The correlation between lightning and various weather parameters in the Padang monsoon system

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ABSTRACT

The correlation between lightning and several weather parameters (rainfall, humidity, air temperature, and wind) in Padang from 2016 to 2020 was statistically analyzed. Lightning data and weather parameters were obtained from two electric field mills (EFMs) and the meteorology, climatology, and geophysics agency (BMKG), Indonesia. The study results show that the highest lightning occurred in November during the wet season. The correlation coefficient between lightning and rainfall during the wet and dry seasons was 0.52 and 0.26, respectively. Furthermore, the correlation coefficient of lightning with humidity, air temperature, and wind during the wet and dry seasons was 0.25, 0.06, 0.15, and -0.45, 0.25, -0.02, respectively. These results indicate a strong relationship between lightning and rainfall during the wet season; rainfall is the only primary variable in lightning frequency.

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1. INTRODUCTION

Thunderstorms can be very destructive due to heavy rain in a short period, often resulting in flash floods. Lightning activity and precipitation in thunderstorms are related to weather and season changes, such as mixed-phase microphysics involving supercooled droplets, ice, and graupel variations during thunderstorms. Therefore, there is a physical connection between lightning and rain. However, the lightning-rainfall relationship can vary greatly from storm to storm, depending on the location of the storm. Many studies conducted in different geographic areas support a correlation between the temporal evolution of lightning and rain in thunderstorms and similarity in their spatial distribution. In most studied storms, an increase in rainfall generally corresponded to lightning activity [1]-[14]. However, the relationship between the two is inconsistent because rain and lightning depend differently on vertical velocity [15].

In general, Indonesia's climate is influenced by monsoons [16], [17]. The western monsoon in the southern hemisphere of Indonesia is more humid than the eastern monsoon in the eastern hemisphere of Indonesia. Therefore, the distribution of monthly rainfall shows a maximum in the west monsoon and a minimum in the east monsoon. The Indonesian monsoon is part of the East and Southeast Asian monsoons. Local winds can also amplify monsoons, producing abundant amounts of rainfall. The spatial scale of convection precipitation usually depends on the convection cell or the shape of the thunderstorm in the weather system. Moreover, rainfall is strongly influenced by the monsoon circulation system, where wet and dry seasons are experienced in Indonesia. According to Aldrian and Susanto [16], northern Sumatra's (Aceh, North

Sumatra, West Sumatra, and Riau) climate belongs to region B's climate, which is different from the climate of regions A (southern Indonesia) and C (Maluku and northern Sulawesi).

This study aimed to find the characteristic features of the relationship between lightning activities and various weather parameters, i.e., rainfall, humidity, air temperature, and wind, in Padang tropical thunderstorms for sixty months from 2016 to 2020. The climate of region B has two peaks in the rainy season, namely October-November (ON) and March-April-May (MAM), while regions A and C have only one peak in the rainy season. The correlation between lightning and various weather parameters in the Padang monsoon system has not been fully studied.

2. METHOD

Padang is located in region B and has two rainfall peaks, in October-November (ON) and March-May (MAM). These two peaks are associated with the southward and northward movement of the inter-tropical convergence zone (ITCZ) [16]. The present study measured the thunderstorm electric field using two atmospheric electric field mills (EFMs). These two EFMs (A and B) are located on the roof of Universitas Andalas in the foothills of Padang and Kuranji, about 10-12 km from the coast, near the equator. The electric charge contained in a thundercloud generates an electric field. The EFMs can detect nearby lightning and high electric field conditions that precede lightning. They are designed to provide a real-time reading of the electric field in the atmosphere and the lightning source distance [18]. A thunderstorm day is an observational day during which the atmospheric electric field measurement station recorded a thundercloud. Based on our database of thunderstorm days, the EFMs sometimes recorded three thunderclouds in one day. This study also used weather parameters, i.e., rainfall, wind, temperature, and humidity data, from the meteorology, climatology, and geophysics agency (BMKG), Indonesia. BMKG station (C) is about 1 km from the coast, as shown in Figure 1. An example of thunderstorm development is shown in Figure 2. A storm location map and thunderstorm electric field in Padang are displayed in Figures 2(a) and 2(b), respectively.

This study uses the Pearson correlation coefficient to determine the intensity of the linear relationship between two variables (x and y). The measure of the Pearson correlation coefficient between two variables is usually denoted by r, as shown in (1). The value of r is always between +1 and - 1. An r value greater than 0 indicates a positive correlation: if one variable increases, the other variable also increases. Meanwhile, r less than 0 shows a negative correlation: if the value of one variable increases, the other variable decreases. A value of r between -0.1 and -0.3, -0.3 to -0.5, and -0.5 to -1.0, respectively, indicates a weak, moderate, or strong negative correlation coefficient, respectively. On the other hand, an r value between 0.1 and 0.3, 0.3 to 0.5, and 0.5 to 1.0 indicates a weak, moderate, or strong positive correlation coefficient, respectively [10].

$$r = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i-\bar{y})^2}} \quad (1)$$

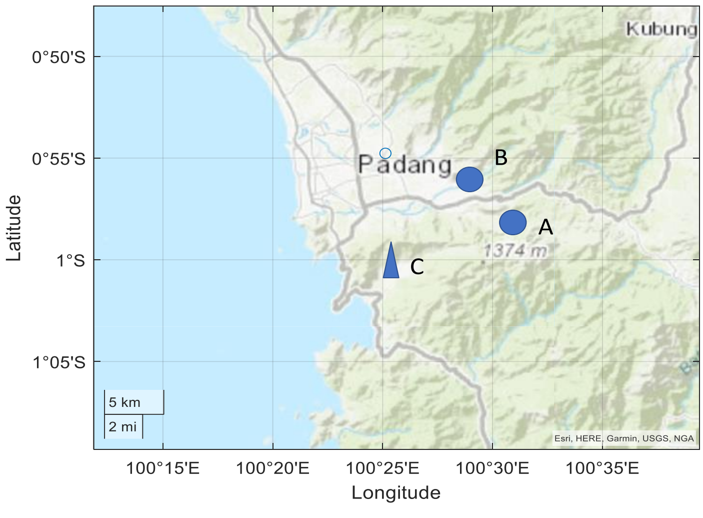
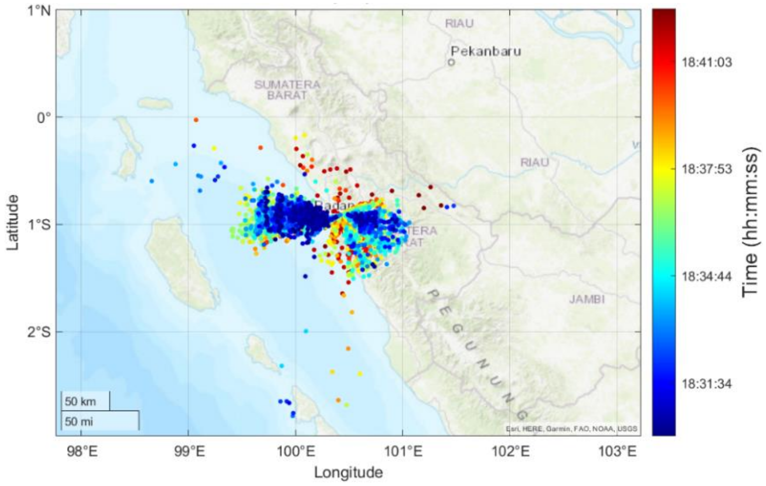
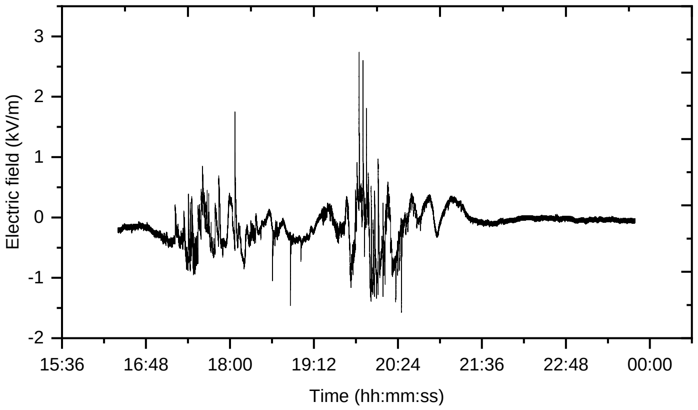


Figure 1. Observation site for lightning activity (A-B) and weather station (C)



(a)



(b)

Figure 2. An example of thunderstorm development: (a) storm location map and (b) atmospheric electric field

3. RESULTS AND DISCUSSION

The EFMs have been operating since 2013 and have recorded much data. However, this paper only reports on Padang tropical thunderstorms and weather data from 2016 to 2020. The EFMs provided data such as the number of lightning and thunderstorm days. Meanwhile, the weather parameters, such as rainfall, humidity, temperature, and wind speed data were provided by the meteorology, climatology, and geophysics agency (BMKG). Table 1 displays the accumulation of the lightning data and the weather parameters. Next, Figure 3 shows thunderstorm day data, ranging from 15 to 24 days/month, where the most thunderstorm days occurred in March from 2016 to 2020. Meanwhile, the rain data also show variations for each month, ranging from 10 to 20 days/month, where the highest rainfall occurred in December. Figure 3 shows that rain is not always followed by lightning. It also indicates thunderstorm days are higher than rainy days in certain months. It probably happens because of the local wind [16], which could be the leading cause of the rain sensor at the BMKG station not detecting rain around the EFM sensors. Furthermore, the total number of lightning flashes varied from 18,180 to 155,764 flashes/month from 2016 to 2020. The highest and lowest number of lightning flashes occurred in November (wet season) and July (dry season), respectively. It can be seen in Figure 4.

3.1. Rainfall

The rainfall data in Table 1 show that the minimum rainfall occurred in February during the dry season, while the maximum rainfall occurred in November during the rainy season. The minimum and maximum recorded rainfall were 202 mm/month and 477 mm/month, respectively. The average number of lightning flashes for days with rainfall can be seen from the histogram in Figure 5. Moreover, the highest number of lightning flashes also occurred in November. Figure 5 indicates that lightning and rainfall had slightly different patterns. Although the peaks of lightning and rainfall occurred in November, as shown in Figure 5, the amount of rainfall does not show a systematic pattern of lightning frequency. The Pearson correlation coefficients were calculated for this period. It was found that there were two positive correlations between monthly rainfall and lightning activity in the wet and dry seasons from 2016 to 2020 as shown in Figure 6. From Figures 6(a) and 6(b), the correlation coefficients (r) for the wet and dry seasons were 0.52 and 0.26, respectively. Figure 6(a) shows a strong positive correlation between lightning and rainfall during the rainy season. On the other hand, the correlation between lightning and rainfall was weak during the dry season, as shown in Figure 6(b). Various studies have shown that the factors that influence lightning-rainfall are: type of thunderstorm, geographic region, local climatology, and convection regime [5], [10], [11], [15]. In general, the lightning-rainfall characteristics in Padang follow the pattern of region B, where region B has two rainfall peaks, namely March-April-May (MAM) and October-November (ON). The peak of lightning and rainfall in November during the wet season may indicate an active monsoon and a measure of the atmospheric conditions, where cloud condensation nuclei (CNN), ice crystals, and graupel particles form in mixed-phase thunderstorms. These particles and strong updrafts contribute significantly to thunderclouds producing high lightning activity. In contrast, low lightning activity during the dry season is due to weaker updrafts [19]-[26].

Table 1. Summary of lightning activities and weather parameters during 2016-2020

Month	Lightning (flash)	Rainfall (mm/month)	Humidity (%)	Temperature range (°C)	Wind speed (m/s)
January	4888 ± 5038.39	293 ± 115.57	80 ± 3.38	19-36	8 ± 4.21
February	8789 ± 12137.55	202 ± 76.04	79 ± 1.26	19-36	6 ± 1.73
March	13331 ± 13010.17	320 ± 103.95	80 ± 1.86	19-35	6 ± 2.49
April	11723 ± 11902.87	295 ± 74.01	82 ± 1.78	19-35	6 ± 1.64
May	18936 ± 17485.68	458 ± 188.68	81 ± 2.60	20-35	6 ± 4.97
June	8884 ± 8136.67	285 ± 127.75	79 ± 1.65	21-35	7 ± 4.38
July	3636 ± 3629.81	249 ± 76.58	80 ± 3.40	19-34	5 ± 0.89
August	23903 ± 35438.51	335 ± 253.06	79 ± 2.62	19-34	6 ± 2.39
September	7353 ± 8012.54	373 ± 185.57	81 ± 2.37	20-34	5 ± 2.07
October	9313 ± 13266.45	445 ± 217.76	81 ± 4.24	20-34	4 ± 0.89
November	31153 ± 51997.65	477 ± 240.39	83 ± 1.24	22-35	10 ± 6.83
December	29999 ± 49870.18	434 ± 138.75	81 ± 3.94	19-35	5 ± 0.84

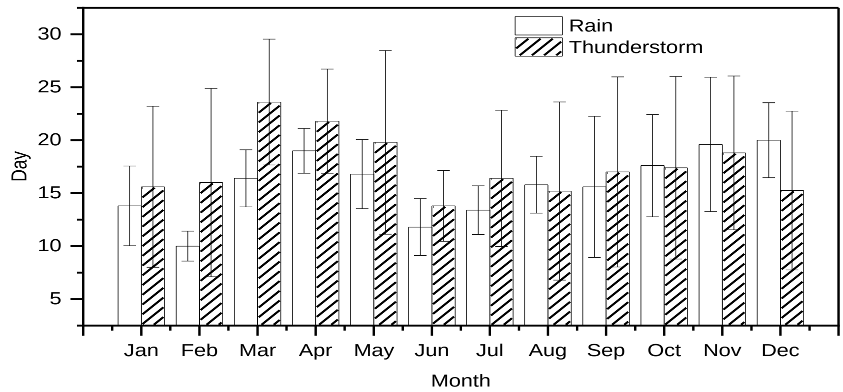


Figure 3. Monthly variation of thunderstorm and rain for five years in Padang

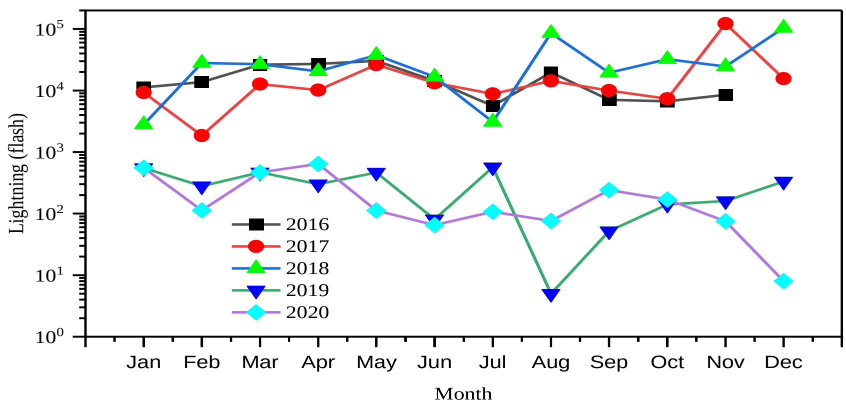


Figure 4. Annual variation of monthly total lightning for five years in Padang

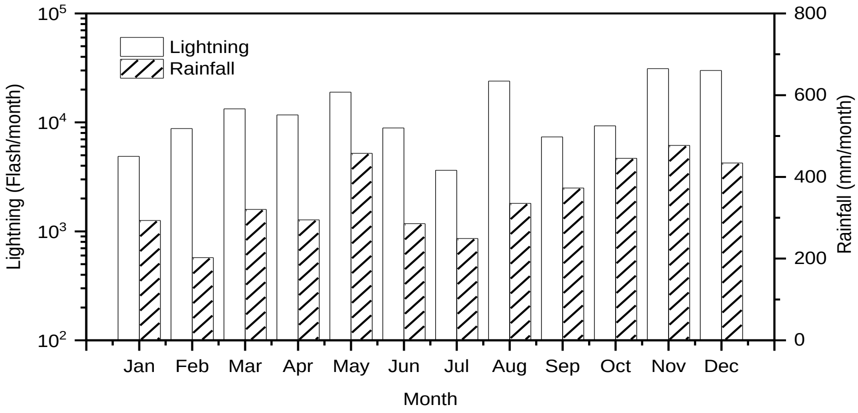


Figure 5. Annual variation of monthly average lightning and rainfall for five years in Padang

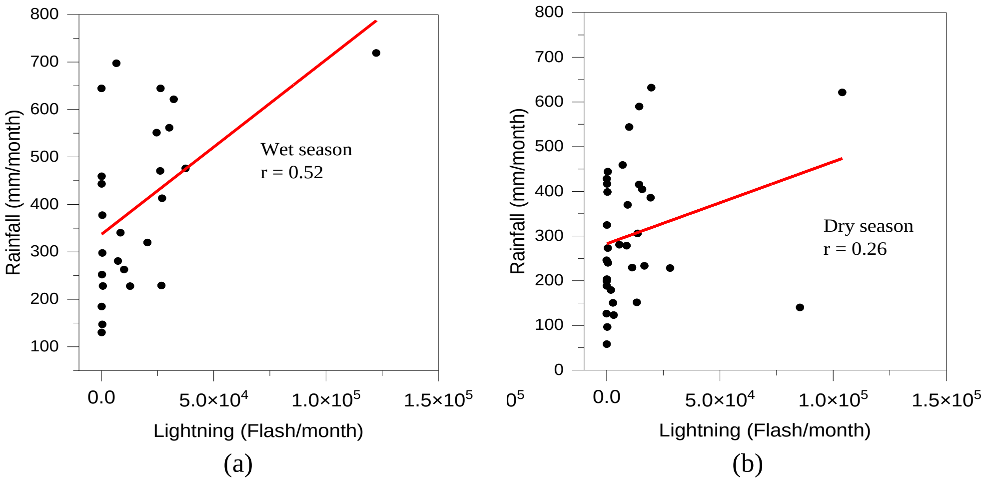


Figure 6. Pearson correlation coefficient of lightning-rainfall during (a) the wet season and (b) the dry season for five years in Padang

3.2. Humidity and temperature

Figure 7 displays the histogram of annual variation of monthly average lightning, humidity, and air temperature. The highest lightning activity and humidity occurred in November. The highest temperature occurred in February. In Table 1, the humidity and temperature ranges were 79-83% and 19-36 ^{o}C, respectively. As mentioned above, peak rainfall occurred in November during the wet season. In relation to the wet season, the wet northwest (NW) monsoon is more humid than the dry southeast (SE) monsoon, so the monthly lightning distribution indicates a maximum in the northwest monsoon. In relation to the dry season, the dry southeast (SE) monsoon is drier than the wet northwest (NW) monsoon, so the dry southeast (SE) monsoon temperature is higher than the wet northwest (NW) monsoon temperature [16]. The correlation between lightning and humidity is shown in Figure 8. It was found that during the wet season, the correlation coefficient (r) was 0.25 as shown in Figure 8(a). This means that the correlation between lightning and humidity is weak. Meanwhile, for the dry season a negative correlation was found in Figure 8(b); its correlation coefficient was -0.45. Furthermore, the correlation between lightning and temperature is shown in Figures 8(c) and 8(d), respectively. It was found that the correlation coefficient (r) during the wet and dry seasons was 0.06 and 0.25, respectively. Figures 8(c) and 8(d) show that the correlation between lightning and temperature is also weak.

3.3. Wind

The wind is the movement of air caused by heat change, for example, between the night and daytime, air over land and sea, or air over valleys and mountains. The difference in heating is the primary driving force of the daily wind system. Wind duration is usually limited and effective only in relatively small areas, so the wind system mainly causes local weather variations [10], [16]. Meanwhile, wind speed is one of the weather parameters caused by air moving from high to low pressure, usually due to temperature changes. In Table 1, the wind speed varied from 4 to 10 m/s, where the highest and lowest wind speeds occurred in November and October, respectively. Figure 9 shows the monthly average lightning-wind speed histogram. The lightning-wind speed correlation is shown in Figure 10. The correlation coefficient (*r*) during the wet and dry seasons was 0.15 and -0.02, respectively as shown in Figures 10(a) and 10(b). This indicates that the correlation between lightning and wind speed is weak.

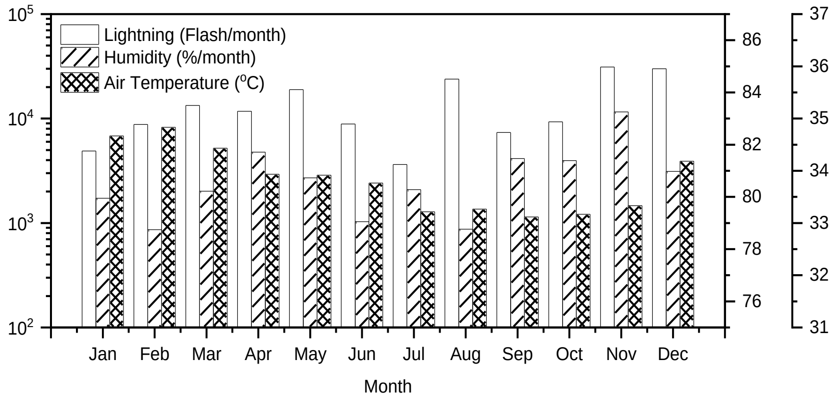


Figure 7. Annual variation of monthly average lightning, humidity, and temperature for five years in Padang

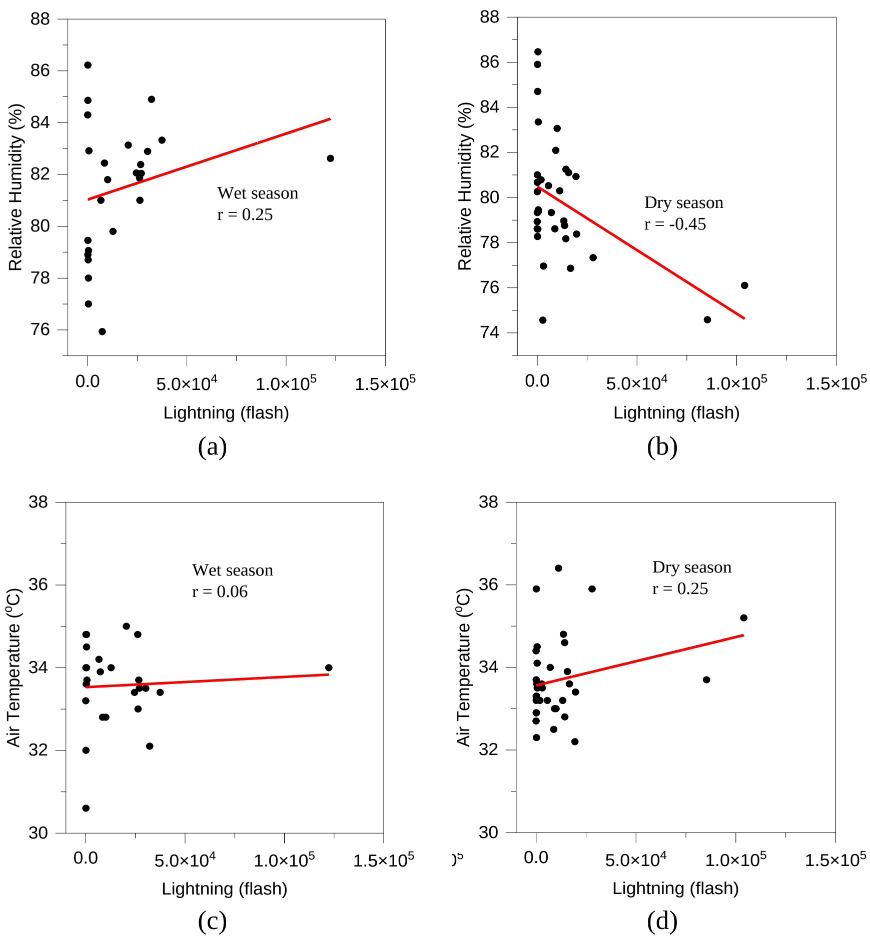


Figure 8. Pearson correlation coefficient of lightning-humidity (a) the wet season and (b) the dry season and lightning-temperature during (c) the wet season and (d) the dry season for five years in Padang

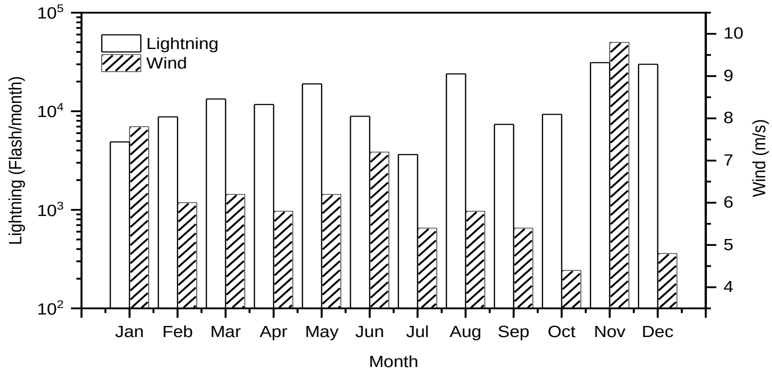
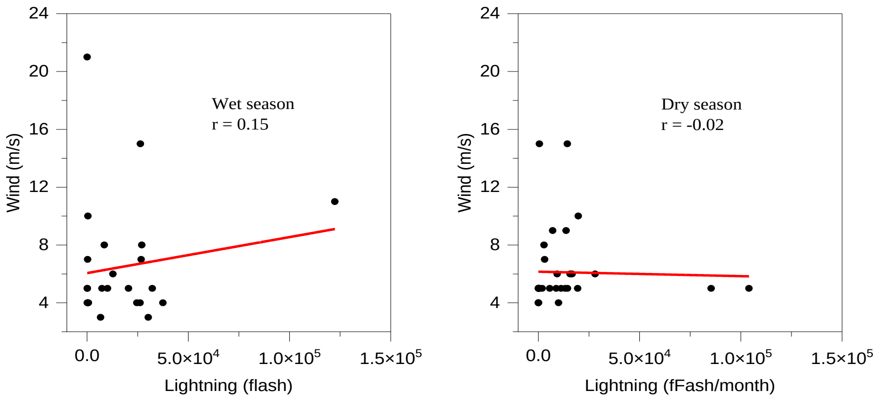


Figure 9. Annual variation of monthly average lightning and wind speed for five years in Padang



(a) (b)

Figure 10. Pearson correlation coefficient of lightning-wind speed during (a) the wet season and (b) the dry season for five years in Padang

4. CONCLUSION

This research was conducted for five consecutive years, from 2016 to 2020. The correlation between lightning and various weather parameters was statistically analyzed during the wet and dry seasons. It was found that the primary variable of lightning frequency is not humidity, temperature, or wind speed but rainfall. There is a slight difference between the lightning and rainfall patterns. The peak of lightning and rainfall occurs in November in the wet season. The amount of rainfall does not show the systematic pattern of lightning frequency. The results show a strong correlation between lightning and rainfall during the wet season. However, this study did not consider cloud-to-ground (CG) lightning, intracloud (IC) lightning, and location (sea-land). Further research is needed to investigate several factors, including lightning type (CG-IC), aerosols, and location (land-sea). More data sets are required for a better understanding of the lightning-rainfall relationship.

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