Journal of Environmental Science and Sustainable Development

Volume 6
Issue 1 *July*

Article 4

7-31-2023

DIURNAL VARIATIONS OF METEOROLOGICAL ELEMENTS TO FLUCTUATION OF AIR QUALITY PARAMETERS

Wandayantolis Wandayantolis
Faculty of Agriculture, Universitas Sriwijaya, Palembang 30139 Indonesia, wan.dayantolis@gmail.com

Firda Amalia Maslakah
East Java Climatology Station, Malang 65152 Indonesia, amaliafirda01@gmail.com

Sugeng Nugroho
Bukit Kototabang Global Atmosphere Watch Station, Agam 26151 Indonesia, sugengnugroho2791@gmail.com

Recommended Citation
Wandayantolis, Wandayantolis; Maslakah, Firda Amalia; and Nugroho, Sugeng (2023). DIURNAL VARIATIONS OF METEOROLOGICAL ELEMENTS TO FLUCTUATION OF AIR QUALITY PARAMETERS. *Journal of Environmental Science and Sustainable Development*, 6(1), 34-49.
Available at: https://doi.org/10.7454/jessd.v6i1.1161

Journal of Environmental Science and Sustainable Development
Volume 6, Issue 1, Page 34-49
ISSN: 2655-6847
Homepage: http://scholarhub.ui.ac.id/jessd

DIURNAL VARIATIONS OF METEOROLOGICAL ELEMENTS TO FLUCTUATION OF AIR QUALITY PARAMETERS

Wandayantolis[1]*, Firda Amalia Maslakah[2], Sugeng Nugroho[3]
[1]Faculty of Agriculture, Universitas Sriwijaya, Palembang 30139 Indonesia
[2]East Java Climatology Station, Malang 65152 Indonesia
[3]Bukit Kototabang Global Atmosphere Watch Station, Agam 26151 Indonesia

*Corresponding author: wan.dayantolis@gmail.com

(Received: 15 March 2022; Accepted: 25 July 2023; Published: 31 July 2023)

Abstract

Many studies have shown the relationship between meteorological elements and air quality. However, some aspects of the relationship are unknown, particularly in Indonesia, which has a variety of topographical landscapes and climatic conditions. This study seeks to define the relationship between meteorological variables and the diurnal pattern of three pollutants that contributes to the so-called Indeks Standard Pencemar Udara (ISPU), similar to the Air Quality Index (AQI), in a remote area in Bukit Kototabang, West Sumatra, Indonesia. The three parameters, namely Particulate Matter 10 micrometers (PM10), carbon monoxide (CO), and tropospheric ozone (O_3), were correlated with diurnal variations in temperature and relative humidity in the months of maximum rainfall and minimum rainfall in 2020. The T-test was used to obtain each parameter's mean and variance sizes and the significant differences among the parameters. The results showed that PM10 has a significant distribution when high and low rainfall, but no significant relationship exists between temperature and relative humidity. Carbon monoxide has significant fluctuations to differences in rainfall and diurnal variations in air temperature. Meanwhile, O_3 shows a weak correlation to the rainfall variation but has a high correlation to diurnal variations in the temperature and relative humidity. The results suggest that air temperature can significantly affect the diurnal concentration of pollutants, which involves photochemical reactions in their formation, such as ozone and carbon monoxide. It also shows the potential for worse air quality during the low rainfall. As the pollutant level can be higher during the dry season compared to the rainy season, efforts to reduce the pollutant emission during the dry season, like forest and land fires, need to gain more attention.

Keywords: Air quality; Diurnal variation; Meteorological parameter.

1. Introduction

Air pollution is a problem that has received considerable attention because of its significant impact on the environment, climate, and health (Perera, 2017; Zhai et al., 2018). World Health Organization (WHO, 2015) states that at least 3 million people die yearly from heart, lung, and acute respiratory diseases associated with ambient air pollution. Information on Air Pollution Index (API) in Indonesia is expressed in a quantity called the Indeks Standard Pencemar Udara (ISPU) (Indonesian Ministry of Environment and Forestry, 2020a). This index is a number without units that provides an overview of surface air quality at a specific time and location. There are seven air quality parameters in the ISPU, which include Particulate Matter 2.5 micrometers (PM2.5), PM10, CO, sulfur dioxide (SO_2), nitrogen dioxide (NO_2), O_3, and hydrocarbons (HC). Each of these pollutants has specific characteristics, either source, diurnal and seasonal variations, or the factors that influence it (Mohtar et al., 2018; Zhao et al., 2018).

An important aspect that should be considered in assessing pollutant trends is that their behavior depends not only on the emission of a particular pollutant but also on the meteorological conditions in the study area. Meteorological factors are the main factors that determine variations in the concentration and distribution of air pollutants (Hou & Wu, 2016; Li et al., 2019; Mohtar et al., 2018;). According to Kliengchuay et al. (2018), meteorological factors also play an essential role in forming, distributing, transporting, and diluting ozone and PM10 in the atmosphere. Rainwater can affect pollutant levels in the atmosphere related to its role as a scavenger of pollutants (Alfiandy & Davi, 2020; Kwak et al., 2017). The relationship between air quality indices and weather parameters can help predict air quality and implement pollution control measures.

Several studies have determined the relationship between air quality and meteorological factors. The results show that weather conditions affect the AQI in various ways. Du et al. (2020) investigated the diurnal pattern of PM2.5 in East China and its modeling capability. It was found that the diurnal variation of PM2.5 is controlled by emission, chemical reaction, and meteorological factors. While a study conducted by Verma et al. (2017) shows that the carbon monoxide concentration pattern in a semi-urban site in Agra, India, is affected by meteorological factors such as wind speed, Planetary Boundary Layer (PBL), which contribute to the pollutant dispersion, accumulation as well as transport. Another study by Kliengchuay et al. (2018) in Mae Hong Son Province, Thailand, indicates that meteorological factors influence PM10 concentration and decrease during the rainy season. The study also found that PM10 may be transported by wind from another area, particularly during haze periods.

Even though many studies show the relationship between air quality and meteorological factors, limited studies explain how diurnal patterns of air pollutants relate to meteorological factors. The unique weather and topographical pattern in Indonesia can affect air pollutant levels. Considering the importance of understanding the behavior of air quality parameters, particularly how it relates to meteorological conditions for pollutant control measures, this study aims to find out the relationship between air quality parameters (consisting of PM10, CO, and O_3) and meteorological factors in Global Atmosphere Watch (GAW) Station of Bukit Kototabang, West Sumatera, which is an air pollutant monitoring station for Indonesia located in a remote area surrounded by tropical forest. The study is expected to provide helpful information about the characteristics of air pollutants concerning weather parameters in this equatorial region.

2. Methods

The data used in this study were meteorological parameters consisting of rainfall (CH), temperature (T), and relative humidity (RH) measured from January to December 2020. Three ISPU parameters, namely PM10, CO, and O3, were also measured within the same period at the GAW Station of Bukit Kototabang (Table 1). This station is the operational executor of the World Meteorological Organisation mission (World Meteorological Organisation, 2017), observing air quality and the environment in Indonesia. Kototabang is in one area representing a "remote area" (Utami et al., 2021). The data for 2020 were chosen because they had good continuity and completeness on all parameters used in processing.

Table 1. Description of Kototabang GAW Station

Location	Latitude	Longitude	Elevation
Kototabang GAW Station	0° 12′ 07″ LS	100^0 19′ 05″ BT	864.5 m

All the data resulted from observations of automatic tools operating 24 hours, except for the rainfall, which resulted from daily manual observations. The PM10 data were generated from the inlet installed on the outside of the top of the station with a height of about 5 meters. The CO and O_3 were sourced from the inlet located in the tower with a height of 32 meters above ground level. The manual rainfall observation tool was located in the tool garden at the rear of the station building, where there was also a meteorological cage containing a thermodigital automatic device. The observation equipment at the GAW Station of Kototabang is periodically calibrated by an agency on Material Science and Technology, Empa Agency (Empa, 2019), except for the PM10 observation tool and other conventional equipment calibrated by the Indonesian Agency for Meteorological, Climatological, and Geophysical (BMKG) internally. The details of the equipment metadata are presented in Table 2.

Each ISPU parameter was displayed in a spatial form, functioning the time in hours on the Y axis and the date on the X axis. It was to obtain diurnal distribution information on a daily and monthly scale using the Surfer Software application trial edition. This application was quite capable of mapping the spatial distribution of values in the form of maps (Li et al., 2018; Prasad & Rao, 2018) and the data extrapolation (Vižintin et al., 2016) in which the *Kringing* method used was the best interpolation method according to Bogusz et al. (2014).

Table 2. ISPU parameter metadata and used meteorological elements

Specification	ISPU			Meteorology		
	PM10	CO	O_3	CH	T	RH
Tool name	BAM	CO Analyzer	O_3 Analyzer	PH-Obs	Thermodigital	Thermodigital
Unit	μg/m^3	ppb	ppb	millimeter	ºC	%
Type	Automatic	Automatic	Automatic	Manual	Automatic	Automatic
Brand	Met One	Picarro	Thermo	-	RM Young	RM Young
Latest Calibration	October 2020	February 2019	September 2020	December 2020	February 2020	February 2020

The correlation calculation method was used to obtain the diurnal distribution relationship between the meteorological parameters and each ISPU parameter, followed by the T-test to test its significance (Kim, 2015; Zambrano-Monserrate et al., 2020). Furthermore, the boxplot diagrams were used to compare the weights of each parameter, either the mean, median, or data variance distribution (Tareen et al., 2019), and correlation analysis to obtain the level of closeness (Daoud, 2018). The T-test, boxplot diagram, and correlation analysis were calculated using the trial version of the Minitab application, with the working procedure from Lesik (2019).

3. Results and Discussions

3.1. The ISPU value

The quality standards of each ISPU parameter based on the Indonesian Ministry of Environment and Forestry regulation of the *Kementerian Lingkungan Hidup dan Kehutanan* (Indonesian Ministry of Environment and Forestry, 2020a) is shown in Table 3.

Table 3. The 24-hour quality standard for each ISPU parameter

ISPU	PM10 (µg/m^3)	CO (µg/m^3)	O_3 (µg/m^3)
0 - 50	50	4,000	120
51 - 100	150	8,000	235
101 - 200	350	15,000	400
201 - 300	420	30,000	800
>300	500	45,000	1,000

(Source: Indonesian Ministry of Environment and Forestry, 2020a)

The results of the ISPU calculation in July and November 2020 at the Kototabang GAW Station, according to the procedure in the Indonesian Ministry of Environment and Forestry (2020b), similar to the Air Quality Index (Jiang, 2021), shows that PM10, CO, and O_3 parameters were at reasonable levels. The percentage of days with each ISPU level is presented in Table 4.

It can be interpreted that throughout 2020, no pollutant emissions significantly affected the air quality around the Kototabang GAW Station. The Kototabang GAW Station is located in a tropical rainforest area of Sumatra with an elevation of 864.5 meters above sea level (masl) and far from primary pollutant sources (Empa, 2019). As per official regulations from World Meteorological Organization (WMO, 2001), a GAW Station is usually located in a remote location, with very low background pollutant levels and a large geographic area. Also, low pollutant concentration is related to the low forest fire hotspots around West Sumatra, which usually impacts air quality (Supeni et al., 2021). Further analysis and calculations were carried out using the original concentration values of each ISPU parameter in order to obtain variations in the data.

Table 4. The percentage of the number of days (%) based on the ISPU level for July and November 2020

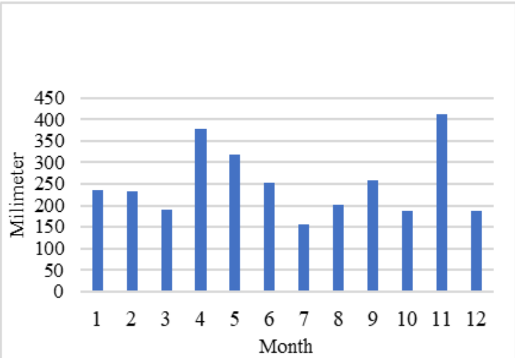
ISPU Level	PM10		CO		O_3	
	Jul	Nov	Jul	Nov	Jul	Nov
Good	100	100	100	100	100	100
Moderate	0	0	0	0	0	0
Unhealthy	0	0	0	0	0	0
Very Unhealthy	0	0	0	0	0	0
Dangerous	0	0	0	0	0	0

Table 4 shows the daily ISPU value for PM10, CO, and O_3 in July and November 2020. The value of ISPU was within the category of goods. Based on Table 3, the value of daily PM10 concentration in July and November 2020 was between 0-50 µg/m^3. This value is also the case of daily CO, which was always below 4000 μg/m^{3}, and tropospheric ozone, below 120 μg/m^{3}.

3.2. Meteorological conditions

The charts of monthly rainfall and temperature observed in Bukit Kototabang in 2020 are presented in Figure 1. It can be seen from Figure 1(a) that monthly rainfall showed two peaks of rain in April and November. This figure shows a typical rainfall pattern in the equatorial region with two rain peaks (Nurdiati et al., 2021). This climate was related to the response of local conditions to the Intertropical Convergence Zone (ITCZ) oscillations when the monsoon winds change direction (Kalisa et al., 2019). The ITCZ is associated with the confluence of air masses from the northern and southern hemispheres that encourage cloud formation and rain. When the annual apparent motion of the sun moves to the southern hemisphere, it will increase rainfall in the area it passes through. Then, when the northern hemisphere returns, the same region responds to increased rainfall again. July, with the lowest rainfall, represents the period with the minimum rainfall, and November represents the period of peak rainfall.

a



b

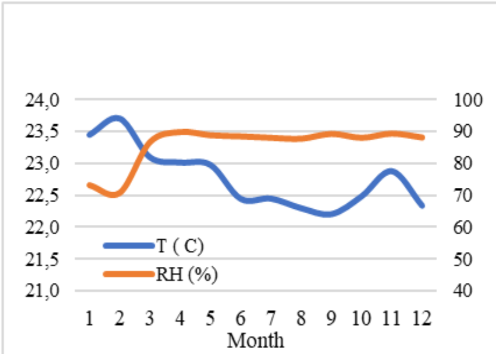
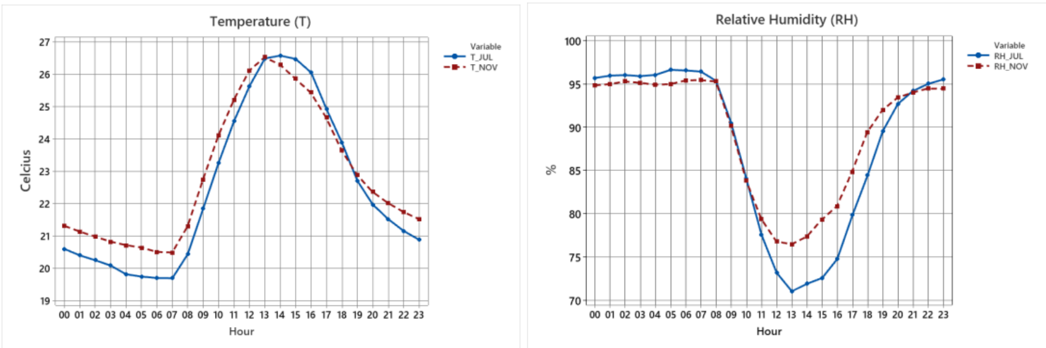


Figure. 1 (a) Monthly rainfall and (b) monthly temperature and humidity of Kototabang GAW Station in 2020

Figure 1(b) presents the monthly temperature and relative humidity mean. The figure shows that monthly air temperature during 2020 showed two maximum peaks with an inversely proportional pattern to relative humidity. The first maximum temperature occurred in February, and the second peak was recorded in November. This temperature pattern is also related to the apparent annual motion of the sun reflected in its declination position (Widén & Munkhammar, 2019), in addition to other meteorological factors such as cloud cover and rain. Shortly after the sun's culmination point passes through a region, the distribution of peak energy occurs. Since relative humidity is the ratio of the pressure of steam and saturated steam at the same temperature, a monthly increase in air temperature decreases relative humidity.

The diurnal variation of temperature and relative humidity at Kototabang GAW Station is shown in Figure 2. Figure 2(a) indicates that the air temperature was maximum at around 13.00 local time and minimum around 05.00 or 06.00 AM local time. In contrast, relative humidity had the opposite pattern, as shown in Figure 2(b). Figure 2(b) shows that the minimum relative humidity value was observed at 13.00 LT when the temperature reached the maximum. The diurnal air temperature variation in July and November showed a slight difference. The November average temperature was more significant than July, with almost the same data variance based on the boxplot diagram in Figure 3(a). The difference in mean temperature showed no significance based on the T-test (P>0.05). It can be explained that although in November 2020, the rainfall was higher, the humidity and cloud levels also increased. This condition leads to the absorbtion of solar radiation (Li et al., 2017). However, the position of the sun's declination in November was closer to the equator than that in July (Widén & Munkhammar, 2019), so the intensive heating of the surface in November would be greater than that in July (Krivoshein et al., 2020).

Air humidity in both months had almost the same average, 88% in July and 89% in November. The difference was that the humidity value variance was more significant in July compared to November, as shown by the width of the boxplot diagram in Figure 3(b). The p-value resulting from T-test for the July and November RH comparison was higher than 0.05, which means that the difference was not statistically significant. These results explain that the high rainfall in November did not impact increasing air humidity. In other words, factors such as air temperature, wind direction, and speed can play a more dominant role in changing humidity levels.



(a) (b)

Figure. 2 Graph of (a) diurnal temperature (T) and (b) relative humidity (RH) in July and November 2020

The fluctuation of three ISPU parameters can be associated with diurnal variation of temperature and relative humidity shown in Figure 2. The correlation varies among parameters, but the level of ISPU is generally categorized into good.

Figures 3(a) and Figure 3(c) also show inversely proportional relationships between T and RH, with each increase in air temperature followed by a decrease in humidity levels, similar to a study by Nguyen & Dockery (2016), which observed the relationship between indoor and outdoor temperature and humidity in several cities. The relative humidity is the vapor pressure ratio to saturated vapor pressure at the same temperature (T). If the air temperature rises, the vapor pressure ratio will decrease (Paris et al., 2013). An increase in RH occurs when additional water vapor enters the atmosphere.

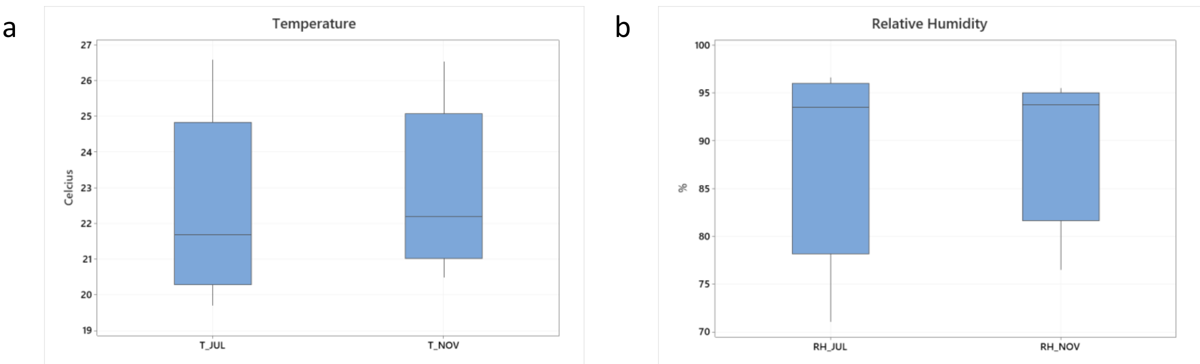


Figure. 3 Boxplot (a) temperature and (b) relative humidity in July and November, respectively

3.3. Variation of ISPU parameters on rainfall

The diurnal distribution in July and November shows a qualitative comparison of each ISPU parameter that could be observed based on the color contrast in Figure 4. From this figure, it can be seen that the diurnal concentration of PM10 generally fluctuated more than O_3 and CO. The PM10 concentrations ranged from 5-52 g/m in July and 3-43µg/m³ in November. The diurnal distribution range of PM10 and CO on certain days could last almost 24 hours, indicated by a uniform color vertically (Figure 4(a) and Figure 4(b)). Quite differently, the O_3 maximum concentration occurred during the day, as shown in Figure 4(c). The diurnal O_3 concentration values ranged from 3.32 to 28.36 ppb in July and from 3.49 to 35.54 ppb in November. Meanwhile, the graph of the diurnal distribution of CO in July and November shows that the CO concentration in the afternoon was lower than in the morning and evening. The diurnal CO concentrations ranged from 66.22 to 263.64 ppb in July and 75 to 242.32 ppb in November.

The distribution of PM10 concentrations in Figure 4(a) shows quite a contrast variation with higher concentrations during the low rainfall period and, conversely, lower concentrations during the high rainfall period. This phenomenon is in line with Zhang et al. (2019), stating that the higher the intensity of rainfall, the more particulate pollutants are deposited on the earth's surface due to the nature of rain as an air wash (Kwak et al., 2017; Olszowski, 2016). The significance of the PM10 distribution is shown in the boxplot diagram (see Figure 5(a)), which shows that the 24-hour average of PM10 was much higher during low rainfall. It can be seen from Figure 5(a) that both PM10 had higher daily mean concentrations in July compared to the concentration in November. The T-test gave the results of $P<0.005$ (see Table 5) with a significant difference between PM10 concentrations at high and low rainfall. However, the data variance in both conditions was almost similar.

In contrast to the condition of PM10 in Kototabang, the findings of Kwak et al. (2017) in urban areas with heavy traffic, rainfall could increase the concentration of PM10 released into the atmosphere. According to them, the rain was one of the causes of increasing traffic jams and the accumulation of motorized vehicles, which released particulate pollutants at the same time. Eventually, the relationship between the rainfall and PM10 dilution will depend on the balance of rainfall intensity with the accumulation of released pollutants.

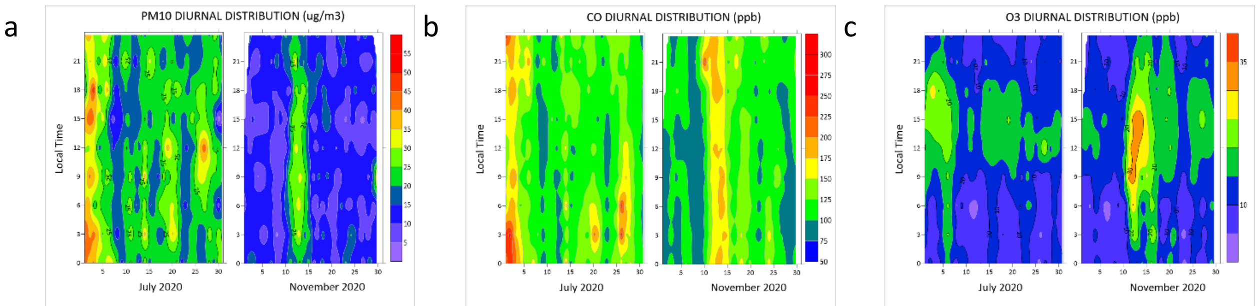


Figure. 4 Comparison of the diurnal distribution of (a) PM_{10}, (b) CO, and (c) O_3 between July and November 2020

The diurnal distribution of CO between July and November was not apparent based on the contours in Figure 4(b). The difference in weight can be analyzed based on the boxplot diagram in Figure 5(b) and the T-test in Table 5. Based on Figure 5 (b), CO had a larger mean and data variance when the rainfall was low. The higher mean concentration of CO in July compared to that in November was similar to PM10. However, the data variance in CO was higher compared to PM10 (Figure 5(a) and Figure 5(b)). This difference was significant based on the T-test value with P<0.005.

Table 5. The statistical description of diurnal ISPU parameters between July (J) and November (N)

Parameter	PM_{10}		CO		O_3	
	Jul	Nov	Jul	Nov	Jul	Nov
N	24	24	24	24	24	24
Mean	23.48	13.20	126.25	118.42	12.82	14.16
Stdev	1.11	0.86	6.45	3.64	3.09	2.91
P-Value (*J vs. N*)		0.000		0.000		0.128
Alfa	0.05		0.05		0.05	

Figure 4(c) shows the diurnal distribution of O_3 between July and November with less apparent color contrast. However, in both months, the maximum O_3 concentration occurred in the afternoon when the air temperature reached its maximum value. The boxplot diagram in Figure 5(c) shows that the mean and variance of the O_3 concentration were higher during the high rainfall, although the difference was not significant (P>0.005, see Table 5).

As ozone is formed due to high-temperature solar radiation, its level in November 2020 was relatively high because the air temperature was high due to the sun's declination factor despite the high rainfall (Chen et al., 2020; Li et al., 2017; Wang et al., 2019).

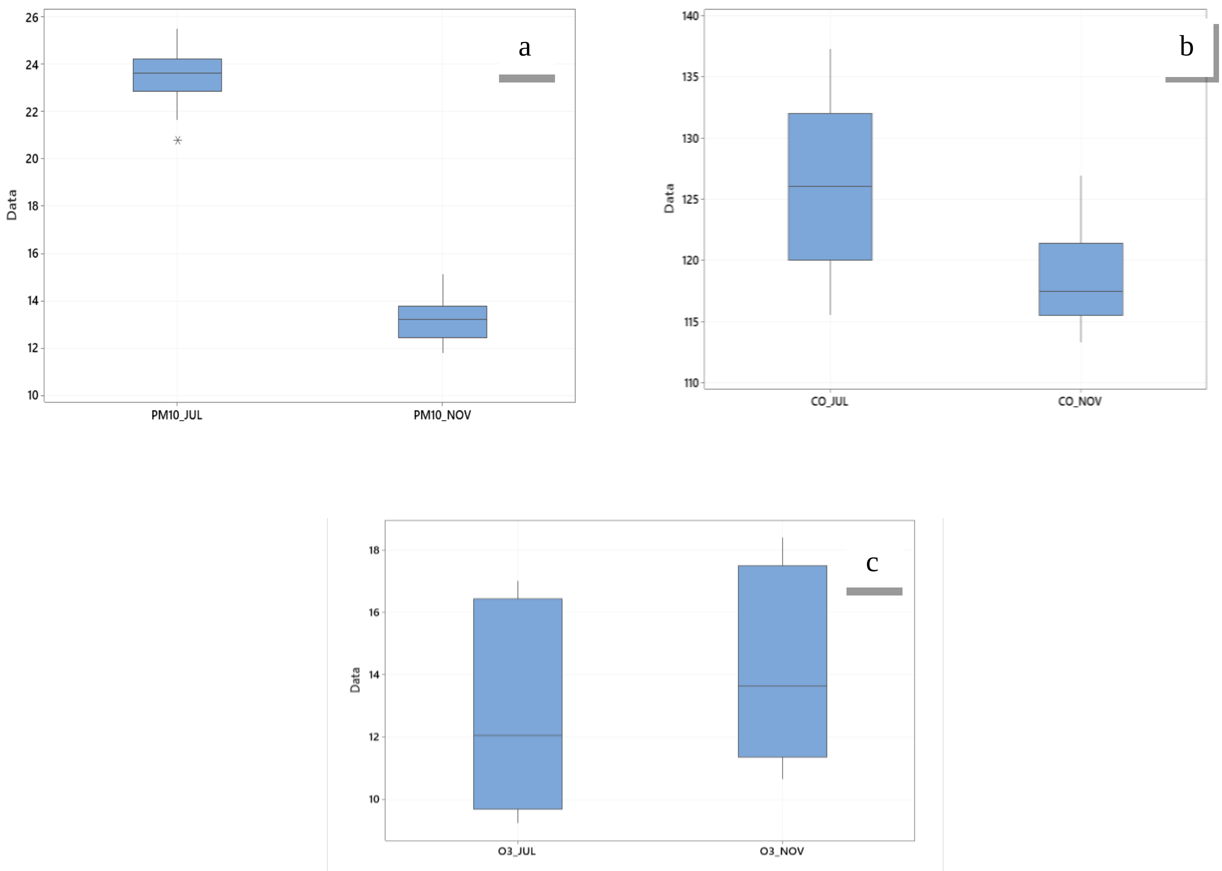


Figure. 5 Comparison of boxplot dimensions of (a) PM10, (b) CO and (c) O_3 between July and November 2020

3.4. Correlation of temperature and humidity to diurnal variations of ISPU parameters

Based on Figures 3(a) and 3(c), the air temperature and humidity had a strong negative relationship. The correlation of ISPU parameters to temperature and humidity may also give the opposite results.

The correlation between PM10 and diurnal temperature distribution in July and November is presented in Figures 6(a) and 6(d). It can be seen from these figures that there were negative correlations between PM10 and diurnal temperature distribution in both periods, with a correlation value of 0.246 for July (fig. 6a) and 0.2 for November (Figure 6(d)). This phenomenon means that PM10 concentration was higher at lower temperatures. The diurnal concentration fluctuated daily, with the maximum concentration in the afternoon around 3.00 PM and 4.00 PM (Local Time). The weak correlation value may be associated with the possible contribution of other factors beyond temperatures, such as emissions from anthropogenic activities and the transport of pollutants from another area (Kliengchuay et al., 2018). Du et al. (2020) state that the main meteorological factor affecting particulate matter distribution is Planetary Boundary Layer. Several studies also found that wind speed is vital in influencing the dispersion and transport of PM10 (Kliengchuay et al., 2018; Kliengchuay et al., 2021).

As regards the relationship with relative humidity, there was a positive correlation between relative humidity and PM10 concentration (Figure 7(a) and Figure 7(d)). Figures 7(a) and 7(d) indicate that the PM10 concentration tends to increase with an increase in relative humidity. Another research shows similar results that PM10 concentration increases with relative humidity up to 75%. Afterward, the correlation is negative (Hernandez et al., 2017). High relative humidity can contribute to influencing air quality through the formation of secondary sulfate and nitrate (Liu et al., 2018). The result is different from the findings of Wang et al. (2019), stating that a favorable correlation humidity is of PM10, and the humidity was only achieved when RH <60%. So, when the RH is >60%, the PM10 rate reverses to decrease against the increase in RH. Similar studies found that PM10 and relative humidity negatively correlate (Kliengchuay et al., 2021; Paraschiv & Paraschiv, 2019).

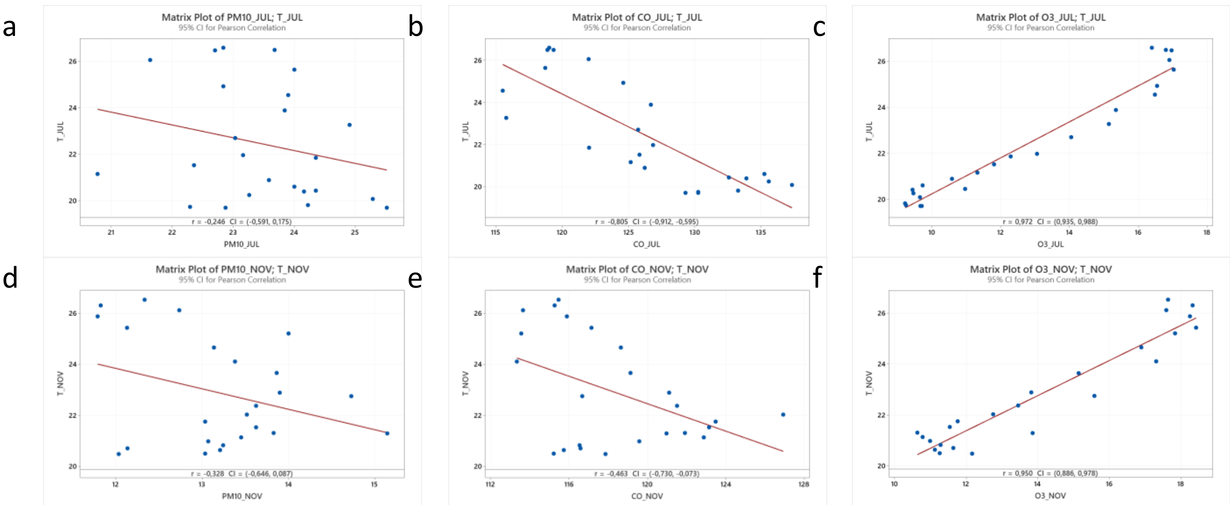


Figure. 6 Trends and correlation of ISPU parameters to diurnal air temperature;
(a) PM10 vs. T July, (b) CO vs T July, (c) O_3 vs T July
(d) PM10 vs T November, (e) CO vs T November, (f) O_3 vs T November

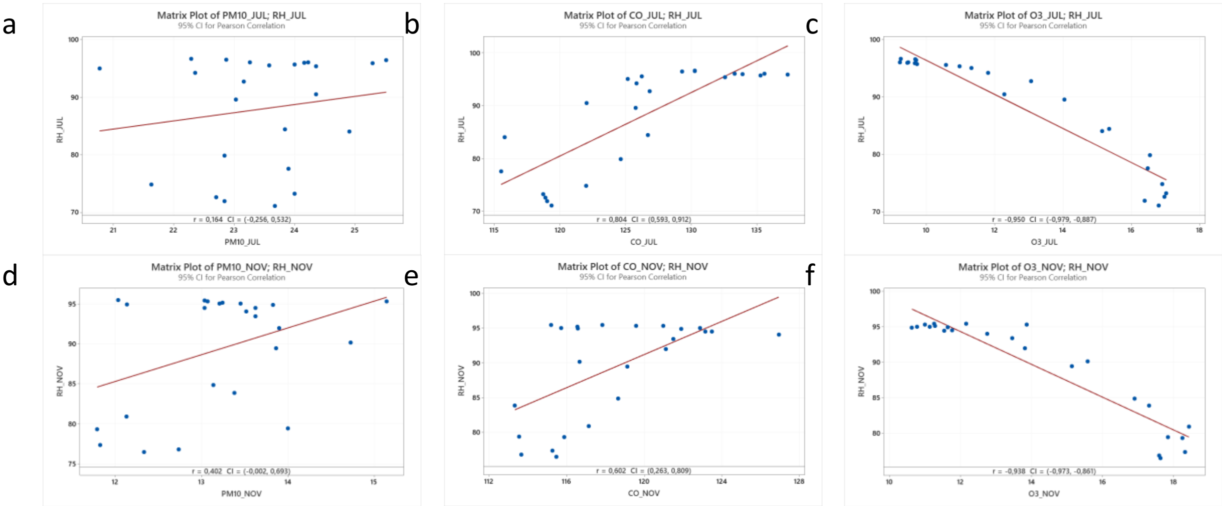


Figure. 7 Trends and correlation of ISPU parameters to diurnal relative humidity;
(a) PM10 vs. RH July, (b) CO vs RH July, (c) O_3 vs RH July
(d) PM10 vs RH November, (e) CO vs RH November, (f) O_3 vs RH November

Carbon monoxide concentration indicated strong opposition to the air temperature with a correlation of r=-0.805 during the low rainfall, see Figure 6(b). Consequently, with higher air temperatures during the day, the CO concentration would be lower than at night. The correlation was low (0.463) when the rainfall was high (Figure 6(e)). The air humidity gave a positive correlation response both during the low rainfall (r=0.805) and high rainfall (r=0.602), as shown in Figures 7(b) and 7(e).

The relationship between diurnal O3 concentration and temperature showed high correlation values in July and November, as presented in Figures 6(c) and 6(f). The correlation value (r) was 0.972 in July and 0.950 in November. The influence of meteorological factors, especially air temperature, is very significant in the diurnal variation of O_3. Tropospheric ozone reaches its maximum concentration when the peak temperature is reached during the day. Sunlight and maximum air temperature help the photochemical process of O_3 formation (Pancholi et al., 2018; Strode et al., 2019). Higher air temperature during the daytime can lead to a higher kinetic rate of chemical reaction. Higher temperature also leads to higher emission of Volatile Organic Compounds (VOCs), ozone precursors involved in the photochemical reaction (Gu et al., 2020). The strong correlation between ozone and temperature did not differ either during the high or low rainfall (Figure 6(c) and Figure 6(f)). The same thing is shown by the relationship between humidity and the diurnal variation of O_3, which was strong but in a negative direction (Figure 7(c) and Figure 7(f)). This relationship is because RH had a strong inverse relationship with temperature, as discussed above.

The rainfall in Kototabang had an equatorial pattern, as shown in Figure 1 above. In line with BMKG (2022), which mapped Indonesia into three main rainfall patterns, namely monsoon, equatorial and local pattern, most of the eastern side of northern Sumatra has an equatorial pattern. The rainfall fluctuations throughout 2020 did not correlate with air temperature and humidity, but there was a significant correlation between temperature and humidity. These meteorological conditions responded respectively to fluctuations in the three ISPU parameters being studied. Various studies have revealed that PM10 and CO are affected by rainfall. Therefore, the ISPU has the potential to increase during the dry season. Much particulate dust is released into the atmosphere, and biomass burning increases during this time (Ribeiro et al., 2020) in various activities. According to Supeni et al. (2021), there is an effect of forest and land fires (*karhutla*) around West Sumatra based on PM10 measurements at the Kototabang GAW Station. These pollutants certainly worsen the air quality in West Sumatra during the dry season, even though it is not a forest fire source area. This is in agreement with Olszowski (2016) that air quality could be well maintained during the high rainfall.

This study did not find a significant correlation between air temperature and humidity and the diurnal distribution of PM10. See Figure 5 (a), Figure 6(a), and Figure 6(b). However, in rainy November, the PM10 variance was seen to be higher at night than that during the day, compared to that in July (Figures 8(a) and Figure 8(d)). Based on the T-test, the distribution of PM10 in July and November was insignificant (Table 6). These results mean that the exposure could last day and night when PM10 were released into the atmosphere. Although there was a positive correlation between humidity and PM10, the findings of Hernandez et al. (2017) suggest that the effect of humidity is only up to the relative humidity value of 75%. Throughout 2020 the RH in Kototabang was always >80%, except in January and February (see Figure 1(b)).

Carbon monoxide is derived from incomplete combustion activities such as from motor vehicle exhaust, chimneys, and furnaces. The 2020 CO data for July and November in Kototabang showed a healthy condition based on ISPU calculations. A strong negative correlation between air temperature and the diurnal pattern of CO (see Figure 6(b) and Figure 6(e)) conveyed a message that at nights when the air temperature was lower, the CO concentration increases, in line with those presented in Figures 8(b) and Figure 8(e). According to Verma et al. (2017), the daily variation of CO concentration can also be associated with the formation of O_3 in the troposphere through photochemical reactions. Since O_3 is a secondary compound resulting from the reactions involving CO, this reaction can contribute to lower CO concentrations during the day compared to one at night (Figure 8(b) and Figure 8(e)). Meanwhile, during the high rainfall in November, the day and night CO T-tests were insignificant (see Table 6).

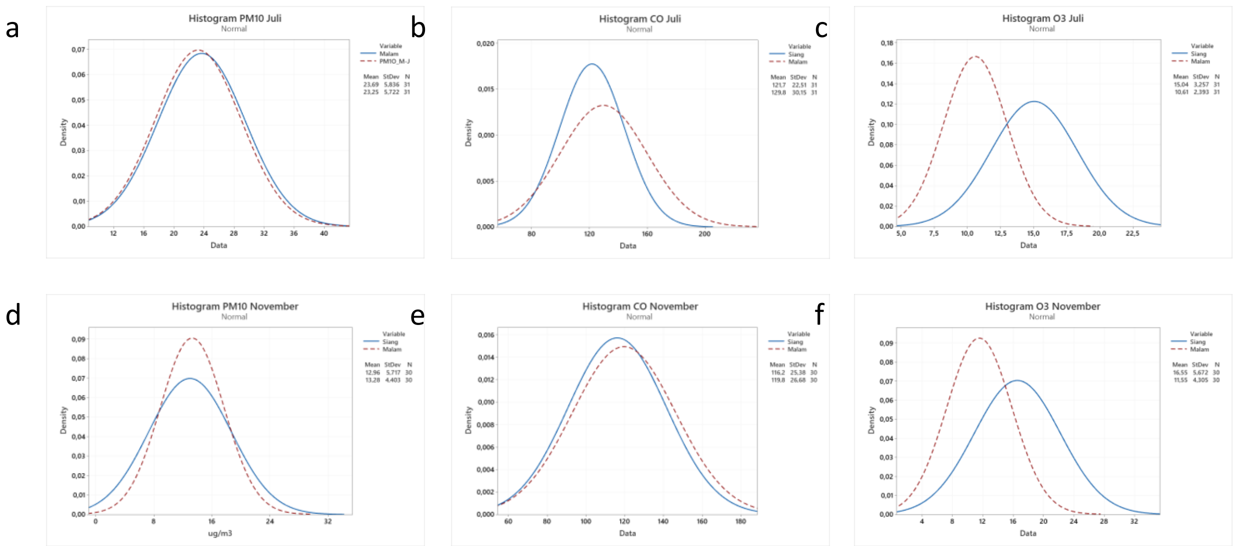


Figure. 8 Comparison of PM10, CO and O_3 distribution between day and night in July and November

Table 6. T-test comparison of the distribution of day (D) and night (N)

Parameter	PM10 (μg/m3)		CO (ppb)		O_3 (ppb)	
	Jul	Nov	Jul	Nov	Jul	Nov
N	31	30	31	30	31	30
Mean (D)	23.69	12.96	121.7	116.2	15.04	16.55
Mean (N)	23.25	13.28	129.8	119.8	10.61	11.55
P-Value (D vs. N)	0.582	0.534	0.006	0.133	0.000	0.000
Alfa	0.05	0.05	0.05	0.05	0.05	0.05

The significant decrease in ISPU during the day was more noticeable in O_3 because the photochemical process influences the nature of the substance, although in the object being studied, the O_3 value was still far below the threshold set. Based on the T-test result (Table 6, $P<0.05$), the O_3 concentration values during the day and night in July and November significantly differed in both the mean and variance. This is supported by the comparison between day and night distribution (Figure 8 (c) and Figure 8(f)) which shows that there was a most significant distribution of nigh time O_3 concentration compared to the concentration during the daytime. The air temperature can contribute to the rate of photochemical reactions of ozone formation and emission of ozone-formation precursor compounds (Gu et al., 2020). Furthermore, according to Wang et al. (2019), PM10 and O_3 have a reciprocal relationship. When the rainfall was low, the increase in PM10 particulates would reduce the solar radiation reaching the earth's surface. This could lower the O_3 concentration due to the lower photochemical process. Table 6 shows that the average O_3 concentration during the day and night was lower in July than in November 2020.

4. Conclusion

To sum up, diurnal fluctuations in ISPU parameters PM10, CO and O_3 were related to the meteorological conditions of rainfall, air temperature, and humidity with various patterns, especially in remote areas such as Kototabang. The PM10 increases during low rainfall but has a weak correlation with the temperature and humidity on a diurnal scale. The CO showed a negative response to the increased rainfall and was strongly influenced by the diurnal fluctuations in temperature but weakly influenced by the diurnal variations of relative humidity. Ozone was only strongly influenced by the air temperature and relative humidity related to the photochemical process of its formation.

The findings in this paper suggest that diurnal patterns of air quality parameters that involve photochemical reaction in their formation, like surface ozone and carbon monoxide can have a significant relationship with air temperature. Since the pollutant level can be higher during the dry season compared to the rainy season, some measures need to be taken to reduce the emission of pollutants during the dry seasons, particularly emissions from forest and land fires.

The diurnal variation of air quality parameters in the atmosphere results from a complex process involving emission sources, transport, dispersion, and even chemical reactions in the atmosphere. To understand the relationship of meteorological elements to the concentration of air quality parameters, a more in-depth study is needed in the future, involving other elements such as wind direction and speed as well as other elements that can affect the formation, transportation, and distribution of pollutants.

Acknowledgment

A big thank you to Ania Supeni for correcting the grammar and writing and to Supari and Rista Hernandi for pre-reviewing this paper's analysis flow.

Author Contribution

Conceptualization, W. and F.A.; methodology, W.; data, S.N.; data quality control; S.N.; analysis and discussion, W. and F.A.; Surfer and Minitab software, W.; research flow, F.A.; instrumentation metadata, S.N.; synchronization of literature, F.A.

References

Alfiandy, S., & Davi, R. S. (2020). Analysis of statistical models for forecasting PM10 in Kototabang region. *Journal of Physics: Conference Series*, *1434*(1). https://doi.org/10.1088/1742-6596/1434/1/012011

Bogusz, J., Kłos, A., Grzempowski, P., & Kontny, B. (2014). modelling the velocity field in a regular grid in the area of poland on the basis of the velocities of european permanent stations. *Pure and Applied Geophysics*, *171*(6), 809-833. https://doi.org/10.1007/s00024-013-0645-2

Chen, S., Wang, H., Lu, K., Zeng, L., Hu, M., & Zhang, Y. (2020). The trend of surface ozone in Beijing from 2013 to 2019: Indications of the persisting strong atmospheric oxidation capacity. *Atmospheric Environment, 242*. https://doi.org/10.1016/j.atmosenv.2020.117801

Daoud, J. I. (2018). Multicollinearity and regression analysis. *Journal of Physics: Conference Series*, *949*(1). https://doi.org/10.1088/1742-6596/949/1/012009

Du, Q., Zhao, C., Zhang, M., Dong, X., Chen, Y., Liu, Z., ... & Miao, S. (2020). Modeling diurnal variation of surface PM 2.5 concentrations over East China with WRF-Chem: Impacts from boundary-layer mixing and anthropogenic emission. *Atmospheric Chemistry and Physics*, *20*(5), 2839-2863. https://doi.org/10.5194/acp-2019-739

Empa. (2019). *system and performance audit of surface ozone, carbon monoxide, methane, and carbon dioxide at the Global GAW Station Bukit Kototabang Indonesia January 2019*.

Gu, Y., Li, K., Xu, J., Liao, H., & Zhou, G. (2020). Observed dependence of surface ozone on increasing temperature in Shanghai, China. *Atmospheric Environment*, *221*. https://doi.org/10.1016/j.atmosenv.2019.117108

Hernandez, G., Berry, T. A., Wallis, S., & Poyner, D. (2017). Temperature and humidity effects on particulate matter concentrations in a sub-tropical climate during winter. https://doi.org/10.7763/ipcbee.2017.v102.10

Hou, P., & Wu, S. (2016). long-term changes in extreme air pollution meteorology and the implications for air quality. *Scientific Reports*, *6*. https://doi.org/10.1038/srep23792

Indonesian Agency for Meteorological, Climatological, and Geophysical (BMKG). (2022). *Buku pemutakhiran zona musim di Indonesia periode 1991-2020*. https://iklim.bmkg.go.id/bmkgadmin/storage/buletin/Buku_ZOM9120_versi_cetak.pdf

Indonesian Ministry of Environment and Forestry. (2020a). *Indeks standar pencemar udara (ISPU) sebagai informasi mutu udara ambien di Indonesia*. https://ditppu.menlhk.go.id/portal/read/indeks-standar-pencemar-udara-ispu-sebagai-informasi-mutu-udara-ambien-di-indonesia

Indonesian Ministry of Environment and Forestry (2020b). *Peraturan Menteri LHK tentang Indeks Standar Pencemar, Pub. L. No. P.14/MENLHK /SETJEN/KUM.1/7/2020*.

Jiang, W. (2021). The data analysis of shanghai air quality index based on linear regression analysis. *Journal of Physics: Conference Series*, *1813*(1). https://doi.org/10.1088/1742-6596/1813/1/012031

Kalisa, W., Igbawua, T., Henchiri, M., Ali, S., Zhang, S., Bai, Y., & Zhang, J. (2019). Assessment of climate impact on vegetation dynamics over East Africa from 1982 to 2015. *Scientific Reports*, *9*(1). https://doi.org/10.1038/s41598-019-53150-0

Kim, T.K. (2015). Statistic and probability. *Korean Journal of Anesthesiology*. http://ekja.org

Kliengchuay, W., Worakhunpiset, S., Limpanont, Y., Meeyai, A. C., & Tantrakarnapa, K. (2021). Influence of the meteorological conditions and some pollutants on PM10 concentrations in Lamphun, Thailand. *Journal of Environmental Health Science and Engineering*, *19*(1), 237-249. https://doi.org/10.1007/s40201-020-00598-2

Kliengchuay, W., Cooper Meeyai, A., Worakhunpiset, S., & Tantrakarnapa, K. (2018). Relationships between meteorological parameters and particulate matter in Mae Hong Son province, Thailand. *International Journal of Environmental Research and Public Health*, *15*(12), 2801. https://doi.org/10.3390/ijerph15122801

Krivoshein, Y. O., Tolstykh, A. v., Tsvetkov, N. A., & Khutornoy, A. N. (2020). Mathematical model for calculating solar radiation on horizontal and inclined surfaces for the conditions of Yakutsk. *IOP Conference Series: Earth and Environmental Science*, *408*(1). https://doi.org/10.1088/1755-1315/408/1/012002

Kwak, H. Y., Ko, J., Lee, S., & Joh, C. H. (2017). Identifying the correlation between rainfall, traffic flow performance and air pollution concentration in Seoul using a path analysis. *Transportation Research Procedia*, *25*, 3552-3563. https://doi.org/10.1016/j.trpro.2017.05.288

Lesik, S.A. (2019). *Applied statistical inference with MINITAB* ® (2nd ed.). Chapman and Hall/CRC. https://doi.org/https://doi.org/10.1201/9780429444951

Liu, F., Tan, Q. W., Jiang, X., Jiang, W. J., & Song, D. L. (2018). Effect of relative humidity on particulate matter concentration and visibility during winter in Chengdu. *Huan jing ke xue= Huanjing kexue*, *39*(4), 1466-1472. https://doi.org/10.13227/j.hjkx.201707112

Li, W., Shi, Y., Gao, L., Wu, C., Liu, J., & Cai, Y. (2018). Occurrence, distribution and risk of organophosphate esters in urban road dust in Beijing, China. *Environmental Pollution*, *241*, 566-575. https://doi.org/10.1016/j.envpol.2018.05.092

Li, Y., Zhang, J., Sailor, D. J., & Ban-Weiss, G. A. (2019). Effects of urbanization on regional meteorology and air quality in Southern California. *Atmospheric Chemistry and Physics*, *19*(7), 4439-4457. https://doi.org/10.5194/acp-19-4439-2019

Li, Z., Guo, J., Ding, A., Liao, H., Liu, J., Sun, Y., Wang, T., Xue, H., Zhang, H., & Zhu, B. (2017). Aerosol and boundary-layer interactions and impact on air quality. In *National Science Review* (Vol. 4, Issue 6, pp. 810–833). Oxford University Press. https://doi.org/10.1093/nsr/nwx117

Mohtar, A. A. A., Latif, M. T., Baharudin, N. H., Ahamad, F., Chung, J. X., Othman, M., & Juneng, L. (2018). Variation of major air pollutants in different seasonal conditions in an urban environment in Malaysia. In *Geoscience Letters* (Vol. 5, Issue 1). SpringerOpen. https://doi.org/10.1186/s40562-018-0122-y

Nguyen, J. L., & Dockery, D. W. (2016). Daily indoor-to-outdoor temperature and humidity relationships: a sample across seasons and diverse climatic regions. *International Journal of Biometeorology*, *60*(2), 221-229. https://doi.org/10.1007/s00484-015-1019-5

Nurdiati, S., Khatizah, E., Najib, M. K., & Hidayah, R. R. (2021). Analysis of rainfall patterns in Kalimantan using fast fourier transform (FFT) and empirical orthogonal function (EOF). *IOP Conference Series: Earth and Environmental Science*, *1796*(1). https://doi.org/10.1088/1742-6596/1796/1/012053

Olszowski, T. (2016). Changes in PM10 concentration due to large-scale rainfall. *Arabian Journal of Geosciences*, *9*(2), 1-11. https://doi.org/10.1007/s12517-015-2163-2

Pancholi, P., Kumar, A., Bikundia, D. S., & Chourasiya, S. (2018). An observation of seasonal and diurnal behavior of O3–NOx relationships and local/regional oxidant (OX = O_3 + NO_2) levels at a semi-arid urban site of western India. *Sustainable Environment Research, 28*(2), 79-89. https://doi.org/10.1016/j.serj.2017.11.001

Paraschiv, S., & Paraschiv, L. S. (2019, September). Effects of wind speed, relative humidity, temperature and air pressure on PM10 concentration for an urban background area. In *IOP Conference Series: Materials Science and Engineering* (Vol. 595, No. 1, p. 012059). IOP Publishing. http://dx.doi.org/10.1088/1757-899X/595/1/012059

Paris, O., San, D., Singapore, F., Tokyo, S., Monteith, J. L., & Unsworth, M. H. (2013). *Principles of environmental physics plants, animals, and the atmosphere fourth edition*. http://elsevier.com/locate/permissions

Perera, F. P. (2017). Multiple threats to child health from fossil fuel combustion: impacts of air pollution and climate change. *Environmental health perspectives*, *125*(2), 141-148. http://dx.doi.org/10.1289/EHP299

Prasad, Y. S., & Rao, B. V. (2018). Groundwater depletion and groundwater balance studies of Kandivalasa river sub basin, Vizianagaram district, Andhra Pradesh, India. *Groundwater for Sustainable Development*, *6*, 71-78. https://doi.org/10.1016/j.gsd.2017.11.003

Ribeiro, I. O., do Santos, E. O., Batista, C. E., Fernandes, K. S., Ye, J., Medeiros, A. S., ... & de Souza, R. A. (2020). Impact of biomass burning on a metropolitan area in the Amazon during the 2015 El Niño: The enhancement of carbon monoxide and levoglucosan concentrations. *Environmental Pollution*, *260*, 114029. https://doi.org/10.1016/j.envpol.2020.114029

Strode, S. A., Ziemke, J. R., Oman, L. D., Lamsal, L. N., Olsen, M. A., & Liu, J. (2019). Global changes in the diurnal cycle of surface ozone. *Atmospheric Environment*, *199*, 323-333. https://doi.org/10.1016/j.atmosenv.2018.11.028

Supeni, A., Permadi, D. A., Gunawan, D., Dayantolis, W., & Suwarman, R. (2021). Variability of PM10 in a Global atmosphere watch station near the equator. *IOP Conference Series: Earth and Environmental Science*, *724*(1). https://doi.org/10.1088/1755-1315/724/1/012051

Tareen, A. D. K., Nadeem, M. S. A., Kearfott, K. J., Abbas, K., Khawaja, M. A., & Rafique, M. (2019). Descriptive analysis and earthquake prediction using boxplot interpretation of soil radon time series data. *Applied Radiation and Isotopes*, *154*. https://doi.org/10.1016/j.apradiso.2019.108861

Utami, A. I., Nasution, R. I., & Asnia, M. (2021). Effect of ozone precursors on surface ozone variations in GAW Kototabang and Cibeureum. *IOP Conference Series: Earth and Environmental Science*, *893*(1). https://doi.org/10.1088/1755-1315/893/1/012073

Verma, N., Satsangi, A., Lakhani, A., Kumari, K. M., & Lal, S. (2017). Diurnal, seasonal, and vertical variability in carbon monoxide levels at a Semi-Urban Site in India. *Clean - Soil, Air, Water*, *45*(5). https://doi.org/10.1002/clen.201600432

Vižintin, G., Kocjančič, M., & Vulić, M. (2016). Study of coal burst source locations in the velenje colliery. *Energies*, *9*(7), 507. https://doi.org/10.3390/en9070507

Wang, Z., Lv, J., Tan, Y., Guo, M., Gu, Y., Xu, S., & Zhou, Y. (2019). Temporospatial variations and Spearman correlation analysis of ozone concentrations to nitrogen dioxide, sulfur dioxide, particulate matters and carbon monoxide in ambient air, China. *Atmospheric Pollution Research*, *10*(4), 1203-1210. https://doi.org/10.1016/j.apr.2019.02.003

Widén, J., & Munkhammar, J. (2019). Solar radiation theory. In *Solar Radiation Theory*. Uppsala University. https://doi.org/10.33063/diva-381852

World Health Organozation (WHO). (2015). *Ambient air pollution: a global assessment of exposure and burden of disease*. https://apps.who.int/iris/bitstream/handle/10665/250141/9789241511353-eng.pdf

World Meteorological Organization (WMO). (2001). World meteorological organization global atmosphere watch global atmosphere watch measurements guide. In *WMO Publication*.

World Meteorological Organization (WMO). (2017). *GAW Report No. 228 - Implementation Plan: 2016-2023*. https://library.wmo.int/doc_num.php?explnum_id=3395

Zambrano-Monserrate, M. A., María, &, & Ruano, A. (2020). Has air quality improved in Ecuador during the COVID-19 pandemic? A parametric analysis. *Air Quality, Atmosphere & Health*. https://doi.org/10.1007/s11869-020-00866-y/Published

Zhai, B., Chen, J., Yin, W., & Huang, Z. (2018). Relevance analysis on the variety characteristics of PM2.5 concentrations in Beijing, China. *Sustainability (Switzerland)*, *10*(9). https://doi.org/10.3390/su10093228

Zhang, L., Zhang, Z., Chen, L., & McNulty, S. (2019). An investigation on the leaf accumulation-removal efficiency of atmospheric particulate matter for five urban plant species under different rainfall regimes. *Atmospheric Environment*, *208*, 123-132. https://doi.org/10.1016/j.atmosenv.2019.04.010

Zhao, S., Yu, Y., Yin, D., Qin, D., He, J., & Dong, L. (2018). Spatial patterns and temporal variations of six criteria air pollutants during 2015 to 2017 in the city clusters of Sichuan Basin, China. *Science of the total environment*, *624*, 540-557. https://doi.org/10.1016/j.scitotenv.2017.12.172