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Correlation Analysis of PM_{10} with Tropospheric Ozone During Forest and Land Fire Events in Sumatera

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Abstract
Indonesia has a forest area of 120,495,702.96 hectares which is vital for human survival. However, significant forest fires, such as those in 1997/1998 and 2015, have caused widespread damage and impacted neighboring countries. These forest fires contribute to an increase in tropospheric ozone (O_3) concentrations which are dangerous for human health. This study aims to evaluate the correlation between PM_{10} and tropospheric ozone in Sumatra during forest fires, using data from the Bukit Kototabang Global Atmospheric Monitoring Station. The analysis method involves measuring PM_{10} and O_3 concentrations using the BAM1020 and Ozone Analyzer Model 49 I, as well as Pearson correlation and linear regression analysis. Results show that there is a positive correlation ($r = 0.53$) between PM_{10} and tropospheric ozone, with PM_{10} increasing as O_3 concentrations increase during extreme conditions. The average monthly concentrations of PM_{10} and O_3 during 2016-2020 were 21.75 $\mu g/m^3$ and 11.61 ppb respectively, with peak concentrations of PM_{10} in September and O_3 in February. Increases in PM_{10} during forest fires contribute to increases in ozone precursors and photochemical processes, accelerating the formation of tropospheric ozone.
Keywords: *air pollution, pearson correlation, PM_{10}, tropospheric ozone*

Abstrak
Indonesia memiliki luas hutan sebesar 120.495.702,96 hektar yang sangat vital bagi keberlangsungan hidup manusia. Namun, kebakaran hutan yang signifikan, seperti yang terjadi pada tahun 1997/1998 dan 2015, telah mengakibatkan kerusakan luas dan berdampak pada negara tetangga. Kebakaran hutan ini berkontribusi terhadap peningkatan konsentrasi ozon troposfer (O_3) yang berbahaya bagi kesehatan manusia. Penelitian ini bertujuan untuk mengevaluasi korelasi antara PM_{10} dan ozon troposfer di Sumatera selama kebakaran hutan, menggunakan data dari Stasiun Pemantau Atmosfer Global Bukit Kototabang. Metode analisis melibatkan pengukuran konsentrasi PM_{10} dan O_3 menggunakan BAM1020 dan *Ozon Analyzer Model* 49 I, serta analisis korelasi Pearson dan regresi linear. Hasil menunjukkan bahwa terdapat korelasi positif ($r = 0.53$) antara PM_{10} dan ozon troposfer, dengan peningkatan PM_{10} seiring peningkatan konsentrasi O_3 selama kondisi ekstrem. Rata-rata konsentrasi bulanan PM_{10} dan O_3 selama 2016-2020 adalah masing-masing 21.75 $\mu g/m^3$ dan 11.61 ppb, dengan puncak konsentrasi PM_{10} pada bulan September dan O_3 pada bulan Februari. Peningkatan PM_{10} selama kebakaran hutan berkontribusi pada peningkatan prekursor ozon dan proses fotokimia, mempercepat pembentukan ozon troposfer.
Kata Kunci: *korelasi pearson, ozon troposfer, PM_{10}, polusi udara*

1. Introduction

According to the Central Bureau of Statistics, Indonesia is a country with a forest area of 120,495,702.96 hectares. Forest is one of the important components for human survival. However, due to human activities and some extreme weather events, Indonesia has been hit by quite large forest fires as recorded in 1997/1998 due to the ENSO (El Nino Southern Oscillation) event causing at least 9.75 million hectares of forest and land in Indonesia to burn [1]. And in 2015 forest fires also occurred in several provinces in Sumatra such as Riau, Jambi and South Sumatra [2], [3]. Forest fires in Indonesia also have a detrimental impact on neighboring countries, especially Malaysia and Singapore [4], [5], [6]. The occurrence of forest fires in tropical countries can affect the concentration of ozone precursors (O_3), thus contributing to an increase in atmospheric ozone concentrations [7].

According to PP No. 22 of 2021, air pollution is the entry or inclusion of substances, energy, and/or other components into the ambient air by human activities so that it exceeds the predetermined ambient air quality standards. and air pollutant sources are any human activity that emits air pollutants into the ambient air. One of the parameters that can be used as a measure of air pollution is the PM_{10} and O_3 (tropospheric ozone) parameters, several studies reveal that the increase in tropospheric ozone and PM_{10} can be caused by forest fires or can be said to be vulnerable to forest fires [8]. When forest fires occur, there are several gases produced including Sulfur Dioxide (SO_2), Nitrogen Oxides (NO), VOC (Volatile Organic Compounds) and other gases that interact with other components to form fine particles, besides that, UV (Ultraviolet) light also supports the process of tropospheric ozone formation [8].

The formation of tropospheric ozone is a process of photochemistry that occurs in the atmosphere caused by biomass burning and UV light [9]. Basically, ozone in the tropospheric layer is a toxic gas or can be categorized as secondary air pollution, so it can have an impact on human health [10]. Tropospheric ozone is also a major pollutant that harms human health, more than 0.2 million premature deaths are estimated due to exposure to tropospheric ozone (O_3) and one of the dominant sources in the formation of tropospheric ozone is carbon monoxide (CO) assisted by nitrogen oxides and photochemical oxidation of Volatile Organic Compounds (VOC) [11]. In addition, tropospheric ozone also has an important role in increasing the oxidation process in the atmosphere, and this can have an adverse impact besides on humans, it can also damage ecosystems and agricultural crops [12].

The interaction between O_3 and particulate matter (PM) occurs simultaneously during haze and has an impact on air pollution. PM that acts as an aerosol can change the rate of photolysis, and some researchers have found that aerosol absorption can reduce UV flux throughout the troposphere, causing a reduction in tropospheric ozone production [12]. Based on this, this study was conducted to see the correlation of PM_{10} with tropospheric ozone (O_3), especially during forest and land fires in Sumatra. The research data used is sourced from the Bukit Kototabang global atmospheric monitoring station, West Sumatra, which is one of the clean air reference stations in Indonesia. Research related to the correlation of PM_{10} with O_3 has previously been conducted in India with a case study in the coastal area of Kannur (11.9° N, 75.4° E) with a comparative analysis of seasonal differences [7]. And in this study, a comparison of the correlation of PM_{10} with tropospheric ozone (O_3) was carried out in a highland area with an altitude of 864.5 m above sea level and 40 km from the western coastline during forest fires in Sumatra. As we know that the Bukit Kototabang global atmospheric monitoring station is a station located in a tropical forest that is also influenced by the coast and is often affected by the impact of forest fires, land and transportation pollution in the atmosphere [13].

2. Material and Methods

2.1 Data Collection

Data collection was carried out using tools available at the Bukit Kototabang global atmospheric monitoring station or GAW.

a. Ozone Analyzer Model 49 I

Tropospheric ozone is measured using an ozone analyzer model 49 I with the principle that O_3 absorbs UV light at a wavelength of 254 nm. Beer-Lembert's law explains that UV light directly affects ozone concentration, which is explained in the following equation:

$$\frac{I}{Io} = e^{-KLC} \quad (1)$$

Description:

K = Molecular absorption coefficient, 308 cm^{-1} (at 0°C)
L = Cell length, 38 cm
C = Ozone concentration in parts per million (ppm)
I = UV light intensity of sample with ozone (sample gas)
Io = UV light intensity of sample without ozone (reference gas)

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b. BAM1020 (*Beta Attenuation Monitor* 1020)

The working principle of BAM1020 is to use the difference in attenuation of beta ray intensity passing through the filter between before the filter is exposed to ambient air and after the filter is exposed to ambient air.

$$I = I0re^{-\mu x} \tag{2}$$

Where:

I = Measured beta ray intensity after the filter is exposed to ambient air
I0 = Beta ray intensity measured before the filter is exposed to ambient air
M = Coefficient of beta ray absorption
X = Meeting of the deposition mass on the filter

2.2 Analysis Method

The method used to analyze the relationship between tropospheric ozone and PM_{10} is using correlation analysis and regression analysis with the following equation.

a. Correlation analysis using the Pearson method [12], [14]. With the following formula.

$$r = \frac{n\sum XY - \sum X \sum Y}{\sqrt{(n\sum X^2 - (\sum X)^2) - (n\sum Y^2 - (\sum Y)^2)}} \tag{3}$$

Description:
r = Pearson correlation coefficient
X = Variable x on an interval scale
Y = Variable y on an interval scale
n = number of respondents

b. Regression Method

The regression method is one of the statistical methods that serves to see the relationship between variables or can be symbolized by variables X and Y. Variable X is also called the independent variable or free variable, and variable Y is also called the dependent variable or dependent variable. In this study using data on the daily average concentration value of PM_{10} as an independent variable and data on the concentration value of O_3 as the dependent variable, and the regression method used in this study is the type of simple linear regression. This simple regression explains the relationship between 2 variables shown by a scatter graph with one linear line. This regression uses a linear line relationship approach or linear equation (Y = a + bX) with variable a as intercept and b as slope.

3. Results and Discussion

3.1. Average monthly conditions of PM_{10} and O_3 at the Bukit Kototabang Global Atmospheric Monitoring Station

The following is a graph of PM_{10} and O_3 data describing the condition of PM_{10} and O_3 (tropospheric ozone) at the Bukit Kototabang Global Atmospheric Monitoring Station, with the average concentration value in each month for five years, from 2016 to 2020. Basically, the air quality in Bukit Kototabang is relatively good as seen in Figure 1, PM_{10} and O_3 are in the range of monthly average values below 50 µg/m^3. However, the concentration of PM_{10} and O_3 in Bukit Kototabang is not always constant, it can occur due to events that can trigger an increase or decrease in air quality, such as land burning activities, transportation and forest fires [13].

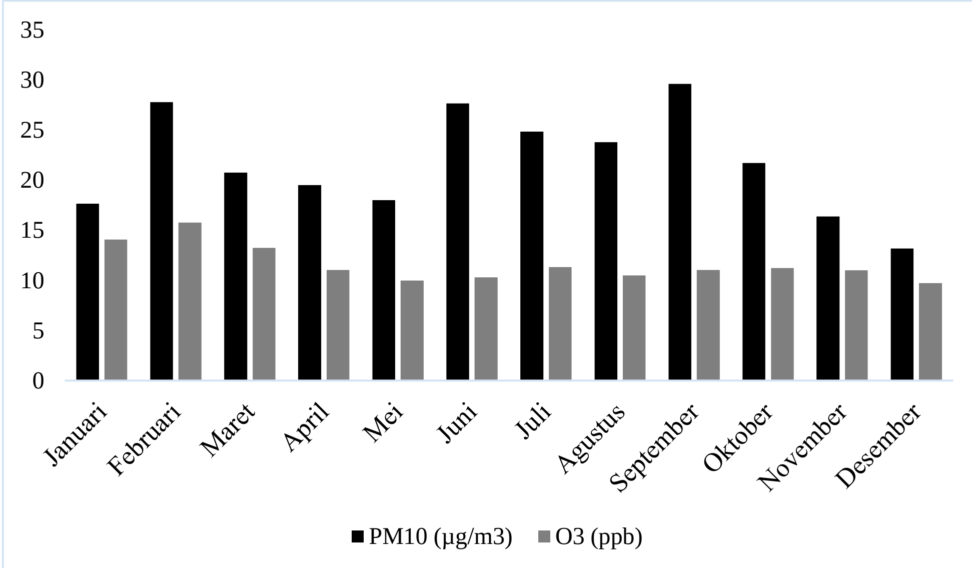

Figure 1. Graph of monthly average PM_{10} and O_3 concentrations from 2016 to 2020

The monthly average concentrations of PM_{10} and tropospheric ozone at the Bukit Kototabang Global Atmospheric Monitoring Station for the period 2016 to 2020 are shown in Figure 1. The figure shows that the maximum PM_{10} value occurred in September with a concentration value of 29.64 µg/m^3 and the minimum value occurred in December with a concentration value of 13.17 µg/m^3. The average value of the monthly PM_{10} concentration for the period 2016 to 2020 is 21.75 µg/m^3. The tropospheric ozone concentration has a maximum value in February with a concentration value of 15.76 ppb, and a minimum value in December with a concentration value of 9.73 ppb and the average value of the monthly tropospheric ozone concentration for the period 2016 to 2020 is 11.61 ppb. Figure 4.1 also shows that the PM_{10} concentration value increases in February, June, and September. Meanwhile, the ozone value is seen to increase along with the increase in PM_{10} concentration in February and July, but there is no significant increase from September to December.

The increase in ozone is caused by an increase in ozone precursors due to forest or land fires [6], [15], [16]. Based on the location of global atmospheric monitoring stations around the equator, it allows changes in the direction of regional circulation winds or is influenced by the monsoon phenomenon [13]. The monsoon is divided into 2 types, namely the east and west monsoon, the phenomenon of the east monsoon or when the wind blows from east to southeast which is usually an indicator of the dry season in Indonesia occurs in June, July, and August, while the west monsoon is usually an indicator of the rainy season in Indonesia which occurs in December, January, and February [17]. The temperature in the east season is higher than the temperature in the west season, it is influenced by monsoon winds which have higher speeds in the west season than the east season [18].

In the situation of the easterly monsoon is usually utilized by farmers to burn the remaining fields or agriculture and can contribute to the increase of smoke into the atmosphere [13]. Basically, the movement of air flow can carry the smoke of forest or land fires from the location of the fire to other locations, so that even though the incident did not occur in West Sumatra, the wind direction that moved from east to southeast caused smoke from the area to enter West Sumatra [19]. In addition, the existence of the west monsoon which impacts the rainy season in the Indonesian region causes cloud growth in Indonesia to also increase, thus blocking solar radiation from reaching the surface [20].

3.2. PM_{10} and O_3 concentration values at Bukit Kototabang global atmospheric monitoring station during extreme events in Sumatra.

In this study, data during extreme events with values greater than 50 µg/m^3 were used to find linear regression and correlation values. This is done because the global atmospheric monitoring station is a clean air reference station, so changes in air quality are seen significantly during extreme events. It can also be seen that on February 13 to 14, 2017 and September 21-23, 2019, the measured PM_{10} concentration exceeded the quality standard limit value set in PP No. 22 of 2021, which is 75 µg/m3 for the PM_{10} quality standard limit value. This is generally caused by forest fires, land or other sources [1], [5].

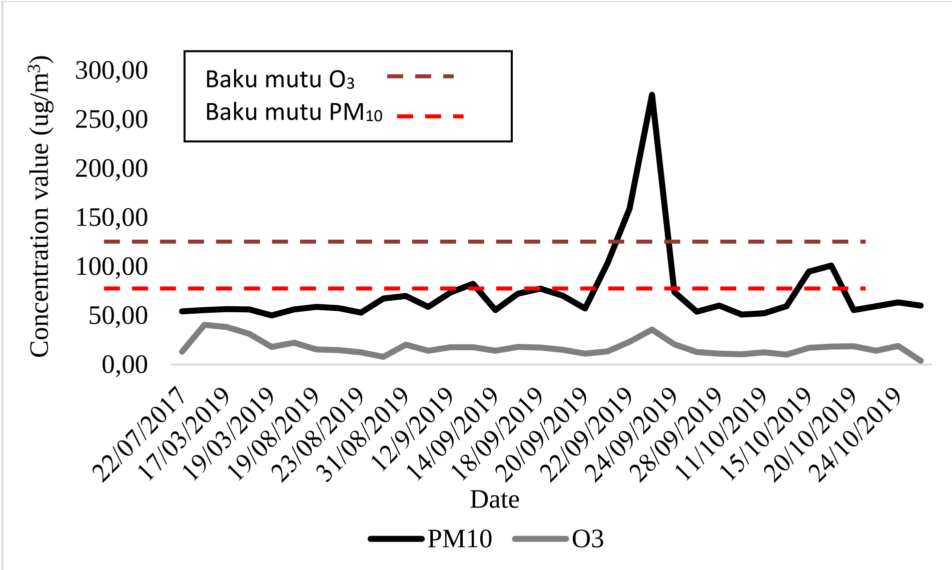

Figure 2. Graphs of PM_{10} and O_3 during extreme events in Sumatra

In the period 2016 to 2020, many cases of forest fires in Sumatra occurred in 2019, BNPB (National Disaster Management Agency) also stated that 2019 had a wider area of burned land than the previous 3 years, for example on March 8 - October 31, 2019 there were forest fires in South Sumatra, and July 23 until October 20, 2019 occurred in Jambi and on February 19 until October 31, 2019 there were also forest fires in Riau, so it can be estimated that the increase in PM_{10} concentrations that exceeded the quality standards in September seen in the graph was caused by forest fires in several areas of Sumatra. It is also known that at that time Singapore stated that it was affected by the forest and land fires that occurred in Indonesia [4].

If seen in Figure 2 the graph of the increase in O_3 (tropospheric ozone) also occurs when there is an increase in PM_{10}, this is because during a fire there is also a release of VOC (Volatile Organic Compounds) which interacts with other components to form fine particles [8]. In addition, the increase and decrease in tropospheric ozone concentration is influenced by the photochemical process whose energy comes from sunlight [21], [16]. This shows that increasing the value of PM_{10} and with the help of the photochemical process can affect the value of Ozone concentration [22]. So that in this study PM_{10} acts as an independent variable, and it is assumed that O_3 concentration will be affected by the presence of PM_{10}, then O_3 becomes the dependent variable.

3.3. Linear Regression Analysis

Data to find regression and correlation values were taken during extreme events with PM_{10} values of more than 50 µg/m^3. The following are the results of the linear regression analysis.

Tabel 1. Regression Results of PM_{10} and O_3

Regression Statistics	
Multiple R	0.53
R Square	0.28
Adjusted R Square	0.28
Standard Error	6.28
Observations	138

The observation value shows the number of samples used in the study, namely 138 samples or 138 events. Based on the linear regression results, the multiple R shows a value of 0.53 or 53%, where this multiple R shows the level of closeness of the linear relationship between the two parameters. For the R Square value or also known as the coefficient of determination R^2 shows 28% of tropospheric ozone is influenced by PM_{10}. However, if it has been corrected with the regression error value, the tropospheric ozone parameter is influenced by PM_{10} by 27.5%. In the regression results it is also known that the resulting standard error value is 6.28.

3.4. Scatter plot of O_3 and PM_{10} data

The following is a picture of the linear regression results between the PM_{10} variable and tropospheric ozone;

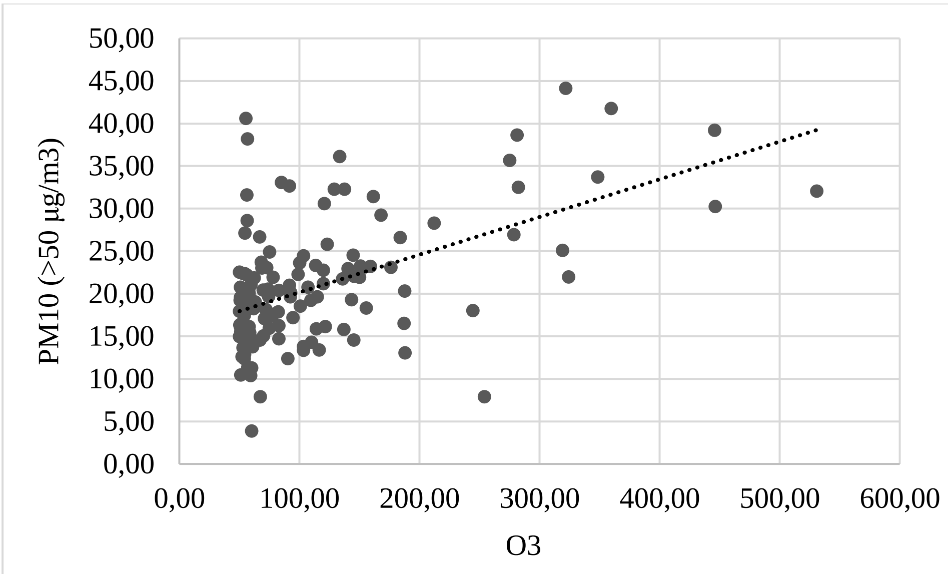

Figure 3. Scatter plot of PM_{10} with tropospheric ozone

Based on **Figure 3**, a positive correlation (r = 0.53) was obtained between tropospheric ozone and PM_{10}, indicating that the increase in PM_{10} in extreme conditions is proportional to the increase in Ozone. This can occur because the increase in PM_{10} is proportional to the increase in ozone precursors and is one of the components that may experience or affect photochemical reactions that can accelerate the process of O_3 formation in an area [23], [24], [16]. In addition, when forest and land fires occur, they will release carbon and other elements, especially on peatlands [25], this carbon will indirectly heat the air above the boundary layer and will affect changes in surface ozone (O_3).

The suppression of the boundary layer causes a large amount of ozone precursors to be trapped under the boundary layer, thus increasing surface ozone [26]. This is also supported based on the results of other studies that obtained a correlation value of r = 0.56 between O_3 and aerosol mass concentrations, the study shows that vehicle and mass transportation fumes are the main components in ambient air that may undergo photochemical reactions to accelerate the O_3 production process [2]. In addition, there are also studies that reveal that the presence of high O_3 concentrations with strong atmospheric oxidation can also trigger the formation of secondary particulates and can increase the quantity of PM in ambient [12].

4. Conclusion

Linear regression results show a positive correlation (r = 0.53) between tropospheric ozone and PM_{10} with the regression equation is y = 15.73 + 0.044 x. The condition of the average value of the monthly PM_{10} concentration from 2016 to 2020 is 21.75 µg/m^3 and the average value of the monthly tropospheric ozone concentration from 2016 to 2020 is 11.61 ppb. PM_{10} and O_3 at the Bukit Kototabang global atmospheric monitoring station also have maximum values in September for PM_{10} with a value of 29.64 and February for O_3 with a value of 15.76 and have a minimum value in December with a value of 13.17 for PM_{10} and 9.73 for O_3. The increase in PM_{10} under extreme conditions is proportional to the increase in Ozone. This can occur because the increase in PM_{10} during forest or land fires is proportional to the increase in ozone precursors and is one of the components that may experience or affect photochemical reactions that can accelerate the formation process of tropospheric ozone (O_3) in an area.

5. Achnowledgment

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6. References

[1] A. Yusuf, H. Hapsoh, S. H. Siregar, and D. R. Nurrochmat, "Analisis Kebakaran Hutan Dan Lahan Di Provinsi Riau," *Dinamika Lingkungan Indonesia*, vol. 6, no. 2, p. 67, 2019, doi: 10.31258/dli.6.2.p.67-84.

[2] T. Nishanth, K. M. Praseed, M. K. S. Kumar, and K. T. Valsaraj, "Influence of ozone precursors and PM10 on the variation of surface O3 over Kannur, India," *Atmos Res*, vol. 138, no. March, pp. 112–124, 2014, doi: 10.1016/j.atmosres.2013.10.022.

[3] Indra, Kamarubayana, Legowo, Kirtaamiana, and M. Taufan, "Studi Kebakaran Hutan Tahun 2015–2019 Berdasarkan Aplikasi Sipongi Menggunakan Citra Satelit Noaa Di Provinsi Kalimantan Timur. Jakt: Jurnal Agroteknologi dan Kehutanan Tropika," *Jurnal Agroteknologi dan Kehutanan Tropika*, vol. 2, no. 1, pp. 47–70, 2024,

[4] N. Bilqis, "Analisis Dampak Kasus Kebakaran Hutan di Indonesia terhadap Hubungan Diplomatik Indonesia dengan Malaysia dan Singapura," *Gorontalo Journal of Government and Political Studies*, vol. 3, no. 2, p. 055, 2020, doi: 10.32662/gjgops.v3i2.1123.

[5] D. Ramadhani, N. B. Simatupang, S. Rahmah, and Andhika Natawijaya, "Identifikasi Kerawanan Kebakaran Hutan di Provinsi Riau," *Jurnal Sains Geografi*, vol. 1, no. 1, pp. 72–87, 2023, doi: 10.2210/jsg.vx1ix.xxx.

[6] L. J. R., Kamurnian Tafonao, Artha Lumban Tobing, "GOVERNANCE : Jurnal Ilmiah Kajian Politik Lokal dan Pembangunan," *Elvandar*, vol. 9, no. 4, pp. 100–104, 2023.

[7] A. C. Nahas, "Kondisi Kualitas Udara Bukit Kototabang Periode 2005-2010," *Megasains*, no. 0, pp. 1–23, 2016.

[8] L. Zhang *et al.*, "Ozone-CO correlations determined by the TES satellite instrument in continental outflow regions," *Geophys Res Lett*, vol. 33, no. 18, pp. 2–6, 2006, doi: 10.1029/2006GL026399.

[9] Munggaran, Gilang Anugerah, Haryoto Kusnoputranto, and Januar Ariyanto. "Korelasi Polusi Udara dengan Insiden Pneumonia Balita di DKI Jakarta pada Tahun 2017-2020." *Jurnal Promotif Preventif* 7.1 (2024): 123-135.

[10] H. Han, J. Liu, L. Shu, T. Wang, and H. Yuan, "Local and synoptic meteorological influences on daily variability in summertime surface ozone in eastern China," *Atmos Chem Phys*, vol. 20, no. 1, pp. 203–222, 2020, doi: 10.5194/acp-20-203-2020.

[11] M. Jerrett *et al.*, "Long-Term Ozone Exposure and Mortality," *Pediatr Neurol. 2013 October ; 49(4): 243–254*, vol. 49, no. 4, pp. 243–254, 2013, doi: 10.1056/NEJMoa0803894.Long-Term.

[12] M. Jia *et al.*, "Inverse Relations of PM2.5 and O3 in air compound pollution between cold and hot seasons over an urban area of East China," *Atmosphere (Basel)*, vol. 8, no. 3, pp. 1–12, 2017, doi: 10.3390/atmos8030059.

[13] A. Kurniawan, "Pengukuran Parameter Kualitas Udara (Co, No2, So2, O3 Dan Pm10) Di Bukit Kototabang Berbasis Ispu," *Jurnal Teknosains*, vol. 7, no. 1, p. 1, 2018, doi: 10.22146/teknosains.34658.

[14] M. K. Alim and D. B. Arianto, "Analisis Korelasi Antara Faktor Ekonomi dan Distribusi Penduduk di Jawa Timur Tahun 2022 Menggunakan Metode Korelasi Pearson," *Kohesi: Jurnal Multidisiplin Saintek*, vol. 1, no. 4, pp. 20–30, 2023.

[15] Qu, Kun, et al. "The effect of cross-regional transport on ozone and particulate matter pollution in China: A review of methodology and current knowledge." *Science of the Total Environment* (2024): 174196.

[16] Z. Oktaviani and M. A. S. Jawwad, "Rencana Pengelolaan dan Pemantauan Kualitas Udara Terhadap Rencana Kegiatan Pembangunan Permukiman," *Environmental Science and Engineering Conference*, vol. 4, no. 1, pp. 154–159, 2023.

[17] N. P. I. Wikandari, H. Harsa, A. F. Assomadi, and R. Boedisantoso, “Penentuan Korelasi Perubahan Kecepatan Angin Dan Kekuatan Radiasi Terhadap Ketinggian Lapisan Inversi Dan Hubungannya Dengan Kualitas Udara Ambien Kota Surabaya,” *Jurnal Teknik Its*, vol. 4, no. 1, p. 64, 2015, [Online]. Available: http://repository.its.ac.id/59909/

[18] Y. W. Millenia, M. Helmi, and L. Maslukah, “Analisis Mekanisme Pengaruh IOD, ENSO dan Monsun terhadap Suhu Permukaan Laut dan Curah Hujan di Perairan Kepulauan Mentawai, Sumatera Barat,” *Indonesian Journal of Oceanography*, vol. 4, no. 4, pp. 87–98, 2023, doi: 10.14710/ijoce.v4i4.14414.

[19] Endarwati, “Identifikasi areal bekas kebakaran hutan dan lahan menggunakan analisis otomatis citra satelit landsat,” *seminar nasional geomatika*, p. 273, 2017.

[20] A. B. Raharja and Kadarsah, “Pengaruh indeks monsun Indonesia terhadap curah hujan di Sumatera Selatan,” *Seminar Sains Atmosfer*, vol. 3, no. November, pp. 8–18, 2014, [Online]. Available: https://www.researchgate.net/publication/335401596_Pengaruh_Indeks_Monsun_Indonesia_terhadap_Curah_Hujan_di_Sumatera_Selatan

[21] D. W. Masdat, Y. S. Putra, and R. Adriat, “Keterkaitan Karbon Monoksida (CO) Terhadap Ozon Permukaan (O3) Di Wilayah Kalimantan Barat,” *Prisma Fisika*, vol. 10, no. 3, p. 251, 2023, doi: 10.26418/pf.v10i3.57853.

[22] F. A. Maslakah and Bu. Setiawan, “pengaruh radiasi matahari ,nitrogen dioksida dan metana pada ozon troposferik di bukit kototabang,” *Angewandte Chemie International Edition, 6(11), 951–952.*, vol. 1, no. April, 2009.

[23] J. Gao *et al.*, “Effects of black carbon and boundary layer interaction on surface ozone in Nanjing, China,” *Atmos Chem Phys*, vol. 18, no. 10, pp. 7081–7094, 2018, doi: 10.5194/acp-18-7081-2018.

[24] G. Zhang *et al.*, “Identifying the O3 chemical regime inferred from the weekly pattern of atmospheric O3, CO, NOx, and PM10: Five-year observations at a center urban site in Shanghai, China,” *Science of the Total Environment*, vol. 888, no. x, p. 164079, 2023, doi: 10.1016/j.scitotenv.2023.164079.

[25] A. Krisanti dan, P. Lestari, and P. Studi Teknik Lingkungan, “Measurement of Pm10 and Black Carbon Concentration Emitted By Smoke From Peat Land and Forest Fire in Desa Pekanheran, Kabupaten Indragiri Hulu, Provinsi Riau,” *Jurnal Teknik Lingkungan*, vol. 17, no. April, pp. 100–111, 2011.

[26] G. He *et al.*, “Characteristics of boundary layer ozone and its effect on surface ozone concentration in Shenzhen, China: A case study,” *Science of the Total Environment*, vol. 791, p. 148044, 2021, doi: 10.1016/j.scitotenv.2021.148044.