Jurnal Presipitasi
Media Komunikasi dan Pengembangan Teknik Lingkungan
e-ISSN: 2550-0023

Vol 21, No 2, 2024, 469-479
Article available at homepage presipitasi

Regional Case Study

The Relationship of Surface Ozone Pollution with Meteorological Conditions in Determining Episode Periods

Taufik Rizki Ramadhan[1], Didin Agustian Permadi[1*]
[1] Enviromental Engineering Program, Faculty of Civil Engineering and Planning, Institut Teknologi Nasional, Bandung, Phh. Mustofa No 23, Bandung, Indonesia 40124
Corresponding Author, email: didin@itenas.ac.id

Abstract
Jakarta, the capital city of Indonesia, is located in a tropical region with abundant sunlight and high temperatures year-round. Ozone and particulate matter (PM) are critical parameters causing unhealthy air pollution. Meteorological data were obtained from the NASA Power website. This study aims to explore the relationship between ozone formation and meteorological factors in Jakarta. Ozone air quality data were measured using the Backman model 950A ozone Analyzer, which detects concentrations as low as 0.05 ppm, with measurements taken every 40 seconds. From January to October 2023, ozone concentrations increased during the dry months of May to October, with the highest hourly value recorded at 263 µg/m³. During this period, average temperatures ranged from 27-29°C, rainfall was 0.3-5.6 mm, wind speeds were 3.14-4.64 m/s, wind direction was 92-171 degrees, and air humidity was 74-82%. Significant episodes were identified on (i) May 5-9, (ii) July 12-15, (iii) September 6-7, (iv) September 13-14, (v) September 21-22, and (vi) October 29-30, 2023. Daily, monthly, and seasonal ozone variations aligned with meteorological conditions, showing higher concentrations during the dry months. Further studies, including photochemical modeling, are required to identify dominant factors causing high ozone concentrations during these episodes. Understanding NOx or VOC emission sensitivities is crucial for effective ozone abatement strategies in Jakarta.

Keywords: Ozone; episode; meteorological factors; airnow; power nasa

1. Introduction

DKI Jakarta is located in the lowlands with coordinates 6-120º South latitude and 106-480º East longitude. The average elevation is about 7 meters above mean sea level (AMSL). The monsoon pattern affected two main seasons commonly observed in the city: the dry season (April-October) and the wet season (November-March) (Supardi and Efendi, 2019). In the big cities with intensive anthropogenic activities, ozone concentrations have been reported to increase annually in recent years; especially in summer (Wang et al., 2022). The concentration of ozone in the tropospheric layer is affected by emissions and the proportion of precursors such as volatile organic compounds (VOCs) and NOx. High ozone concentrations can damage agricultural products and disrupt ecosystem balance as well as endanger human health with respiratory disorders and cardiovascular problems. The photochemical reactions of precursors, meteorological conditions and emission loads are the main sources of factors that affect ozone formation (Li et al., 2020).

Over the past few decades, rapid population growth, industrial advancement, urbanization, and increased vehicle activity have deteriorated the air quality of Jakarta especially PM10, PM2.5 and ozone. As it is located in a tropical area, the city has experienced high sun exposure and temperatures throughout the year, which intensifies ozone formation. The decline in air quality is a serious issue that needs special attention especially to anticipate worsened impacts on public health. Air quality reached its highest level in August 2023 at 262.64 µg/m3 from January to October 2023 (Airnow.gov., 2023). The concentrations were reported to violate the National Ambient Air Quality Standards (NAAQS) of Indonesia as well as to create the air pollution index to be in a very unhealthy level. The Jakarta Provincial Environmental Agency (DLH) has been collecting air quality data through their automatic ambient air quality monitoring networks with fragmented information published in the website. The level of ozone precursors , surface temperature and other meteorological parameters influence the complex and non-linear relationship in ozone formation (Porter and Heald, 2019). Ozone in Jakarta has been a focus of research, mainly due to its proximity to the equator, which results in exposure to high levels of sunlight and temperature, as well as climatic influences. During the dry season of May - October, the southeast monsoon winds dominate, bringing cool and dry air with little rainfall, while during the rainy season, the northwest monsoon winds bring warm and humid air, resulting in significant evaporation over the Java Sea as a source of rain (Wasi'ah and Driejana, 2020 ; Permadi and Kim Oanh, 2008) . The process of dry deposition when plants absorb ozone is an illustration of the relationship between ozone and humidity. When relative humidity is high, plants open stomata (pores for the exchange of CO_2 and water vapor) and inadvertently absorb ozone. The presence of lightning during rain can also increase ozone concentrations during the rainy season compared to the dry season. However, NO_2 concentration during the rainy season tends to be lower than that during the dry season because rainwater dissolves NO_2.

Despite the availability of continuous air quality monitoring data for ozone in Jakarta, hourly data are often not published, which prevents a detailed analysis. AirNowDOS is a web application that collects air quality monitoring information from all U.S. consulates and embassies around the world and publishes hourly data in their website (Airnow.gov., 2023). Nasa Power is a web application that uses NASA research data on solar power and meteorology to support renewable energy, building energy efficiency, and agricultural needs (NASA, 2023) and the data are freely available for access. This research aims to investigate the relationship between meteorological conditions and ozone concentrations to further identify ozone episodes using temporal high-resolution data provided by highly acknowledged global databases. The results can serve as a status of ozone pollution in Jakarta for the most recent year to help shape strategies (i.e., early warning), especially during high ozone episodes. International attention on short-lived climate forcers (SLCF), in which ozone is included, has grown rapidly to highlight global efforts under the umbrella of climate and clean air co-benefits.

2. Methods

2.1. Data collection

Most of the data collected in this study are predominantly originated from secondary data, and with the QA/QC information provided by AirNow and the Prediction of Worldwide Energy Resources (POWER) database accessible through National Aeronautics and Space Administration (Nasa, 2023). The data used consisted of the ozone air quality and meteorological data (temperature, humidity, wind speed, wind direction, and rainfall). Hourly ozone concentrations were collected during January–October 2023 from the air quality monitoring system managed by the United States (US) Department of State located in Central Jakarta. Data Quality Objective (DQO) processes have been implemented worldwide to determine the data quality requirements for ambient criteria air pollutants generated from the AirNow network. . AirNow uses the Beckman model 950 ozone air analyzer, that is known for its lower cost, portability, and generally easier operation compared to regulatory-grade monitors widely used in the US for regular air quality compliance.

2.2. Data analysis

In this study, a quantitative descriptive analysis method was done for the analysis. This means that data obtained from the website were converted into graphs and numerical forms using the Origin Pro application. Hourly ozone concentrations were also compared with the National Ambient Air Quality Standard (NAAQS) of Indonesia following Ministry of Environment and Forestry Regulation No. 22 of 2021 (Annex VII). Ozone concentrations exceeding the hourly NAAQS throughout the day for a minimum of two consecutive hours for more than one day have been identified for ozone episodes (Zhang and Kim Oanh, 2002). To investigate favorable meteorological conditions during the identified ozone episodes, monthly and daily variations of both parameters were constructed and simple linear regression analysis was performed (Sari et al., 2020; Permadi et al., 2008).

3. Result and Discussion

3.1. Time Series Ozone (O3)

In this study, the time series plot was generated during the period January-October 2023 for hourly ozone monitoring data taken from the AirNow database for a U.S. The Department of State Indonesia's monitoring station is located in Central Jakarta.

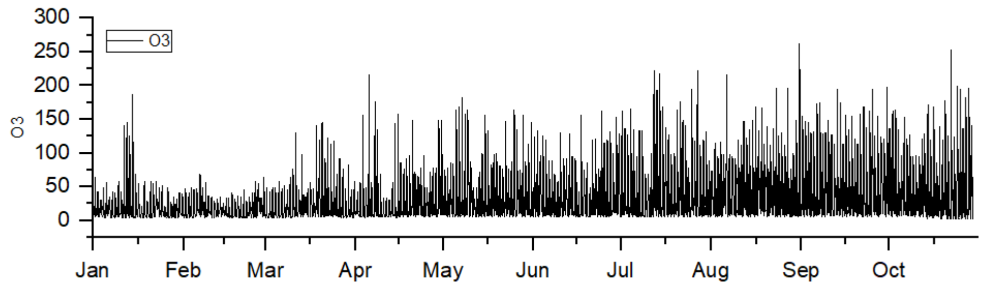


Figure 1. Time series of hourly ozone concentration for the period of January-October 2023

The trend of hourly ozone concentration during the period of January-October 2023 exhibits a typical pattern for cities influenced mainly by seasonality of precursor emissions and meteorological conditions (Wasi'ah and Driejana, 2020; Permadi and Kim Oanh, 2008). Ozone concentrations increased from January to October 2023 and typically moved up from rainy to dry months. Higher ozone concentrations during the dry months of August – October can also be caused by intensified open burning of biomass occurring in the surrounding areas. Solar radiation, temperature, and humidity collectively contribute to ozone production by increasing the rate of photochemical reactions. The role of wind speed and direction is more on the transport of precursors (i.e., anthropogenic and biogenic) and also on maintaining sufficient atmospheric residence time for photochemical reactions to occur. The creation of ozone arises from the photodissociation of hydrocarbon compounds in the atmosphere and is influenced by radical compounds. As a way of example, through a modeling study, maximum ozone tends to be formed at the down wind direction when the anthropogenic precursors (i.e. NOx, VOC, and CO), and reacted with the biogenic emissions coming from the vegetation region under intensive solar radiation exposure (Permadi, 2017). The connection between precursor emissions and meteorological factors leads to a nonlinear relationship with ozone formation, which poses a significant challenge for the formulation of mitigation strategies.

Several peak ozone concentrations were observed from April to October 2023, with the highest hourly concentration occurring in September 2023 at 263 µg/m3 (Figure 1). Increased concentrations in Jakarta occur due to high precursor emissions of VOCs and NOx from major anthropogenic sources available in the most recent emission inventory study, which reported that NOx emissions were predominantly contributed by the transportation sector (72%), followed by industry (11.5%). For VOC, on-road transport contributed even higher (98%), as well as CO emissions (96%) (Vital Strategies, 2020). This was a strong signal that transportation emissions were the single dominant source of air pollutants, except for SO2, where the manufacturing industry was a major contributor, followed by transportation and other sources. During the dry season, intensive open burning of crop residue is normally reported at the outskirts of Jakarta, as can be seen from fire mapper monitoring (Permadi and Oanh, 2008). This was mainly related to open burning of rice straw, which was performed after harvesting. This emission intensified the build-up of the local precursor emissions. According to (Ariestanty and Andri, 2013) in (Supardi and Efendi, 2019) in the tropical hemisphere April-October is known as the dry season, where temperature is normally measured high with low relative humidity and rainfall intensity. According to (Permadi and Oanh, 2008), the influence of the dry season is very close to the formation of ozone in an area affected by higher pressure gradient which can cause high ozone concentrations. The concentration of ozone in Jakarta was measured significantly higher in the dry season (April-October) than in the rainy season (November-March). During the dry season, the synoptic southeast monsoon (SE) wind brings cold winds and dry air, resulting in low rainfall, high temperatures, low humidity, and low wind speed due to high pressure gradient over the region (Kusumaningtyas et al., 2018)

3.2. Monthly Variation of in Central Jakarta and Meteorology

Monthly variations in ozone concentration and meteorological conditions (temperature, wind speed, wind direction, rainfall, and air humidity) were analyzed using data from the NASA Power site extracted for the area of Jakarta. The ozone concentration increased in the dry months (April-October), with the highest monthly average value of 52 µg/m3 measured in September (Figure 2).

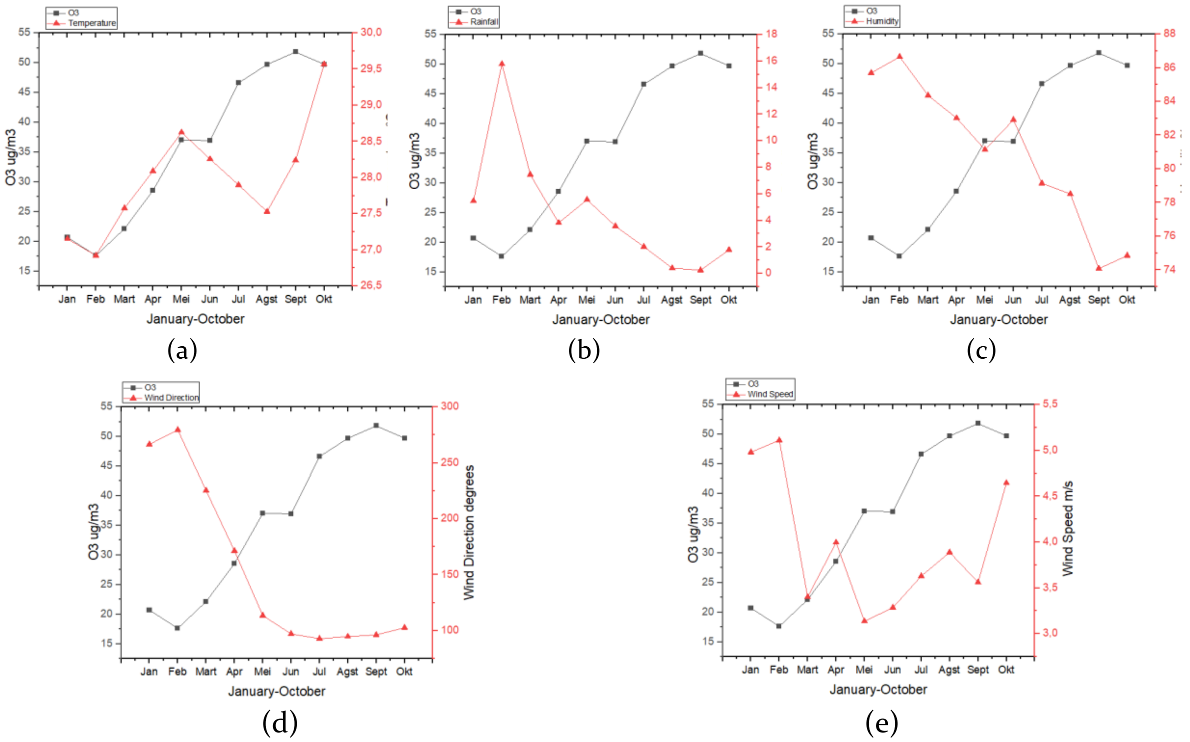


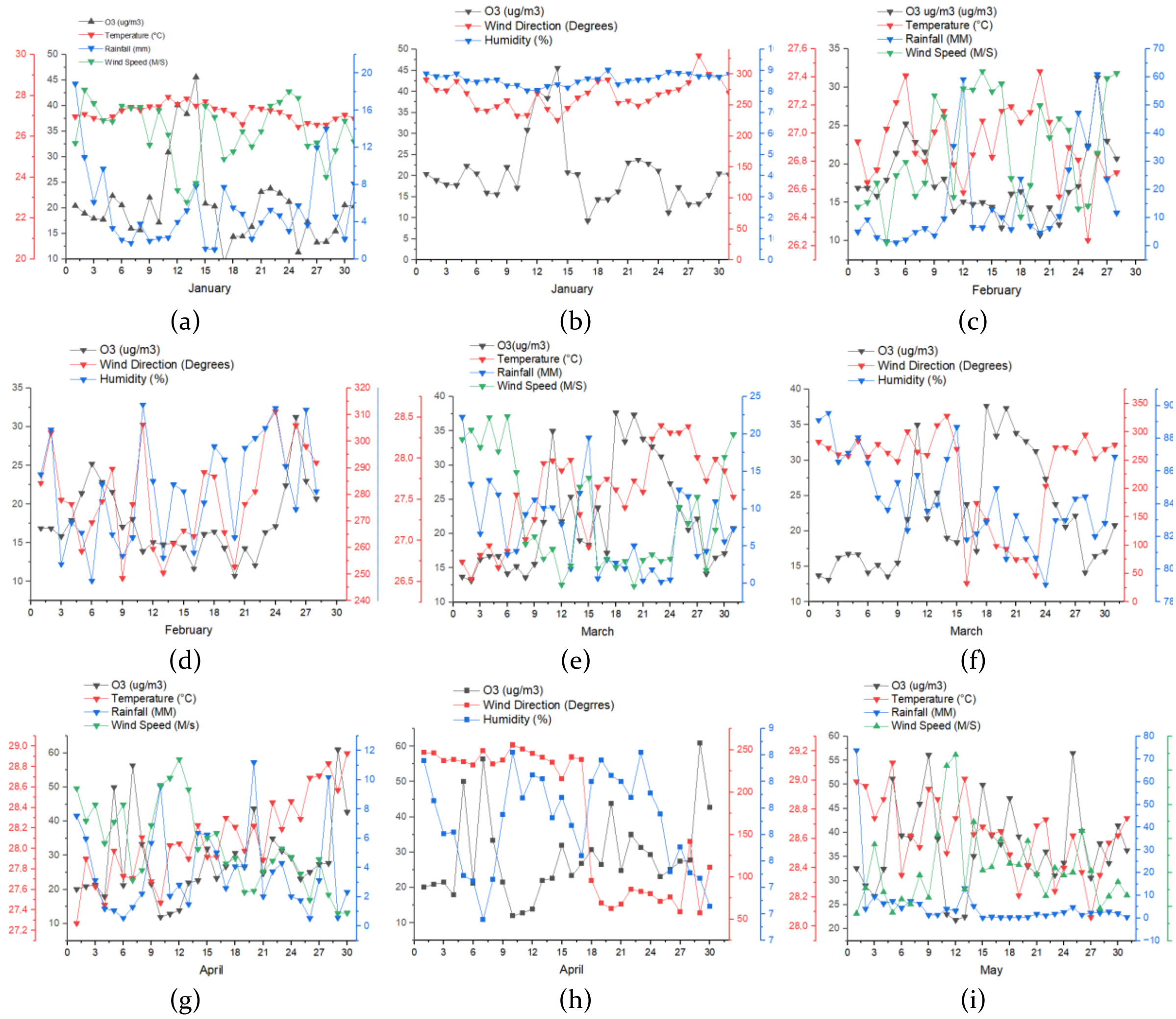
Figure 2. Monthly variation of o3 and temperature (a), monthly variation of o3 and rainfall (b), monthly variation of o3 and humidity (c), monthly variation of o3 and wind direction (d), monthly variation of o3 and wind speed (e)

During the dry months of April-October the range of measured temperature was from 27-33°C) while rainfall was 0.3-5.6 mm. Wind speed value was measured within a range f 3.14-4.64 m/s and relative humidity was measured of 74.07-82.91% (Figure 2). Changes in ozone concentration trends in the rainy and dry seasons were very significant, showing strong seasonality. The rainy season period (January-March) shows that ozone pollution was relatively safe, as can be seen from the rare occasions of exceedances to the NAAQS. The condition was similar to the research that was conducted by Permadi and Oanh (2008), where the seasonal factor in an area significantly affects the meteorological conditions and the increase in pollutant concentrations in an area. Ozone concentrations began to decrease in February and began to increase in March 2023 which shows seasonal changes when entering the transition period from the rainy to the dry season. In the case of changes in the meteorological situation during the period of January-February which was indicated by low temperature, high rainfall, high wind speed , and high humidity seemed to bring in good pollutant dispersion hence less formation of ozone in the site so that there was no photo-chemical interaction between precursors in that month and resulting in low ozone concentrations in DKI Jakarta in that month.

The status of ozone concentrations in the dry season (April-October) shows significant increase of ozone concentrations in April-October 2023. The highest daily average concentration was 94 µg/m3 on August 31, which was influenced by high temperature and low wind speed, humidity, and rainfall intensity. These meteorological conditions intensified photochemical reactions with high local emissions, creating high concentration of ozone during that period. During the dry season, low rainfall leads to minimum wash-out of precursor emissions; hence, photochemistry occurs intensively, resulting in a high ozone concentration in the air (Uttamang et al., 2020). The concentration of tropospheric ozone is highly correlated with surface temperature during the daytime, especially in regions with high air pollution. Additionally, a high air pressure gradient and temperature would increase reactivity in photochemistry owing to a relatively low wind speed and stagnant air (Permadi ; Oanh, 2008 ; Ambarsari, 2015).

3.3. Daily Variation of O3 in Central Jakarta and Meteorology

Relationships between daily average meteorological conditions (except for prevalent wind direction) and ozone concentrations during the period of January – October 2023 are presented in Figure 3.



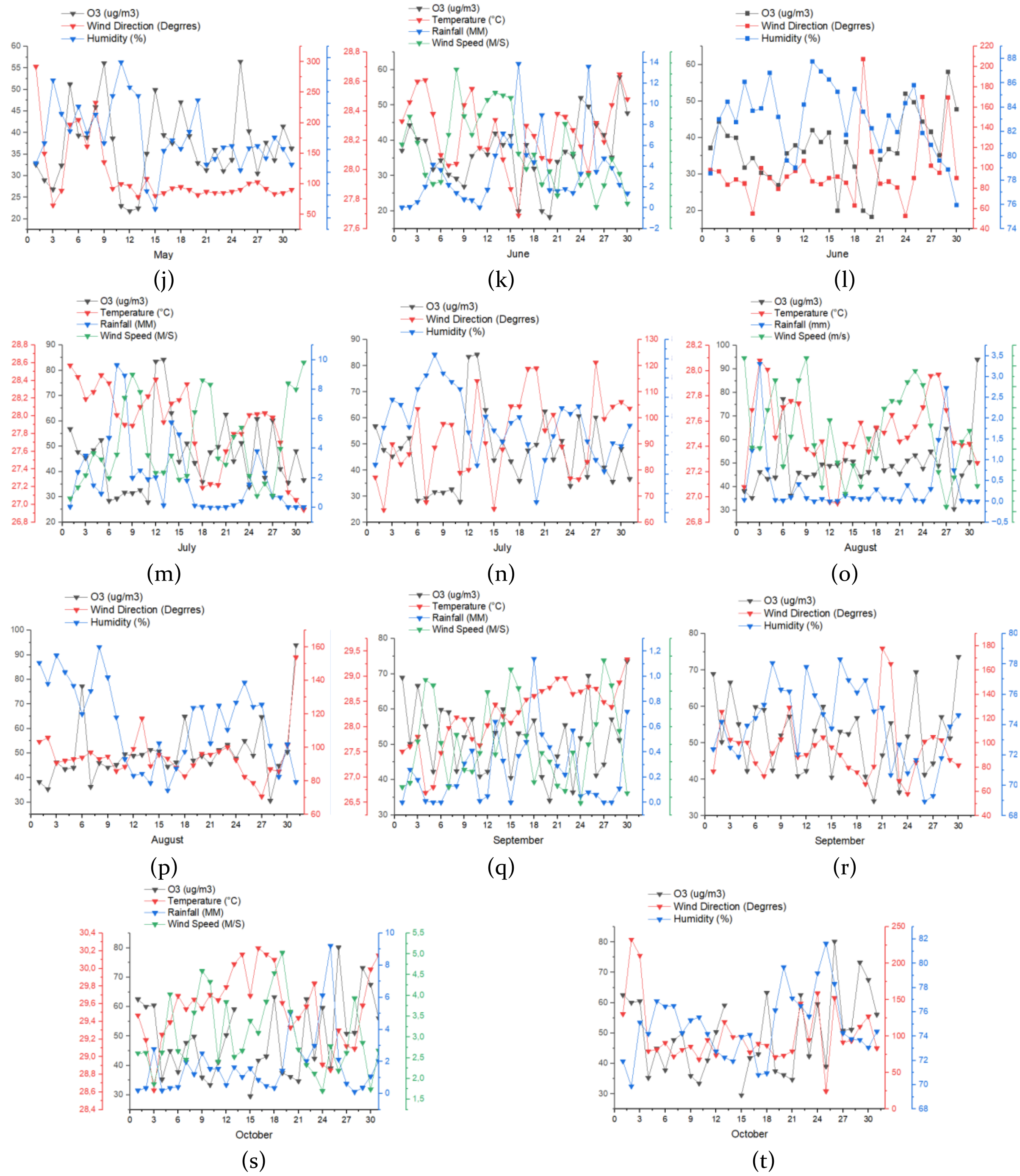


Figure 3. Daily average meteorological conditions and ozone concentrations, (a) (b) January, (c) (d) February, (e) (f) March, (g) (h) April, (i) (j) May, (k) (l) June, (m) (n) July, (o) (p) August, (q) (r) September, (s) (t) October.

The maximum daily peak ozone concentration occurs between 11:00 and 14:00, as measured by the AirNow monitoring station in DKI Jakarta. This condition is similar to that measured in Bangkok, Thailand (Uttamang et al., 2020) which was affected by a typical tropical meteorological conditions as well as a bimodal pattern of anthropogenic emissions In Jakarta, there is an increase in ozone concentration on busy weekdays (Monday to Friday). DKI Jakarta, being a metropolitan city with a high population density, experiences heightened vehicular usage and industrial activities during weekdays, contributing to the release of ozone precursor pollutants such as CO, VOCs, and NOx in the formation of tropospheric ozone. The high level of anthropogenic activities (e.g., transportation, power generation, industrial activities, etc.) led to photochemical reaction buildup in addition to favorable meteorological conditions, hence increasing ozone concentrations.

The impact of seasonal and meteorological conditions in a region greatly influences the high or low levels of ozone concentration in that area (Ambarsari, 2015). High concentrations occur when air temperature and humidity are high, but wind direction and speed are low, along with low rainfall. This leads to photochemical reactions resulting in elevated ozone concentrations in DKI Jakarta.

Table 1. Linear regression analysis

No	Mode	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	Ozon-Temperature				
		0.625[a]	0.391	0.315	10.89762
2	Ozon-Rainfall				
		0.822[a]	0.676	0.636	7.94769
3	Ozon-Wind Speed				
		0.383[a]	0.147	0.040	12.90287
3	Ozon-Wind Direction				
		0.925[a]	0.855	0.837	5.31620
4	Ozon-Humidity				
		0.942[a]	0.888	0.874	4.67425

Correlation between ozone concentration and meteorological parameters for the period of January – October 2023 using simple linear regression analysis is presented in Table 1. The results revealed that the highest coefficient of determination (R^2) was for relative humidity (0.942) followed by wind direction (0.925), rainfall (0.822), temperature (0.625) and wind speed (0.383). Relative humidity and other meteorological factors had a strong influence on ozone concentration. Temperature can contribute to ozone production in a region by enhancing the rate of photochemical reactions which is also linked to relative humidity. Additionally, it can accelerate the decomposition of NO2, thereby promoting an increase in ozone concentration in DKI Jakarta.

Rainfall can significantly influence the increase in ozone concentration in a particular region. Rainfall plays important role for sink processes of precursor emissions through wet deposition and wash out processes (Faisal, 2019 ; Wie and Moon, 2016) . Wet deposition occurs when ozone dissolves in rainwater and descends to the Earth's surface, reducing atmospheric ozone concentration. On the other hand, dry deposition involves ozone absorption by the ground surface and vegetation. Therefore, rainfall would help to reduce ozone concentration by cleansing the atmosphere of these components despite it contains chemicals, such as nitrogen oxides (NOx) and hydrocarbons which can contribute to ozone formation at the surface through complex chemical reactions.

Wind speed can play a crucial role in the dynamics of ozone concentration in a region according to research conducted in Chine (Fu et al., 2019;Yang et al., 2019). Wind speed affects the ability of the atmosphere to mix and disperse pollutants, including ozone, formed through photochemical reactions. Swift winds aid in mixing ozone and other chemicals in the atmosphere, preventing their accumulation in a specific area. As a result, ozone concentrations tend to be more uniform and lower when wind speed is high. Wind speed also affects the transport of ozone from emission sources to distant areas. At high wind speeds, ozone may break down or react with other components in the atmosphere, leading to changes in ozone concentration. In addition, wind speed is critical parameter for stability of the air hence affecting dispersion of precursor emissions.

Wind direction plays a vital role in the distribution of ozone in a given region according to research (Fu et al., 2019) in China. If there is an ozone emission source in a particular area, the wind can transport ozone from that source to other areas. When the region experiences winds flowing from the ozone source, the ozone concentration in that area may increase. In Jakarta, northeasterly - easterly winds during the dry month of October seemed to bring precursor emissions downwind of Southern Jakarta, where vegetation areas are located (source of biogenic emissions). Wind flow patterns affected the downwind transport of precursor emissions, which enabled the reaction between reactive biogenic VOCs and other precursors.

Atmospheric humidity can impact the formation and distribution of ozone in a region. According to previous research (Domínguez-López et al., 2015; Kavassalis and Murphy, 2017), photochemistry is influenced by chemical reactions occurring in the atmosphere due to sunlight exposure. Humidity can affect the reaction rate and stability of molecules involved in ozone formation. Generally, high humidity can hinder certain photochemical reactions essential for ozone formation. Conversely, low humidity can enhance photochemical activity. Humidity also plays a role in both wet and dry deposition processes. High humidity supports wet deposition, where ozone dissolves in rainwater and descends to the ground surface while wet deposition also aids in cleansing ozone from the atmosphere. On the other hand, low humidity can increase dry deposition, where ozone is absorbed by the ground surface or vegetation. For Jakarta, coastal city located in the southern hemisphere, humidity is generally high throughout the year and regression result showed strong positive correlation with ozone formation. Photochemical smog modeling study is further required to study sensitivity of each meteorological parameter as well as precursor emissions.

3.4. Ozone Episode Analysis

The focus of research is centered on the ozone levels in Central Jakarta due to its proximity to the equator, where abundant sunlight and high temperatures, coupled with dense urban industrial and transportation activities, contribute to increased ozone concentrations. Hourly ozone concentrations throughout each day from January to October 2023 were recorded to surpass the NAAQS of 150 μg/m3 as presented in Figure 4. . Notably, during the January-October 2023 period, concentrations exceeding the NAAQS started in January, decreased in February (rainy season), and rose above the NAAQS again from April to October 2023. Selected episodes for further analysis include (i) May 5-9, (ii) July 12-15, (iii) September 6-7, (iv) September 13-14, (v) September 21-22, and (vi) October 29-30.

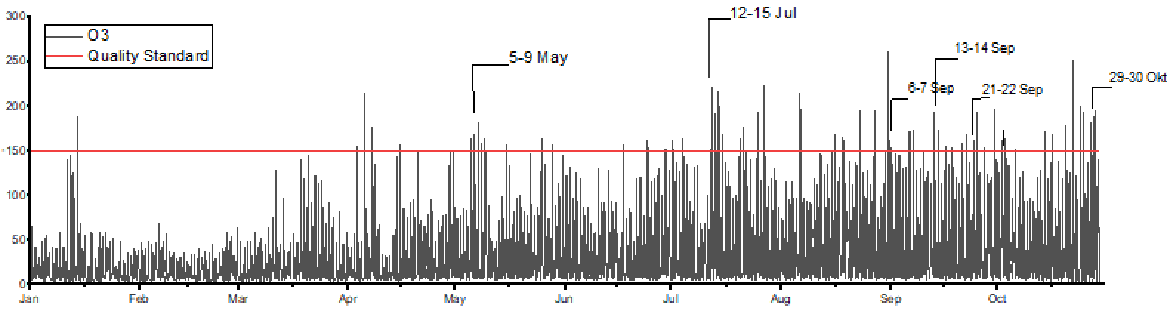


Figure 4. Time series of ozone concentrations January-October 2023 and Quality Standards

During the episode from May 5-9, ozone concentrations ranged from 135 to 197 μg/m3, humidity from 80.6% to 83.75%, temperature between 28.94°C and 29.12°C, rainfall from 1.25 to 7.46 mm, and wind speed from 1.83 to 2.27 m/s. For the period of July 12-15, ozone concentrations fluctuated between 168 and 218 μg/m3, wind direction ranged from 65.19 to 80.19 degrees, humidity varied from 78.38% to 78.56%, temperature from 28.41°C to 28.18°C, rainfall between 0.14 and 2.05 mm, and wind speed from 2.44 to 2.67 m/s. On September 6-7, ozone concentrations measured between 172.48 and 174.44 μg/m3, with wind direction ranging from 72.62 to 83.44 degrees, humidity levels from 74.44% to 75.31%, temperature between 27.48°C and 27.98°C, rainfall from 0 to 0.13 mm, and wind speed from 2.29 to 3.54 m/s. For September 13-14, ozone concentrations ranged from 174.44 to 194.4 μg/m3, wind direction from 98.31 to 104.56 degrees, humidity between 74.69% and 75.94%, temperature from 28.21°C to 28.44°C, rainfall from 0.33 to 0.64 mm, and wind speed from 3.22 to 4.08 m/s. On September 21-22, ozone concentrations were between 150 and 168.56 μg/m3, with wind direction ranging from 165.19 to 177.94 degrees, humidity levels from 70.69% to 75.12%, temperature from 28.96°C to 28.97°C, rainfall between 0.22 and 0.29 mm, and wind speed from 2.18 to 2.33 m/s. Lastly, during October 29-30, ozone concentrations ranged from 182.28 to 196 μg/m3, wind direction from 113.06 to 127 degrees, humidity levels between 73.06% and 73.69%, temperature from 29.58°C to 29.99°C, rainfall from 0.37 to 1.07 mm, and wind speed from 1.74 to 2.86 m/s.

The period of the episode from May 5-9 occurred from Friday to Monday, was characterized by a high daily temperature pattern, low rainfall, low wind speed, small wind direction, and low humidity. The highest concentrations were observed on the 9th, and the ozone levels recorded from monitoring stations lasted from 11:00 to 17:00. During this time, a daily pattern similar to the first episode emerged, with elevated concentrations due to photokinetic intensity influenced by meteorological conditions and the season. Episodes three, four, and five took place in September, all occurring on Wednesdays and Thursdays, with the highest concentrations on Thursdays beginning to increase from 10:00 to 17:00. The daily patterns in episodes three, four, and five closely resembled those of episodes one and two. The sixth episode occurred on October 29-30, falling on Sunday to Monday, with the highest concentrations observed on Monday. Ozone concentrations began to rise from 10:00 to 19:00. The elevated ozone concentrations on that date resulted from increased community activities on that day, and the meteorological daily pattern showed similarities to episodes occurring in the preceding months.

During the September-October episodes in (Sari et al.,2020); Permadi and Oanh (2008), the synoptic situation in the Northern Hemisphere was generally characterized by the presence of the Intertropical Convergence Zone (ITCZ) over Southeast Asia (crossing southern Thailand) and a high-pressure gradient system. In the southern hemisphere, a high-pressure cell developed over the continent of Australia, influencing the study area and causing the Southeast Monsoon circulation over Jakarta. April-May represents a transitional period between the rainy season and the dry season. For example, during the transition period in April, high ozone levels were observed when the area was under the influence of warm low-pressure systems. The topography of the study area has modified the synoptic-scale southeasterly winds into local northeasterly winds, further strengthened by onshore winds during the day.

The elevated concentrations on those specific dates in the central area of Jakarta are attributed to meteorological factors and precursor emission build up over the grater Jakarta Metropolitan Area. The identified ozone episodes provided typical favorable meteorological conditions leading to high ozone concentrations in Jakarta. Our results were somehow consistent with the previous research conducted in Jakarta (Permadi ; Oanh, 2008) that the meteorological conditions during the episodes were characterized by low wind speed, high temperature, stong solar radiation and stagnant air. Photochemical smog modeling application is able to describe detail ozone chemistry in the city if the precursor emission is available. Simulation can be done for the ozone episodes identified in this work.

4. Conclusions

Analysis of ozone concentrations using air quality monitoring data from AirNow database showed that daily, monthly and seasonal variations in ozone are well connected to meteorological conditions. Strong influence of meteorological factors on ozone concentrations in central Jakarta was seen clearly in addition to the influence of local precursor emissions. The highest ozone concentration occured in the dry season April-october. Low air temperature, especially in areas with high levels of air pollution, formed high ozone concentrations. Limited rainfall results in elevated ozone concentrations due to a deceleration in the rate of O3 photochemistry. Low wind speed due to high pressure gradient during the dry months caused the air to be poorly dispersed so that precursor emissions were involved in the photochemical reactions. Relatively low humidity caused plants to close their stomata to avoid evaporation so ozone was not uptake from the ambient air . Further research on local emission inventory and photochemical modeling is highly recommended for future studies especially to simulate ozone formation during the episodes identified in this article. This can provide a more in-depth analysis of ozone formation from anthropogenic sources influenced by meteorological conditions. The aim is to determine the priority scale for air pollution control and also as an early warning system for ozone air pollution in Jakarta.

Acknowledgement

We acknowledge AirNow and Power NASA for providing valuable data to be used in this research.

References

Airnow.gov. 2023. AirNow US State Department's air quality monitoring system (Ozone). airnow.gov US. [WWW Document].

Ambarsari, N., 2015. Efek radikal hidroxyl (OH) dan nitric oxide (NO) dalam reaksi kimia ozon Di atmosfer. Berita Dirgantara 16, 47–54.

DKI Jakarta, 2023. DKI Jakarta Dalam Angka 2023

Domínguez-López, D., Vaca, F., Hernández-Ceballos, M.A., Bolívar, J.P., 2015. Identification and characterisation of regional ozone episodes in the southwest of the Iberian Peninsula. Atmosphere Environmental 103, 276–288.

Faisal, I. 2019. Analisis pengaruh variasi musiman terhadap dispersi No 2 di kota Tangerang dengan menggunakan model WRF-Chem seasonal variation effect on No 2 dispersion in Tangerang using WRF-Chem model adalah weather reseach and forecasting with chemical (WRF-Chem). WRF-Chem adalah senyawa-senyawa kimia yang ada di atmosfer secara spasial dan temporal. Simulasi WRF- baik dibandingkan dengan model skala global (Power, dkk ., 2017). 25, 1–14.

Fu, X., Li, N., Ren, B., Jiang, G., Liu, Y., Hassan, F.M., Su, D., Zhu, J., Yang, L., Bai, Z., Cano, Z.P., Yu, A., Chen, Z. 2019. Tailoring FeN 4 Sites with edge enrichment for boosted oxygen reduction performance in proton exchange membrane fuel cell. Advance Energy Material 9, 1–7.

Kavassalis, S.C., Murphy, J.G. 2017. Understanding ozone-meteorology correlations: A role for dry deposition.Geophysical Research Letters 44, 2922–2931.

Kusumaningtyas, S.D.A., Aldrian, E., Wati, T., Atmoko, D., Sunaryo. 2018. The recent state of ambient air quality in Jakarta. Aerosol Air Quality Research 18, 2343–2354.

Li, K., Jacob, D.J., Shen, L., Lu, X., De Smedt, I., Liao, H. 2020. Increases in surface ozone pollution in China from 2013 to 2019: Anthropogenic and meteorological influences. Atmosphere Chemistry Physic 20, 11423–11433.

Nasa, P. 2023. Prediction of Worldwide Energy Resources (POWER) data base (temperature, wind direction, wind speed, rainfall, Humudity) power.larc.nasa.gov

Permadi, D.A. 2007. Surface O3 air quality in Jakarta: current status, precursor emission inventory, and modeling efforts. AIT Master Thesis, Bangkok, Thailand.

Porter, W.C., Heald, C.L. 2019. The mechanisms and meteorological drivers of the summertime ozoneerature relationship. Atmosphere Chemistry Physics 19, 13367–13381.

Sari, D., Incecik, S., Ozkurt, N., 2020. Analysis of surface ozone episodes using WRF-HYSPLIT model at Biga Peninsula in the Marmara region of Turkey. Atmospheric Pollution Research 11, 2361–2378.

Supardi, B., Efendi, D. 2019. Cuaca dan Iklim Bumi. Jurnal Internasional 7, 34–41.

Uttamang, P., Campbell, P.C., Aneja, V.P., Hanna, A.F., 2020. A multi-scale model analysis of ozone formation in the Bangkok Metropolitan Region, Thailand. Atmospheric Environmental 229, 117433.

Wang, T., Xue, L., Feng, Z., Dai, J., Zhang, Y., Tan, Y. 2022. Ground-level ozone pollution in China: A synthesis of recent findings on influencing factors and impacts. Environmental Research Letters 17.

Wasi'ah, N.R., Driejana. 2020. Kinetika Formaldehida (HCHO) dan Ozon (O3) di Daerah Urban (Studi Kasus: Jakarta). Jurnal Riset Kesehatan 12, 213–223.

Wie, J., Moon, B.K. 2016. Seasonal relationship between meteorological conditions and surface ozone in Korea based on an offline chemistry-climate model. Atmospheric Pollution Research 7, 385–392.

Yang, J., Liu, J., Han, S., Yao, Q., Cai, Z. 2019. Study of the meteorological influence on ozone in urban areas and their use in assessing ozone trends in all seasons from 2009 to 2015 in Tianjin, China. Meteorology and Atmospheric Physics 131, 1661–1675.

Yang, L., Xie, D., Yuan, Z., Huang, Z., Wu, H., Han, J., Liu, L., Jia, W. 2021. Quantification of regional ozone pollution characteristics and its temporal evolution: Insights from identification of the impacts of meteorological conditions and emissions. Atmosphere (Basel) 12.

Vital Strategies. 2020. Report on emission inventory of air pollutants for Jakarta for base year of 2018. Jakarta, Indonesia.

Zhang, B., Kim Oanh., N.T. 2002. Photochemical smog pollution in the Bangkok Metropolitan Region of Thailand in relation to O_3 precursor concentrations and meteorological conditions. Atmospheric Environment, 36, 4211–4222.