Influence of Weather Conditions on COVID-19 Case in Several Regions of Indonesia

Bella Deswanti[1], Marzuki[1]*, Robi Muharsyah[2], Helmi Yusnaini[1], Ravidho Ramadhan[1]

[1] Department of Physics, Universitas Andalas, Padang, Indonesia.
[2] Agency for Meteorology, Climatology and Geophysics of Republic Indonesia, Jakarta, Indonesia.

Abstract: This study investigates the relationship between COVID-19 and weather conditions in six regions in Indonesia, namely South Jakarta, East Jakarta, North Jakarta, Jember Regency, Semarang City, and West Pasaman Regency. The study uses the daily number of positive cases of COVID-19 and weather data. Weather parameters used in this study are the average, maximum, and minimum temperature, rainfall, and relative humidity. Weather data were obtained from surface observation of Agency for Meteorology, Climatology and Geophysics (BMKG) and reanalysis product (ERA-5) from European Centre for Medium-Range Weather Forecasts (ECMWF). The effect of weather conditions on the number of COVID-19 cases was evaluated using the Spearman and Kendall correlation. It was found that the number of positive cases of COVID-19 had a relationship with weather parameters. A negative correlation was found between the temperature and the number of positive COVID-19 cases. Thus, the number of positive COVID-19 cases increases when the temperature decreases. On the other hand, rainfall and relative humidity positively correlate to the number of positive cases of COVID-19, which means that when the rainfall and relative humidity increase, the number of positive cases of COVID-19 increases. The relationship between weather conditions and the number of COVID-19 cases is more apparent in areas with a higher population density, such as Jakarta. The results of this study can be valuable information in handling COVID-19 cases.

Keywords: COVID-19; Indonesia; Weather condition; Temperature; Rainfall

Introduction

The World Health Organization (WHO) detected a new type of virus, SARS-CoV-2 (Severe Acute Respiratory Syndrome Coronavirus-2), in Wuhan, China, on December 31, 2019 (WHO, 2020b). The disease caused by this virus is named Coronavirus Disease 2019 (COVID-19). SARS-CoV-2 is a type of RNA (Ribonucleic Acid) virus that can cause infections in the respiratory tract. The virus can be transmitted from human to human through droplets (splashes) that come out of the mouth or nose. The virus spreads quickly to all countries, and on January 30, 2020, WHO declared a world public health emergency (WHO, 2020a). The COVID-19 in Indonesia was first reported on March 2,

2020. Two weeks later, based on the Health Quarantine Law (UUKK), the government implemented a lockdown system policy which was later adapted as Large-Scale Social Restrictions (PSBB). Based on the Committee for Handling COVID-19 and National Economic Recovery report as of July 14, 2021, the total number of positive cases of COVID-19 was 2,670,046, with a death toll of 69,210 and recovery of 2,157,363 (KPCPEN, 2021).

The spreading of a virus is influenced by several factors such as immunity, migration flows, population density, medical care, and weather conditions (Mecenas, et al., 2020). Weather conditions can determine the viability and spread of the virus. Weather changes can affect human health. For example, when the temperature is colder, people are more susceptible to disease because

* Corresponding Author: marzuki@sci.unand.ac.id

the immune system is weaker, and viruses are more stable in winter, especially influenza. Influenza viruses can spread and survive well in cold temperatures. The ideal temperature for influenza viruses is 5 °C (Lowen, et al., 2007). Through its official website, WHO explains that the SARS-CoV-2 virus has several similarities with the influenza virus, in which they both cause respiratory diseases and spread the same way (WHO, 2020a).

Several studies have estimated that weather parameters such as temperature, humidity, and rainfall can affect the transmission of COVID-19 Mecenas et al. (2020) found the effect of temperature and humidity on the spread of COVID-19 in various countries. Kumar (2020) show a positive correlation between meteorological parameters and the COVID-19 pandemic in Singapore. Bashir et al. (2020) have also researched the correlation between weather parameters and the COVID-19 pandemic in New York, United States, by analyzing the relationship between COVID-19 and climate using the Kendall and Spearman correlation test. The results showed that the minimum temperature, average temperature, and air quality significantly related to the increase in the number of COVID-19 cases. Then Meyer et al. (2020) stated that the temperature in the tropics could help inhibit the virus's spread because the virus's condition in a tropical climate tends to be unstable. They found a negative correlation between temperatures above 1°C and COVID-19 cases per day. Sajadi et al. (2020) found that the spread of COVID-19 to high latitude (sub-tropical) countries is riskier than in low-latitude (tropical) countries because the SARS-CoV-2 virus tends to be stable at cold temperatures.

Although most studies show a relationship between weather and the spread of the coronavirus, there are also research showing that weather factors alone do not significantly affect the spread. Qi and Yu (2020) reported that changes in the weather alone without intervention to the wider community would not necessarily lead to decreased COVID-19 cases. They concluded by comparing changes in weather between provinces in China with the number of COVID-19 cases in the province.

From the above review, it can be seen that one conclusion regarding the effect of weather on COVID-19 is not yet available. This condition has prompted a similar study in the Indonesian region. Research on the influence of weather on the spread of COVID-19 in Indonesia is still minimal. There is only one study related to this topic, namely that conducted by Tosepu et al. (2020), with the result that weather is an essential factor in determining the incidence of COVID-19 in Jakarta. In this study, it was seen that the average temperature was significantly correlated with COVID-19. However, the study of Tosepu et al. (2020) was limited to three months of data and a single location. Therefore, in this paper, the influence of weather on the spread of COVID-19 in Indonesia was investigated in several regions, including South Jakarta, East Jakarta, North Jakarta, Jember Regency, Semarang City, and West Pasaman Regency. This area was chosen because the seven areas are included in the red or high-risk zone for COVID-19 transmission. In addition, there are in-situ observation data of weather parameters in the area. The relationship between COVID-19 and the weather parameter was evaluated using the Kendall and Spearman correlation, as also used in several previous studies (Bashir et al., 2020; Tosepu et al., 2020). These two correlation tests are commonly used to measure the strength of the relationship between two variables when the data used is ordinal in scale and does not have to be normally distributed.

Method

This study uses positive COVID-19 data obtained from the Covid19.go.id website. We used daily data from May 2020 to March 2021 for South Jakarta, East Jakarta, North Jakarta, Jember Regency, Semarang City, and West Pasaman Regency. Weather parameter data for each region, including average temperature (°C), maximum temperature (°C), minimum temperature (°C), rainfall (mm/day), and relative humidity (%), were provided by Agency for Meteorology, Climatology and Geophysics (BMKG). In addition to BMKG data, reanalysis product (ERA-5), especially for average temperature (°C) and rainfall (mm), were also used, which was downloaded from the European Center for Medium-Range Weather Forecasts (ECMWF) website.

The relationship between COVID-19 and the weather parameter was evaluated using the Kendall τ correlation, given by the following equation.

$$\tau = \frac{2S}{n(n-1)} \tag{1}$$

where S is number of concordant pairs-number of discordant pairs, and n is total number of samples. In addition, we also compare the results with the Spearman correlation (ρ), given by:

$$\rho = 1 - \frac{6 \sum d_i^2}{n(n^2-1)} \tag{2}$$

where d_i = difference in paired ranks and n = number of cases.

The weather condition in Indonesia varies in time scales (Ramadhan et al., 2022b), such as seasonal variations (Marzuki et al 2016b; Oktaviani, 2019; Ramadhan et al., 2022a), intra-seasonal (Marzuki, et al., 2016a), and diurnal variations (Marzuki et al., 2016b; Marzuki et al., 2021, 2022). Although this data can cover seasonal and intra-seasonal variations, this variation is not discussed in this study because the data used is only

one year. In addition, the data used is a daily scale, so diurnal variations are disregarded in this study.

Figure 1. Time series of (a) COVID-19 cases, (b) Average temperature (°C), (c) Maximum temperature (°C), (d) Minimum temperature (°C), (e) Rainfall (mm/day), (f) Relative humidity (%) for the South Jakarta area. Weather data were obtained from BMKG observations.

Result and Discussion

South Jakarta

Figure 1 shows the time series for the number of positive COVID-19 cases and several weather parameters in South Jakarta. There are several dates for which there is no weather data from the BMKG, such as October 24 - December 8, 2020, and January 29 - February 18, 2021. The COVID-19 data when there is no weather data from the BMKG are also not analyzed. COVID-19 cases increased from May 2020 to January 2021 and decreased from February 2021 to March 2021. The highest total positive COVID-19 cases occurred on January 22, 2021. In January 2021, the total number of positive COVID-19 cases was 15799, with an average of 564 cases per day. The lowest cases occurred in May 2020 (123 cases), averaging 11 cases per day.

The number of positive cases of COVID-19 has a relationship with weather parameters. The daily average of weather data shows the highest average temperature of 34.80 °C occurred on October 17, 2020, and the lowest occurred on August 13, 2020, at 23.75 °C. The highest maximum temperature of 38.72 °C occurred on October 16, 2020, and the lowest temperature of 24.63 °C on August 13, 2020. The highest minimum temperature of 34.28 °C occurred on October 17, 2020, and the lowest temperature of 23.68 °C on August 13, 2020. Although the lowest daily temperature was observed on August 13, 2020, on monthly scale, the lowest temperature was observed in January, coinciding with the peak of cases of COVID-19. Thus, as the positive case of COVID-19 increases, the average, maximum, and minimum temperature (Figure 1a) decrease. On the other hand, rainfall (Figure 1b) and relative humidity (Figure 1c) are directly proportional to the increase in positive cases of COVID-19. The highest rainfall of 292.20 mm occurred in February 2021, coinciding with the peak cases of COVID-19. The highest average RH of 98.49% occurred on August 13, 2020, and the lowest was 53.14% on July 1, 2020. However, on monthly scale, the highest RH was observed in January-February 2021, coinciding with the peak cases of COVID-19.
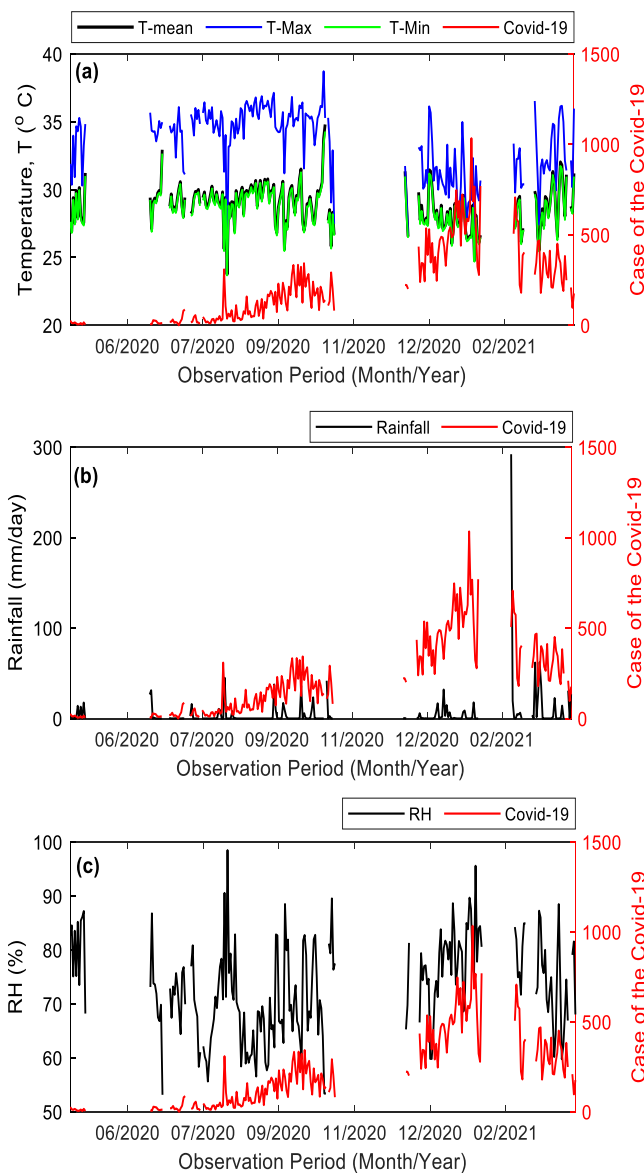
Table 1. Correlation coefficients between COVID-19 and weather variables for the South Jakarta area.

Correlation	Data	Mean T (°C)	Max. T (°C)	Min. T (°C)	Rainfall (mm)	RH (%)
ρ	BMKG	-0.3258	-0.4534	-0.3316	0.1589	0.2750
	ERA-5	-0.4619			0.3762	
τ	BMKG	-0.2073	-0.2950	-0.2124	0.1163	0.1842
	ERA-5	-0.2977			0.2512	

Table 1 shows the results of the Spearman correlation test (ρ) and the Kendall correlation test (τ) for the South Jakarta area. Average, maximum, and temperature negatively correlate with the number of

COVID-19 cases. Thus, the lower the temperature, the more positive cases of COVID-19, as can also be seen in Figure 1a. This correlation is at a very weak (0-0.25) and moderate level (0.25-0.50). The correlation coefficient

obtained by the Spearman correlation test is higher than the Kendall correlation test, both on BMKG and ERA-5 data. Rainfall and relative humidity in South Jakarta positively correlate with the number of COVID-19 cases. Thus, the higher the rainfall and relative humidity, the more positive cases of COVID-19, as can also be seen in Figure 1b-c.

East Jakarta

Figure 2 shows the number of positive cases of COVID-19 in East Jakarta. The number of cases increased from May 2020 to February 2021 and decreased in March 2021. The highest monthly positive COVID-19 cases occurred in February 2021, amounting to 20050 cases, with an average of 716 cases per day. The lowest cases occurred in May 2020, with a total of 502 cases with an average of 17 cases per day. Figure 2a shows weather data for East Jakarta. Weather data shows that the highest monthly average temperature of 28.52 °C occurs in September 2020, and the lowest occurs in January 2021, which is 26.55 °C. The highest monthly average temperature of 34.23 °C occurred in September 2020; the lowest was 30.75 °C in January 2021. The highest minimum temperature of 28.31 °C occurred in September 2020; the lowest was 26.42 °C in January 2021. Thus, the increase in the number of COVID-19 cases occurs in months with low temperatures. On the other hand, the increase in the number of COVID-19 cases occurs in months with high rainfall and relative humidity. The highest rainfall of 16.62 mm and relative humidity of 84.74% occurred in February 2021. Furthermore, the lowest rainfall of 1.12 mm was observed in July 2020 (Figure 2b) while the lowest relative humidity of 69.87% occurred in September 2020 (Figure 2c).
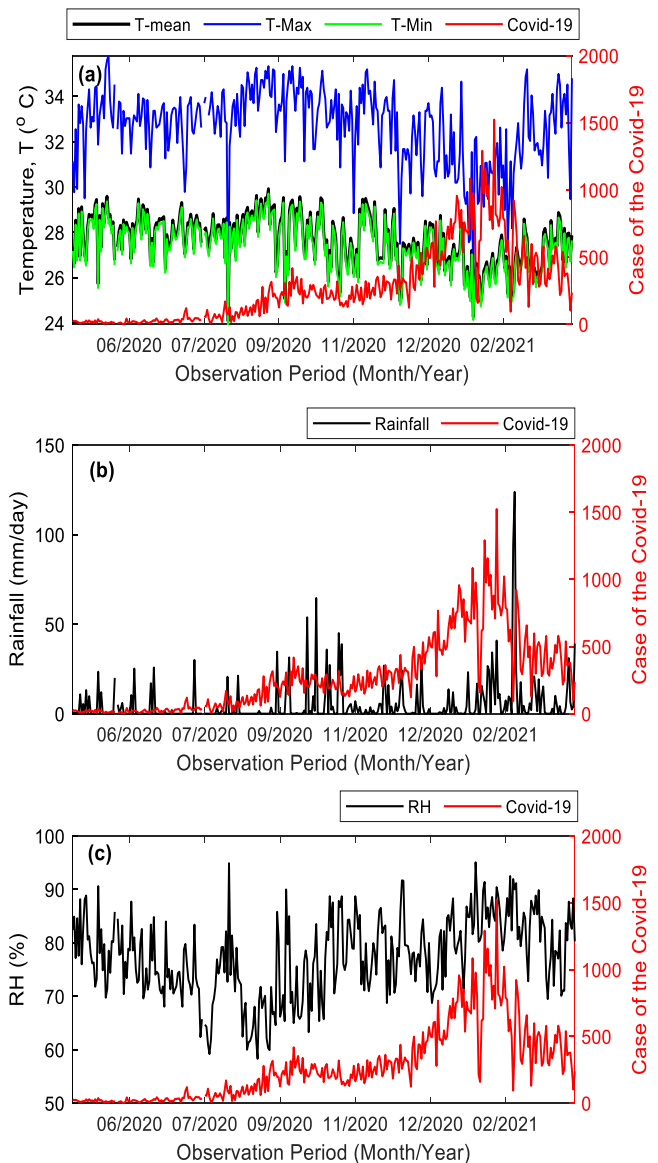

Figure 2. Same as Figure 1 but for East Jakarta area.

Table 2. Correlation coefficients between COVID-19 and weather variables for East Jakarta.

Correlation	Data	Mean T (°C)	Max. T (°C)	Min. T (°C)	Rainfall (mm)	RH (%)
ρ	BMKG	-0.4359	-0.3065	-0.4412	0.3142	0.3272
	ERA-5	-0.4088			0.3931	
τ	BMKG	-0.2916	-0.2017	-0.2954	0.2283	0.2175
	ERA-5	-0.2717			0.2664	

As in South Jakarta, the number of positive cases of COVID-19 has a relationship with weather parameters in East Jakarta. When the temperature value drops and rainfall and humidity increase, the number of positive COVID-19 cases increases (Figure 2), this is seen from the correlation test (Table 2). Temperature negatively correlates with the number of positive cases of COVID-19, while rainfall and humidity positively correlate with COVID-19 cases. The value of the correlation coefficient is at a very weak (0-0.25) and moderate level (0.25-0.50), as found in South Jakarta.

North Jakarta

Figure 3 shows the number of positive cases of COVID-19 in North Jakarta. The number of cases increased from May 2020 to February 2021 and decreased in March 2021, as in South and East Jakarta. The highest total positive COVID-19 cases occurred in February 2021, amounting to 7940 cases, with an average of 318 cases per day. The lowest cases occurred in May 2020, with 508 cases with an average of 16 cases per day. The trend in positive cases of COVID-19 is the same as in South Jakarta and East Jakarta, but with a lower

number of cases. Such difference can be due to differences in population density, where the population density of North Jakarta is lower than East Jakarta and South Jakarta. The population density of East Jakarta, South Jakarta, and North Jakarta are 17,199/km², 15,370.00/km², and 12,570/km², respectively. The number and density of the population significantly affect the number of positive cases of COVID-19, as found by many researchers s (Ahmadi et al., 2020; Briz-Redón & Serrano-Aroca, 2020; Pedrosa, 2020).

As in South Jakarta and East Jakarta, the number of positive cases of COVID-19 in North Jakarta also has a relationship with weather parameters. When the temperature decreases (Figure 3a), rainfall (Figure 3b), and humidity increases (Figure 3c), the number of positive cases of COVID-19 increases. Weather data shows the highest average temperature of 29.27 °C in May 2020 and the lowest in January 2021 at 26.10 °C. The highest maximum temperature of 32.10 °C occurred in May 2020, and the lowest temperature of 28.27 °C in January 2021. The highest minimum temperature of 29.00 °C occurred in June 2020; the lowest was 25.95 °C in January 2021. The highest rainfall occurred in January 2021, and the lowest was observed in August 2020. The highest monthly average humidity of 81.60% occurs in January 2021, and the lowest is 67.46% in August 2020. Thus, months with low temperatures, high rainfall, and high relative humidity are associated with a high increase in COVID-19 cases. The relationship between the amount Positive cases of COVID-19 with weather parameters in North Jakarta can be seen in Table 3. In general, the trend of the correlation is the same as in East Jakarta and South Jakarta.
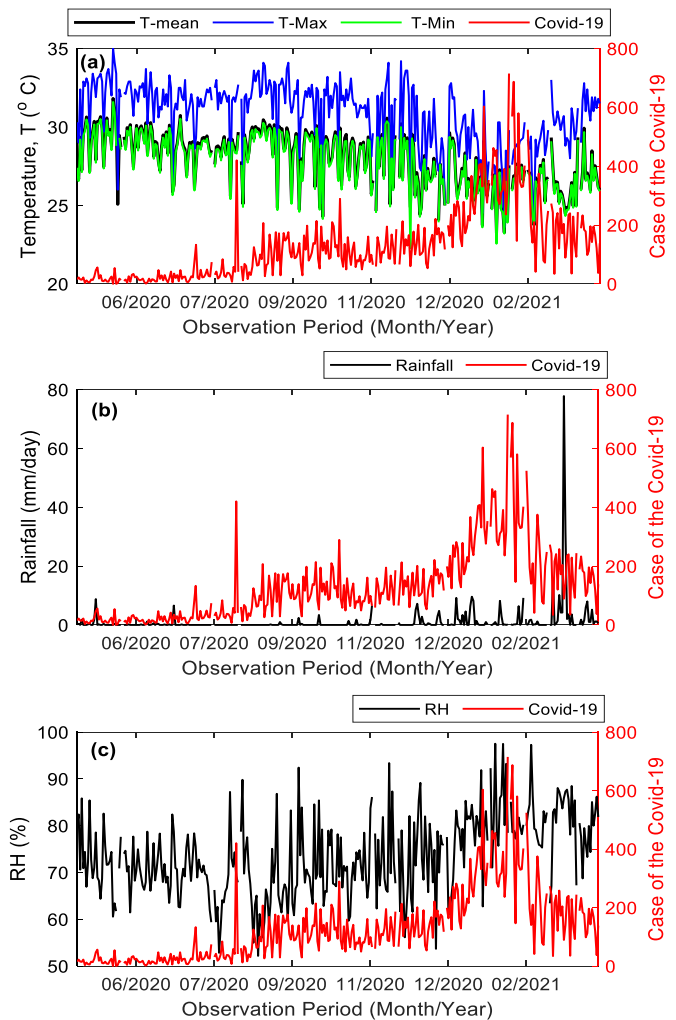

Figure 3. Same as Figure 1 but for North Jakarta area.

Table 3. Correlation coefficients between COVID-19 and weather variables for North Jakarta.

Correlation	Data	Mean T (°C)	Max. T (°C)	Min. T (°C)	Rainfall (mm)	RH (%)
ρ	BMKG	-0.4150	-0.3966	-0.4096	0.2187	0.2841
	ERA-5	-0.3787			0.2528	
τ	BMKG	-0.2801	-0.2764	-0.2759	0.1620	0.1832
	ERA-5	-0.2550			0.1655	

Semarang

Figure 4 shows the number of positive cases of COVID-19 and the weather parameters in Semarang City. The highest positive cases of COVID-19 occurred in June 2020, with about 9483 cases with an average of 316 cases per day. The lowest cases occurred in October 2020, with an average of 19 cases per day. Weather data shows a relationship with the number of positive cases of COVID-19. The number of positive Covid-19 cases increases when temperatures are low and rainfall and humidity are high. The highest monthly average temperature of 28.88 °C occurred in May 2020, and the lowest of 26.19 °C occurred in February 2021. Furthermore, the highest maximum temperature of 35.43 °C occurred in September 2020; the lowest was

29.89 °C in February 2021. Moreover, the highest minimum temperature of 28.71 °C occurred in May 2020; the lowest was 26.05 °C in February 2021. The highest rainfall of 26.66 mm occurred in February 2021, and the lowest was 0.38 mm in August 2020. The highest average humidity of 86.94% occurred in February 20201, and the lowest was 67.67% in August 2020. The relationship between the number of positive cases of COVID-19 in Semarang City and the weather parameters can be seen more clearly in Table 4. Temperature negatively correlates with the number of COVID-19 cases, while rainfall and relative humidity have a positive correlation, as was also observed in Jakarta. However, the correlation coefficient in Semarang is lower than in Jakarta, which is observed in all-weather parameters.

Table 4. Correlation coefficients between COVID-19 and weather variables for Semarang city.

Correlation test	Data	Mean T (°C)	Max. T (°C)	Min. T (°C)	Rainfall (mm)	RH (%)
ρ	BMKG	-0.0361	-0.1287	-0.0310	0.0005	0.0963
	ERA-5	-0.1084			0.1517	
τ	BMKG	-0.0244	-0.0865	-0.0218	0.0040	0.0634
	ERA-5	-0.0638			0.1007	

Jember Regency

Figure 5 shows the number of positive cases of COVID-19 and weather parameters in the Jember Regency. The highest number of positive COVID-19 cases occurred in December 2020, averaging 64 cases per day. Furthermore, the lowest cases occurred in May 2020, with an average of 2 cases per day. Weather data shows the highest monthly average temperature of 26.30 °C occurred in September 2020, and the lowest occurred in July 2020 at 24.93 °C. The highest maximum temperature of 33.09 °C occurred in September 2020, and the lowest temperature of 30.92 °C in July 2020. The highest minimum temperature of 26.16 °C occurred in September 2020, and the lowest was 24.80 °C in July 2020. The highest rainfall of 22.82 mm occurred in January 2021, and the lowest was 0.30 mm in July 2020. The highest average humidity of 86.69% occurred in January 2021, and the lowest was 64.59% in July 2020. It can be seen clearly that the number of positive cases of COVID-19 has increased in months with low temperatures, rainfall, and high humidity (Figure 5a-c). The relationship between the number of positive cases of COVID-19 in Jember Regency and weather parameters can be seen from the correlation test (Table 5). As with Jakarta and Semarang, the number of positive cases of COVID-19 has a negative correlation with temperature and a positive correlation with rainfall and relative humidity. The correlation coefficient for rainfall and humidity is at a moderate level (0.25-0.50), and the temperature from BMKG correlates at a very weak level (0-0.25) temperature from BMKG. However, the temperature of ERA-5 showed a moderate correlation.
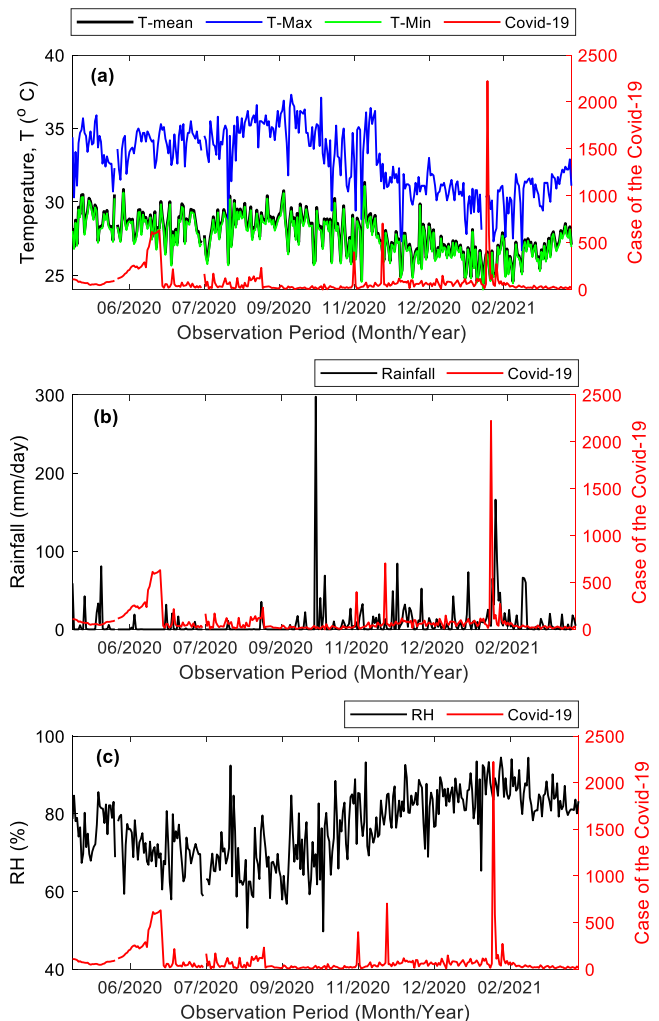

Figure 4. Same as Figure 1 but for Semarang area.

Table 5. Correlation coefficients between COVID-19 and weather variables for Jember regency.

Correlation	Data	Mean T (°C)	Max. T (°C)	Min. T (°C)	Rainfall (mm)	RH (%)
ρ	BMKG	-0.0051	-0.0130	-0.0032	0.4788	0.5127
	ERA-5	-0.3845			0.3838	
τ	BMKG	-0.0084	-0.0020	-0.0025	0.3495	0.3591
	ERA-5	-0.2541			0.2586	

West Pasaman Regency

Figure 6 shows the number of positive cases of COVID-19 and the weather parameters in the West Pasaman Regency. The relationship between the number of Covid-19 cases and weather parameters was also observed, although not as straightforward as in Jakarta. The highest positive cases of COVID-19 occurred in November 2020, amounting to 173 cases with an average of 5 cases per day. The lowest cases occurred in May,

June, July, and August 2020, with an average of 0 cases per day. Weather data shows the highest average monthly temperature of 27.26 °C occurred in May 2020, and the lowest of 25.28 °C occurred in September 2020. The highest maximum temperature of 34.51 °C occurred in February 2021, and the lowest was 31.33 °C in November 2020. The highest minimum temperature of 27.10 °C occurred in May 2020, and the lowest was 25.43 °C in September 2020. The highest rainfall of 21.43 mm

occurred in November 2020; the lowest was 5.38 mm in February 2021. The highest average humidity of 88.10% occurred in November 2020, and the lowest was 75.14% in February 2021. Thus, months with low temperatures, high rainfall, and high relative humidity are associated with a high increase in COVID-19 cases. The relationship between the number of positive cases of COVID-19 and weather parameters is shown in Table 4.6. The relationship pattern is generally similar to that found in Jakarta, Semarang, and Jember regency, where the temperature is negatively correlated. In contrast, rainfall and relative humidity are positively correlated with the number of positive cases of COVID-19. However, the correlation coefficient in west Pasaman Regency is lower than in Jakarta, which is observed in all-weather parameters.
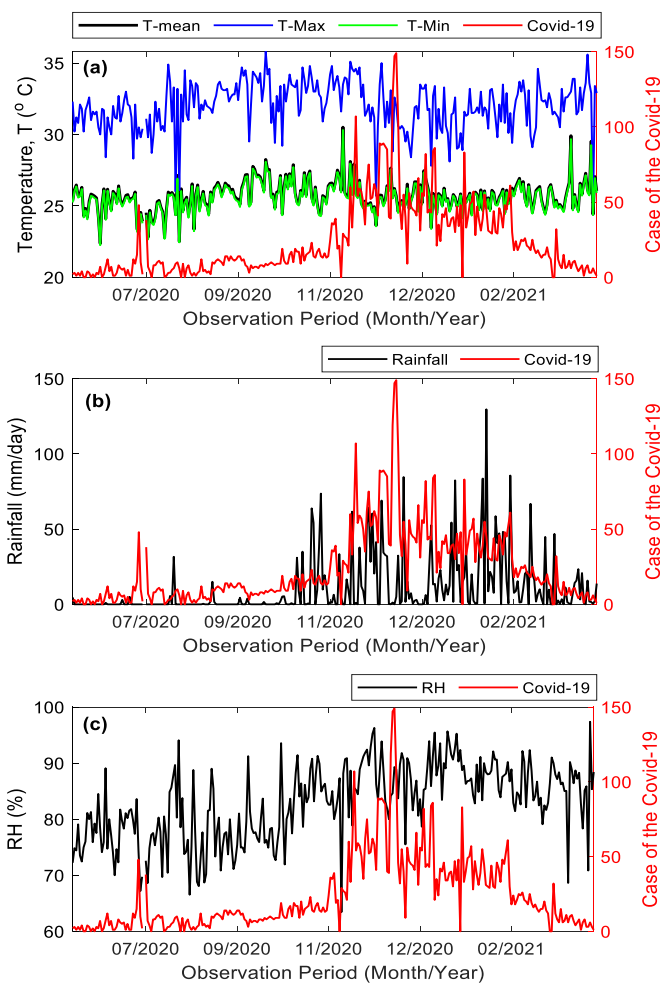

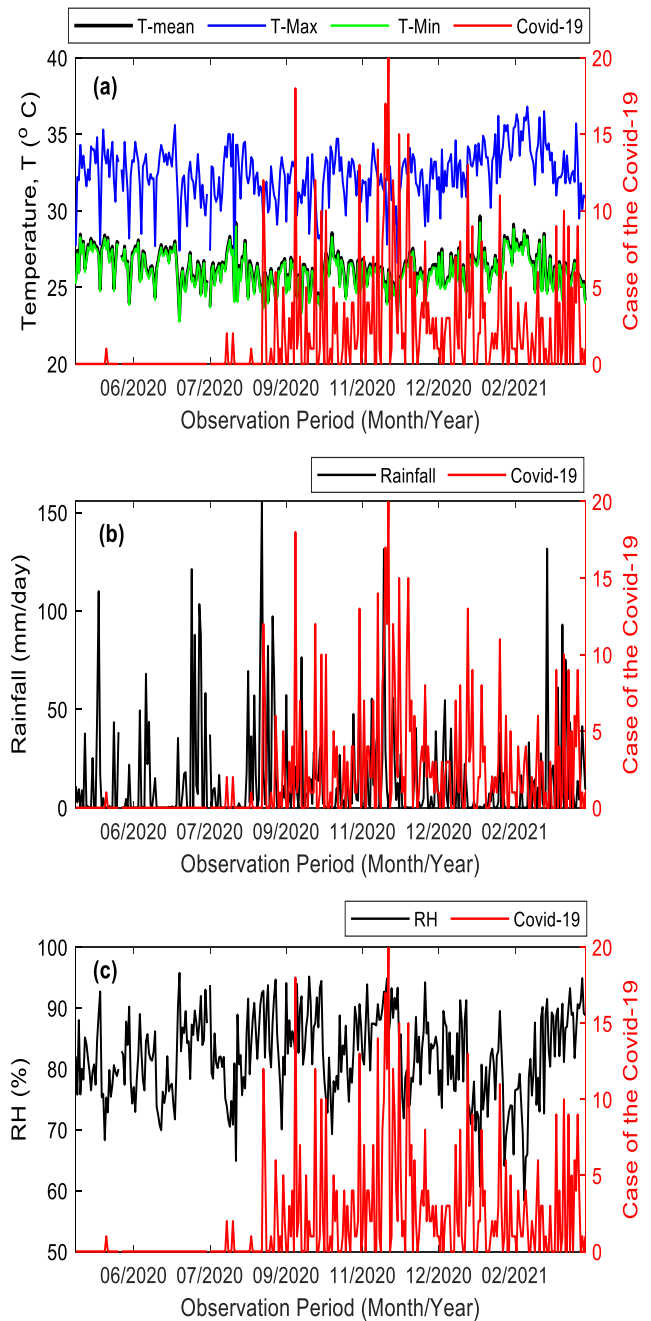Figure 5. Same as Figure 1 but for Jember regency area.

Figure 6. Same as Figure 1, but for west Pasaman regency area.

Table 6. Correlation coefficients between COVID-19 and weather variables for west Pasaman regency.

Correlation	Data	Mean T (°C)	Max. T (°C)	Min. T (°C)	Rainfall (mm)	RH (%)
ρ	BMKG	-0.1167	-0.0039	-0.1203	0.0391	0.0886
	ERA-5	-0.1735			0.0568	
τ	BMKG	-0.0867	-0.0025	-0.0896	0.0328	0.0649
	ERA-5	-0.1298			0.0429	

Discussion

The negative correlation between temperature and the number of positive COVID-19 cases found in this study is consistent with studies in California (Gupta, 2020), Japan (Ujiie, Tsuzuki, & Ohmagari, 2020), Ghana (Iddrisu et al., 2020), Spain (Abdollahi & Rahbaralam, 2020; Tobías & Molina, 2020), Italy (Livadiotis, 2020) and China (Oliveiros et al., 2020; H. Qi et al., 2020; Shi et al., 2020; Sil & Kumar, 2020). However, this result is different from that of Tosepu et al. (2020) for Jakarta. By utilizing the Spearman correlation test, Tosepu et al. (2020) found a positive correlation between the number of COVID-19 cases and temperature. This difference may be caused by the difference in the amount of data used where Tosepu et al. (2020) only analyzed three months of data, namely from January 1 to March 29, 2020. Figures 1-3 show Jakarta temperatures were lower from January to March than in other months. Therefore, the data used by Tosepu et al. (2020) only covers one weather condition, while the data used in this study includes all weather conditions in one year, so it is more realistic.

A positive correlation between rainfall and humidity with the number of COVID-19 cases found in this study was also found by Tosepu et al. (2020). However, the correlation value was more robust than that obtained by Tosepu et al. (2020). Tosepu et al. (2020) found a correlation of 0.002 for RH and 0.139 for rainfall. A positive correlation between humidity and the number of COVID-19 cases was also found in China (Luo et al., 2020; Oliveiros et al., 2020) and globally (Pedrosa, 2020).

The relationship between weather parameters and the number of COVID-19 cases was strongest among the six regions studied in Jakarta. This may be influenced by population density. The population density of East Jakarta, South Jakarta, North Jakarta, Semarang, Jember Regency, and West Pasaman are 17,199/km², 15,370.00/km², and 12,570/km², 4,854, 770/km², and 113/km², respectively (Kemendagri, 2021). In areas with high population density, weather factors can exacerbate the spread of COVID-19. This combination of weather and population factors has also been found by Kubota et al. (2020). In addition to weather factors, the number of travelers, and the age of the population, can also affect the number of COVID-19 cases (Ahmadi et al., 2020; Briz-Redón & Serrano-Aroca, 2020). However, these variables were not considered in this study. However, all the studied areas are in the red zone with the same PSBB level.

Conclusion

This study found that the number of positive cases of COVID-19 in several regions in Indonesia had a relationship with weather parameters. A negative correlatión was found between the temperature value and the number of positive cases of COVID-19. When the temperature drops, the number of positive COVID-19 cases increases. Rainfall and humidity positively correlate with the number of positive cases of COVID-19, which means that when the rainfall and humidity increase, the number of positive cases of COVID-19 increases. The results of this study can be valuable information in handling COVID-19 cases. In addition to regulating community movement and health protocols, temperature control treatments may help handle COVID-19 cases.

Acknowledgements

References

Abdollahi, A., & Rahbaralam, M. (2020). Effect of temperature on the transmission of COVID-19: A machine learning case study in Spain. *MedRxiv*. 2020(May). https://doi.org/10.1101/2020.05.01.20087759

Ahmadi, M., Sharifi, A., Dorosti, S., Ghoushchi, S. J., & Ghanbari, N. (2020). Investigation of effective climatology parameters on COVID-19 outbreak in Iran. *Science of the Total Environment*, *729*, 138705. https://doi.org/10.1016/j.scitotenv.2020.138705

Bashir, M. F., Ma, B., Komal, B., Bashir, M. A., Tan, D., & Bashir, M. (2020). Correlation between climate indicators and COVID-19 pandemic in New York, USA. *Science of the Total Environment*, *728*, 138835. https://doi.org/10.1016/j.scitotenv.2020.138835

Briz-Redón, Á., & Serrano-Aroca, Á. (2020). A spatio-temporal analysis for exploring the effect of temperature on COVID-19 early evolution in Spain. *Science of the Total Environment*, *728*, 138811. https://doi.org/10.1016/j.scitotenv.2020.138811

Gupta, D. (2020). Effect of ambient temperature on COVID-19 infection rate. *Available at SSRN 3558470*. https://dx.doi.org/10.2139/ssrn.3558470

Iddrisu, W. A., Appiahene, P., & Kessie, J. A. (2020). Effects of weather and policy intervention on COVID-19 infection in Ghana. *ArXiv Preprint ArXiv:2005.00106*. https://doi.org/10.48550/arXiv.2005.00106

Kemendagri. (2021). Visualisasi Data Kependudukan - Kementerian Dalam Negeri 2021. Retrieved January 1, 2022, from www.dukcapil.kemendagri.go.id

KPCPEN. (2021). COVID-19 Distribution Map. Retrieved August 1, 2021, from https://covid19.go.id/peta-sebaran

Kubota, Y., Shiono, T., Kusumoto, B., & Fujinuma, J.

(2020). Multiple drivers of the COVID-19 spread: role of climate, international mobility, and region-specific conditions. Plos One. 15(9). https://doi.org/10.1371/journal.pone.0239385

Kumar, S. (2020). Effect of meteorological parameters on spread of COVID-19 in India and air quality during lockdown. *Science of the Total Environment*, *745*, 141021. https://doi.org/10.1016/j.scitotenv.2020.141021

Livadiotis, G. (2020). Statistical analysis of the impact of environmental temperature on the exponential growth rate of cases infected by COVID-19. *PLoS One*, *15*(5), e0233875. https://doi.org/10.1371/journal.pone.0233875

Lowen, A. C., Mubareka, S., Steel, J., & Palese, P. (2007). Influenza virus transmission is dependent on relative humidity and temperature. *PLoS Pathogens*, *3*(10), e151. https://doi.org/10.1371/journal.ppat.0030151

Luo, W., Majumder, M. S., Liu, D., Poirier, C., Mandl, K. D., Lipsitch, M., & Santillana, M. (2020). The role of absolute humidity on transmission rates of the COVID-19 outbreak. *MedRxiv*. https://doi.org/10.1101/2020.02.12.20022467

Marzuki, Hashiguchi, H., Kozu, T., Shimomai, T., Shibagaki, Y., & Takahashi, Y. (2016). Precipitation microstructure in different Madden-Julian Oscillation phases over Sumatra. *Atmospheric Research*, *168*. https://doi.org/10.1016/j.atmosres.2015.08.022

Marzuki, Hashiguchi, H., Shimomai, T., & Randeu, W. L. (2016). Cumulative distributions of rainfall rate over Sumatra. *Progress In Electromagnetics Research M*, *49*. https://doi.org/10.2528/PIERM16043007

Marzuki, M., Suryanti, K., Yusnaini, H., Tangang, F., Muharsyah, R., Vonnisa, M., & Devianto, D. (2021). Diurnal variation of precipitation from the perspectives of precipitation amount, intensity and duration over Sumatra from rain gauge observations. *International Journal of Climatology*, *41*(8). https://doi.org/10.1002/joc.7078

Marzuki, M., Yusnaini, H., Tangang, F., Muharsyah, R., Vonnisa, M., & Harmadi, H. (2022). Land–sea contrast of diurnal cycle characteristics and rain event propagations over Sumatra according to different rain duration and seasons. *Atmospheric Research*, *270*, 106051. https://doi.org/10.1016/j.atmosres.2022.106051

Mecenas, P., Bastos, R. T. da R. M., Vallinoto, A. C. R., & Normando, D. (2020). Effects of temperature and humidity on the spread of COVID-19: A systematic review. *PLoS One*, *15*(9), e0238339. https://doi.org/10.1371/journal.pone.0238339

Meyer, A., Sadler, R., Faverjon, C., Cameron, A. R., & Bannister-Tyrrell, M. (2020). Evidence that higher temperatures are associated with a marginally

lower incidence of COVID-19 cases. *Frontiers in Public Health*, *8*, 367. https://doi.org/10.3389/fpubh.2020.00367

Oktaviani, R. (2019). Estimation of Rainfall Rate Cumulative Distribution in Indonesia Using Global Satellite Mapping of Precipitation Data. *KnE Engineering*, 259–265. https://doi.org/10.18502/keg.v1i2.4450

Oliveiros, B., Caramelo, L., Ferreira, N. C., & Caramelo, F. (2020). Role of temperature and humidity in the modulation of the doubling time of COVID-19 cases. *MedRxiv*. https://doi.org/10.1101/2020.03.05.20031872

Pedrosa, R. H. L. (2020). The dynamics of Covid-19: weather, demographics and infection timeline. *MedRxiv*. https://doi.org/10.1101/2020.04.21.20074450

Qi, H., Xiao, S., Shi, R., Ward, M. P., Chen, Y., Tu, W., … Zhang, Z. (2020). COVID-19 transmission in Mainland China is associated with temperature and humidity: A time-series analysis. *Science of the Total Environment*, *728*, 138778. https://doi.org/10.1016/j.scitotenv.2020.138778

Qi, Z., & Yu, Y. (2020). Epidemiological Features of the 2019 Novel Coronavirus Outbreak in China. *Current Topics in Medicinal Chemistry*, *20*(13), 1137–1140. https://doi.org/10.2174/1568026620999200511094117

Ramadhan, R., Marzuki, M., Yusnaini, H., Muharsyah, R., Suryanto, W., Sholihun, S., … Hashiguchi, H. (2022). Capability of GPM IMERG Products for Extreme Precipitation Analysis over the Indonesian Maritime Continent. *Remote Sensing*, *14*(2), 412. https://doi.org/10.3390/rs14020412

Ramadhan, R., Yusnaini, H., Marzuki, M., Muharsyah, R., Suryanto, W., Sholihun, S., … Battaglia, A. (2022). Evaluation of GPM IMERG Performance Using Gauge Data over Indonesian Maritime Continent at Different Time Scales. *Remote Sensing*, *14*(5), 1172. https://doi.org/10.3390/rs14051172

Sajadi, M. M., Habibzadeh, P., Vintzileos, A., Shokouhi, S., Miralles-Wilhelm, F., & Amoroso, A. (2020). Temperature, humidity, and latitude analysis to estimate potential spread and seasonality of coronavirus disease 2019 (COVID-19). *JAMA Network Open*, *3*(6), e2011834–e2011834. https://doi.org/10.1001%2Fjamanetworkopen.2020.11834

Shi, P., Dong, Y., Yan, H., Zhao, C., Li, X., Liu, W., … Xi, S. (2020). Impact of temperature on the dynamics of the COVID-19 outbreak in China. *Science of the Total Environment*, *728*, 138890. https://doi.org/10.1016/j.scitotenv.2020.138890

Sil, A., & Kumar, V. N. (2020). Does weather affect the growth rate of COVID-19, a study to comprehend

transmission dynamics on human health. *Journal of Safety Science and Resilience*, *1*(1), 3–11. https://doi.org/10.1016/j.jnlssr.2020.06.004

Tobías, A., & Molina, T. (2020). Is temperature reducing the transmission of COVID-19? *Environmental Research*, *186*, 109553. https://doi.org/10.1016%2Fj.envres.2020.109553

Tosepu, R., Gunawan, J., Effendy, D. S., Lestari, H., Bahar, H., & Asfian, P. (2020). Correlation between weather and Covid-19 pandemic in Jakarta, Indonesia. *Science of the Total Environment*, *725*, 138436. https://doi.org/10.1016/j.scitotenv.2020.138436

Ujiie, M., Tsuzuki, S., & Ohmagari, N. (2020). Effect of temperature on the infectivity of COVID-19. *International Journal of Infectious Diseases*, *95*, 301–303. https://doi.org/10.1016/j.ijid.2020.04.068

WHO. (2020a). Coronavirus disease (COVID-19). Retrieved April 24, 2022, from https://www.who.int/health-topics/coronavirus#tab=tab_1

WHO. (2020b). COVID-19 - China. Retrieved April 24, 2021, from https://www.who.int/emergencies/disease-outbreak-news/item/2020-DON229