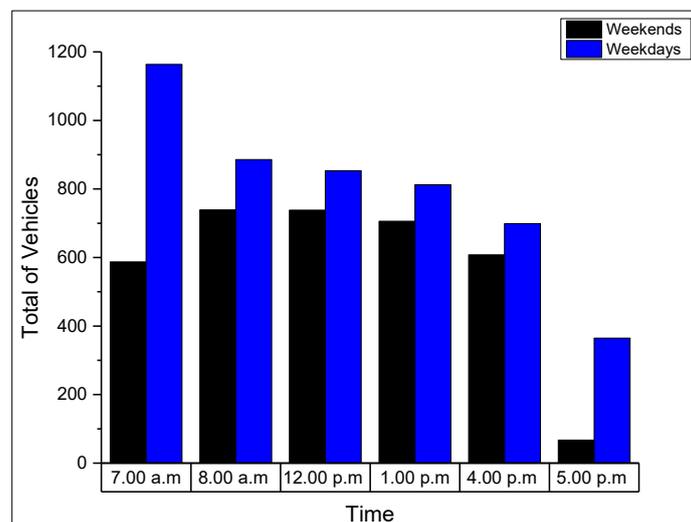

Fig. 9 *Average daily trend for traffic volume during weekdays and weekends in Jeli*
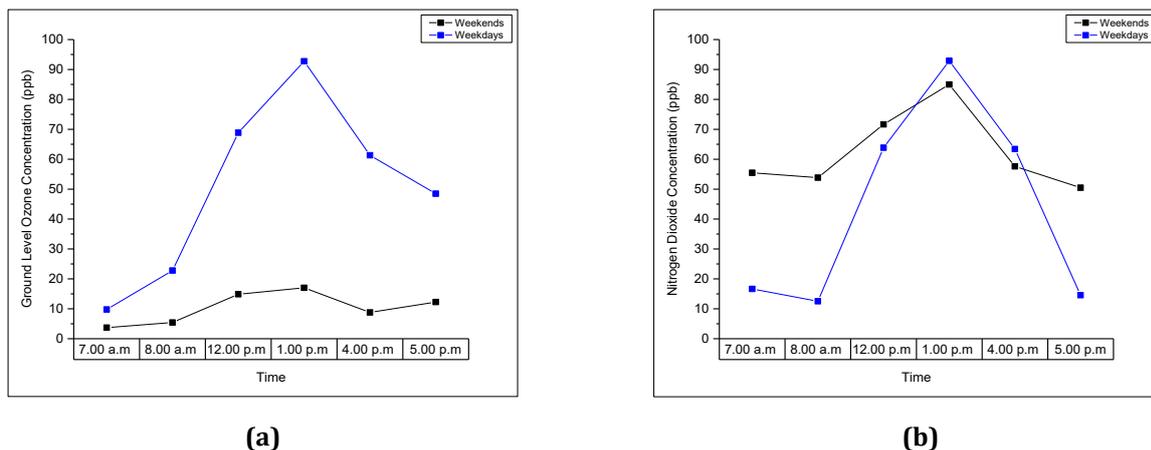
(a)

(b)

Fig. 10 *Average daily trend for (a) Ground-level ozone; and (b) Nitrogen dioxide concentration (ppb) during weekdays and weekends in Jeli*

3.4 Independent T-test

In this study, the independent sample T-test was used to compare pollutant concentrations between weekdays and weekends. The results in Table 1 provide evidence of whether the differences observed between the groups are statistically significant or not.

Traffic volume is a significant factor in understanding the difference in air quality between weekdays and weekends. The average traffic volume on weekends was 627 vehicles per day, while on weekdays this number increased to 749 vehicles per day. Although there was an initial expectation that a reduction in traffic on weekends could lead to a significant decrease in emissions of pollutants such as NO_2 and O_3, the results of the T-test showed no significant difference (p-value = 0.33) between weekdays and weekends. This indicates that the null hypothesis is accepted, indicating that the reduction in traffic volume did not result in a significant decrease in air pollution in the study area. A study by Blanchard et al. [17] linked increased recreational activity on weekends to replacing work vehicles with vehicles for unscheduled purposes, which does not necessarily reduce the total NO_2 emissions directly. Therefore, focusing on traffic alone is not enough to predict a continuous decline in air pollution, given that various vehicles are used for various social and recreational weekend activities. These findings underscore the importance of considering various sources of pollution, including industrial activities and non-traffic alone, in managing air quality in developed areas such as Jeli.

The results of the analysis showed that there was no significant difference in ground-level ozone concentrations between weekdays and weekends. The average ozone concentration on weekends was 10.34 ± 5.28 ppb, while on weekdays, ozone concentrations increased slightly to 11.13 ± 6.11 ppb. Although it was expected that a reduction in traffic volume on weekends will reduce nitrogen dioxide emissions and eventually increased ozone concentrations, but it did not affect the ozone concentrations during the weekends in this study. This is due to the complex interaction between pollutant emission sources, such as nitrogen dioxide and volatile organic compounds, that produce almost similar ozone concentrations even when human activity decreases. This also p-value obtained is 0.43, higher than the significance level of 0.05. Therefore, the null hypothesis was not rejected, suggesting that there was no statistically significant difference in ozone concentrations between weekdays and weekends. This observation aligns with findings by Zakaria et al. [23], who reported that NO_2 concentrations increased with traffic volume in Makassar's urban toll roads, also highlighting the modifying influence of local meteorological conditions. The absence of significant differences in ozone levels can be due to complex interactions between precursor pollutant emissions, NO_2 and volatile organic compounds and photochemical activity. This is because ozone formation is greatly influenced by sunlight. Studies show that sunlight-driven chemical reactions involve NO_2 and volatile organic compounds (VOCs) in maintaining ozone levels even as traffic emissions are reduced. While a reduction in traffic on weekends can lower NO_2 emissions, the available photochemical conditions may be similar, resulting in nearly identical ozone concentrations. A similar weekend ozone pattern was observed in rural Southern Italy, where reduced weekday traffic and ongoing photochemical activity caused ozone concentrations to rise over weekends (11).

Table 1 *T-test result of O_3, NO_2 concentration (ppb), and traffic volume*

Variable	Classification	Mean	Standard Deviation	p-value
O_3	Weekends	10.34	5.28	0.43
	Weekdays	11.13	6.11	
NO_2	Weekends	62.34	5.42	0.92
	Weekdays	61.99	6.93	
Traffic Volume	Weekends	627.88	118.43	0.33
	Weekdays	749.88	109.00	

The results showed no significant difference between weekdays and weekends concerning nitrogen dioxide concentrations. Table 1 shows the results of the T-test, where the average NO_2 concentration was 62.34 ± 5.42 ppb, compared to 61.99 ppb on weekdays with a standard deviation of 6.93 ppb, and there is no statistically significant difference in NO_2 concentrations between weekdays and weekends. A study by Beirle et al. [14] stated that NO_2 emissions come from traffic and other sources such as domestic fuel burning and household activities. Therefore, the stability of NO_2 concentrations throughout the week in this study area may be due to constant and persistent sources of pollution from other human activities such as open burning and constructions in addition to traffic. These findings assert that while traffic reductions may influence certain pollution emissions, there are other factors to consider in analysing changes in pollutant gas concentrations, such as NO_2.

The lack of statistically significant differences in O_3 and NO_2 concentrations between weekdays and weekends may result from the restricted sampling duration, fluctuations in daily meteorological conditions, or the impact of additional emission sources, including domestic and industrial activities. Given that the study spanned merely two weeks, the dataset may inadequately reflect broader temporal trends. Extended studies over multiple seasons are essential to ascertain whether these differences endure or attain statistical significance under diverse environmental conditions.

3.5 Pearson's correlation

Table 2 shows a significant positive correlation between O_3 and NO_2, which is slightly weaker on weekends (r = 0.7332) than on weekdays. This correlation may be due to decreased traffic activity or a change in sunlight intensity. Nitrogen dioxide, a major precursor in the formation of ozone, undergoes photolysis under sunlight to produce nitrogen monoxide (NO) and atomic oxygen (O), which react with molecular oxygen (O_2) to form ozone [5]. A moderate to strong correlation on weekends suggests that photochemical processes are still active, supported by adequate levels of sunlight and NO_2.

On weekends, the reduction in NO_2 emissions weakens the effects of ozone titration, a process in which NO reacts with ozone, reducing its concentration near traffic sources. Favourable meteorological conditions, such as sunlight and warm temperatures, increase the photochemical reaction. Regional polluter transport also contributes to persistent ozone levels by bringing pollutants from nearby urban or industrial areas. These factors underscore the need for air quality models integrating local and regional influences to manage ozone effectively. Pearson's correlation shows a weak but positive correlation (r = 0.07579) between traffic volume and O_3 over the weekend, suggesting minimal traffic influence on ozone concentrations. Ozone formation is driven by a photochemical reaction involving nitrogen oxides (NOx) and volatile organic compounds (VOCs) under sunlight. On weekends, traffic emissions are reduced, NOx levels are lower, and the direct impact of traffic on ozone dynamics is reduced.

The reduction of NO emissions reduces the effects of ozone titration, allowing ozone levels to stabilise or increase. Meteorological factors such as temperature, solar radiation, and wind patterns have a major influence on ozone formation, often outweighing the effects of traffic. On weekdays, a weak negative correlation (r = -0.08158) between O_3 and traffic volume suggests that high NO emissions from vehicles may reduce ozone near traffic sources. This emphasises the dominance of meteorological conditions and regional pollutant transport in determining ozone levels versus traffic volume alone. Pearson's correlation coefficient between NO_2 and traffic volume was moderate on weekends (r = 0.41048) and weak on weekdays (r = 0.23887), indicating that traffic volume contributed to NO_2 levels but was not the only determinant. Nitrogen dioxide mainly comes from vehicle emissions, with an additional contribution from industrial activities and regional pollutant transportation. In addition, on weekends, lower traffic density reduces overall NOx emissions, yet a modest correlation reflects traffic as the main source of NO_2 [15,16]. Regional pollutant transport also affects NO_2 levels when wind patterns carry pollutants from urban or industrial areas to Jeli. Meteorological factors, such as wind speed and atmospheric stability, also influence the dispersion and concentration of pollutants.

On weekdays, higher traffic volumes increase NO_2 levels, but weak correlations suggest significant contributions from other factors such as industrial emissions and regional polluter transport. These findings highlight the importance of addressing various emission sources and atmospheric conditions in air quality management. The weak correlation between O_3 and traffic volume shows the role of meteorological factors and regional pollutant transport in ozone dynamics. A comprehensive air quality strategy must integrate these variables alongside traffic control measures. Similarly, the correlation between NO_2 and traffic volume underscores the importance of addressing regional polluter transport and industrial emissions in semi-urban areas such as Jeli. Policies that promote cleaner vehicle technology, efficient traffic management, and regional cooperation are essential for reducing NO_2 and O_3 pollution. Incorporating meteorological data into air quality models can improve the accuracy of forecasts and guide effective mitigation measures. A holistic approach considering local emissions, regional transportation, and atmospheric conditions is essential for managing air quality in Jeli and similar areas [9].

These findings highlight the impact of traffic patterns and photochemical processes on the time-based distribution of ground-level ozone (O_3) and nitrogen dioxide (NO_2) in Jeli. During weekdays, NO_2 concentrations were elevated as a result of heightened traffic activity, whereas weekend O_3 levels rose due to reduced NO titration effects. It is essential to acknowledge that this study was limited to two weeks in August 2024. The data gathered provides important insights into the differences in air pollutants during weekdays and weekends in Jeli. However, to enhance the generalizability and robustness of these findings, a longer-term or seasonal dataset is essential. Future investigations ought to incorporate multi-seasonal monitoring to obtain a more comprehensive understanding of pollutant patterns and the meteorological factors that influence them over time.

Table 2 *Relationships between O_3, NO_2 concentration (ppb), and traffic volume during weekdays and weekend*

Classification	Variable	O_3	NO_2	Traffic Volume
Weekdays	O_3	1	0.849	-0.081
	NO_2	0.849	1	0.238
	Traffic Volume	-0.081	0.238	1
Weekends	O_3	1	0.733	0.075
	NO_2	0.733	1	0.410
	Traffic Volume	0.075	0.410	1

Conflict of Interest

The authors declare that there is no conflict of interest regarding the paper's publication.

Author Contribution

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