The Influence of Monsoon Winds on Humidity, Cloud Cover, and Rainfall in Bengkulu City

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Abstract - *The city of Bengkulu, which borders the Indian Ocean, has unique weather and climate. The ENSO phenomenon in 2023 will also strengthen the impact of monsoon winds on weather parameters in Bengkulu City. This research aims to analyze the influence of monsoon winds on air humidity, cloud cover and rainfall in Bengkulu City during 2022-2024. Data including wind speed and direction, humidity, cloud cover, and rainfall, were analyzed using WRPLOT View, ArcGIS, Panoply, and Excel software. The method used is descriptive, quantitative and statistical analysis. The results show that during the Northwest Monsoon (January 2022–2024), the dominant winds are from the northwest and northeast with cloud cover (80%) and the highest rainfall is 449 mm/month and the lowest is 208 mm/month. In Transition Monsoon I (April 2022–2024), the wind direction is from the northwest, the highest humidity is 94%, cloud cover (75%) and rainfall is medium to high. In the Southeast Season (August 2022), the wind direction varies greatly with the highest (95%) and lowest (77%) air humidity and the highest rainfall of 558 mm/month. Meanwhile, August and October 2023 will see a decrease in rainfall, where the rainfall will be 10 – 84 mm/month due to the El Niño phenomenon. Transition Season II (October 2022 and 2024) the wind direction varies greatly, namely from the southeast, northwest and north, rainfall varies from low to high. The highest correlation coefficient for rainfall with humidity was 0.45 at the Bengkulu Climatology Station and the lowest was 0.22 at the Bengkulu University Station. The highest correlation with cloud cover was 0.67 at Tanjung Agung Station and the lowest was 0.53 at Bengkulu Climatology Station.* This study reveals that the northwest monsoon contributes *to high humidity and rainfall, and El Niño will reduce rainfall significantly in 2023. These results indicate that monitoring seasonal winds is very important for predicting hydrometeorological disasters in Bengkulu City.*

Keywords*: Cloud Cover; Humidity; Monsoon Winds; Rainfall*

INTRODUCTION

Monsoon winds are the dominant factor influencing climate variability in Indonesia. This phenomenon occurs due to differences in air pressure between the Asian and Australian continents, which change periodically throughout the year. These changes have a significant impact on weather patterns, including air humidity and rainfall (Haryanto et al., 2020).

Bengkulu City has a very unique weather because it is located in the coastal area of the west coast of Sumatra, directly bordering the western Indian Ocean. This condition causes the air in the Bengkulu region to be relatively hot, with humidity levels ranging from 81% to 91%, maximum wind speeds in the range of 14-19 knots and monthly rainfall ranging from 200-600 mm (Fernalia et al., 2022). Based on the Schmith-Ferguson climate classification, Bengkulu City is classified as a type A climate (very wet) with 10 wet months starting from October to July. This is due to the influence of the monsoon winds carrying water vapor from the Indian Ocean. The increasing intensity of rainfall will cause Bengkulu City to experience frequent flooding (Sitompul et al., 2023).

Global phenomena such as the El Niño-Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), and Madden Julian

Oscillation (MJO) can also affect the climate and weather in Bengkulu City. In addition to the influence of global phenomena, rainfall in Bengkulu is also influenced by the topography of the Bengkulu area (Giarno et al., 2020; Wardani et al., 2023).

Research by Pandia et al., (2019) examined the relationship between monsoon winds and rainfall variations in Central Java using the Asian and Australian monsoon indices (WNPMI and AUSMI). The results showed a strong correlation between zonal wind speed and rainfall, with the largest coefficient value of -0.956. The Asian monsoon winds affect rainfall variability during the rainy season and the Australian monsoon winds affect rainfall variability during the dry season.

However, until now there has not been much research that quantitatively examines the direct relationship between monsoon wind direction and variables of air humidity, cloud cover, and rainfall spatially-temporally, especially in the Bengkulu City area. To analyze wind direction and speed at a particular location, the Wind Rose method is often used as a tool to describe the comparison of winds blowing from various directions (Winaktu & Ingsih, 2022). In addition, the correlation coefficient method is also effective in determining the effect of wind on other weather parameters.

Based on this, the focus of this study is to examine in depth the influence of monsoon winds on air humidity, cloud formation, and rainfall in Bengkulu City. Unlike previous studies that tend to focus on wider areas or use limited meteorological parameters, this study integrates high-resolution multi-station data to measure the seasonal impact of monsoon winds on local climate variables in more detail and spatially-temporally. Thus, this research offers novelty in the approach and scope of analysis that can enrich the understanding of climate dynamics in Bengkulu City.

RESEARCH METHODS

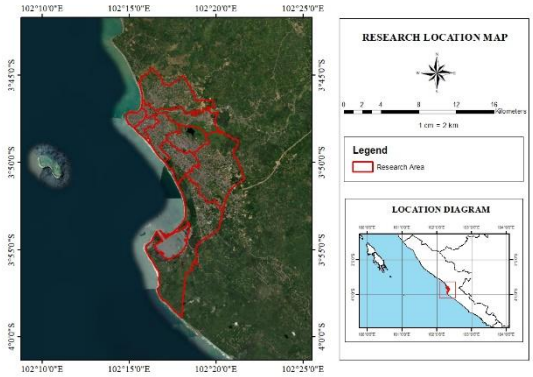

Figure 1. Research Location Map

The research was conducted in Bengkulu City with coordinates 3°45'-3°59' S and 102°14'-102°22' E. The research location map can be seen in Figure 1. The data used include hourly wind speed and direction, daily air humidity, monthly cloud cover, and average monthly rainfall from seven stations (Bengkulu Meteorology, Muara Bangkahulu, Padang Harapan, Sawah Lebar, Tanjung Agung, Bengkulu Climatology, and Bengkulu University) during 2022–2024. Wind, humidity, and rainfall data were obtained from BMKG Bengkulu Climatology, while cloud cover data was downloaded from the NOAA Physical Sciences Laboratory (PSL). The software used in data processing was Microsoft Excel, ArcGis, Panoply, and WRPLOT View.

Descriptive analysis and quantitative analysis are used to identify rainfall, humidity, and wind patterns based on averages over a certain period of time in Bengkulu City. Furthermore, statistical analysis using the correlation coefficient equation is used to determine the relationship between rainfall, air humidity and cloud cover in Bengkulu City.

Data analysis in this study is based on monsoon periodization, with January

(Northwest Monsoon), April (Transitional Monsoon I), August (Southeast Monsoon), and October (Transitional Monsoon II). This division is adjusted to the rainfall pattern in Indonesia (Estiningtyas et al., 2020). The selection of this period aims to describe the variation in atmospheric dynamics that occur in each monsoon phase and how changes in wind direction affect humidity distribution, cloud cover formation, and rainfall intensity in Bengkulu City.

RESULTS AND DISCUSSION

Results

1. Northwest Monsoon

During the northwest monsoon, dominant winds from Asian continent significantly enhance humidity and precipitation, supported by high cloud cover values.

Figure 2a shows the dominant wind direction from the northwest (16%) with a speed of 3.6 – 8.8 m/s and northeast (30%) with a speed of 0.5 – 5.7 m/s. The rainfall map (Figure 2b) shows areas with high rainfall indicated by the orange color on the map. In Figure 2c, the daily humidity in January is the highest at 88% and the lowest at 74%. Figure 2d shows cloud cover of 80%.

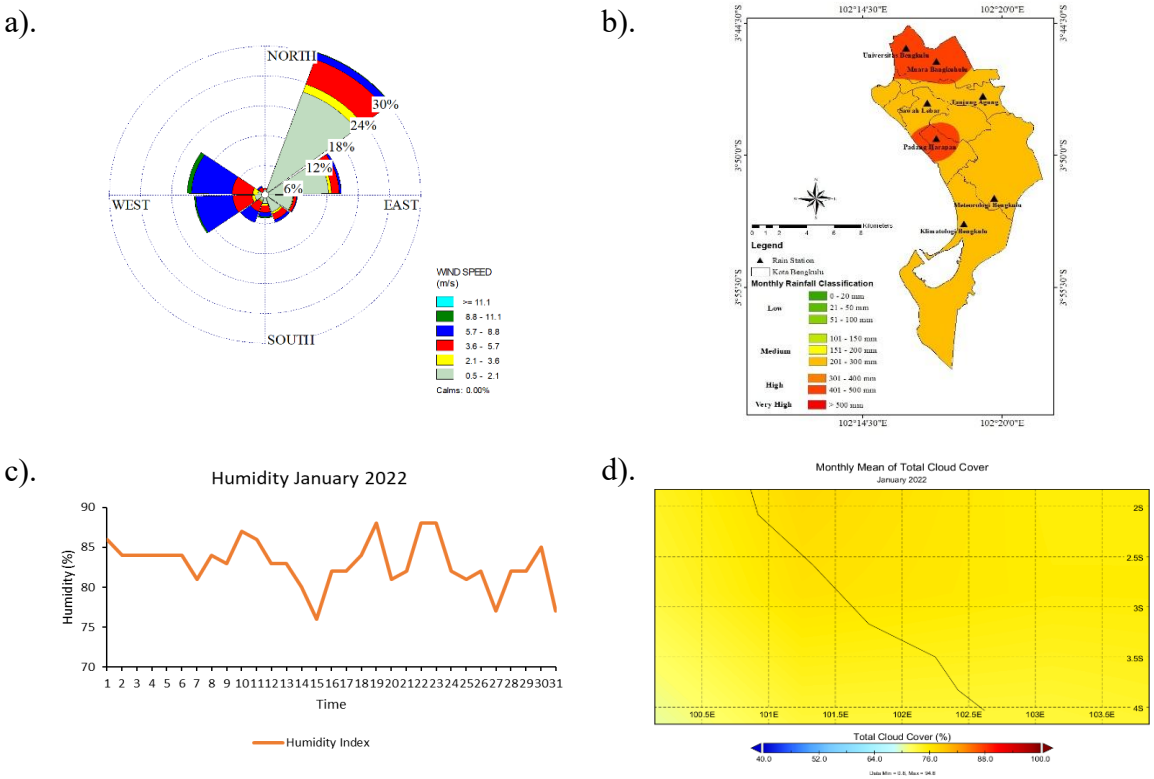

Figure 2. Results of Processing (a) Windrose Graph of Wind Direction and Speed, b) Rainfall Distribution Map, c) Air Humidity, d) Cloud Cover) in January 2022 in Bengkulu City.

Figure 3(a) shows that the dominant wind direction comes from the Northwest (30%) with a speed ranging from 3.6 - 8.8 m/s. High rainfall (Figure 3b). Humidity ranges from 72-95% (Figure 3c). The highest cloud cover intensity (>80%) (Figure 3d). Figure 4 shows that wind direction and speed in January 2024 varied greatly, with dominant directions from the west (20%) and northeast (25%) (Figure 4a). Rainfall variations were high to medium (Figure 4d). The highest humidity was 93% and the lowest was 78% (Figure 2c) with cloud cover ranging (>80%).

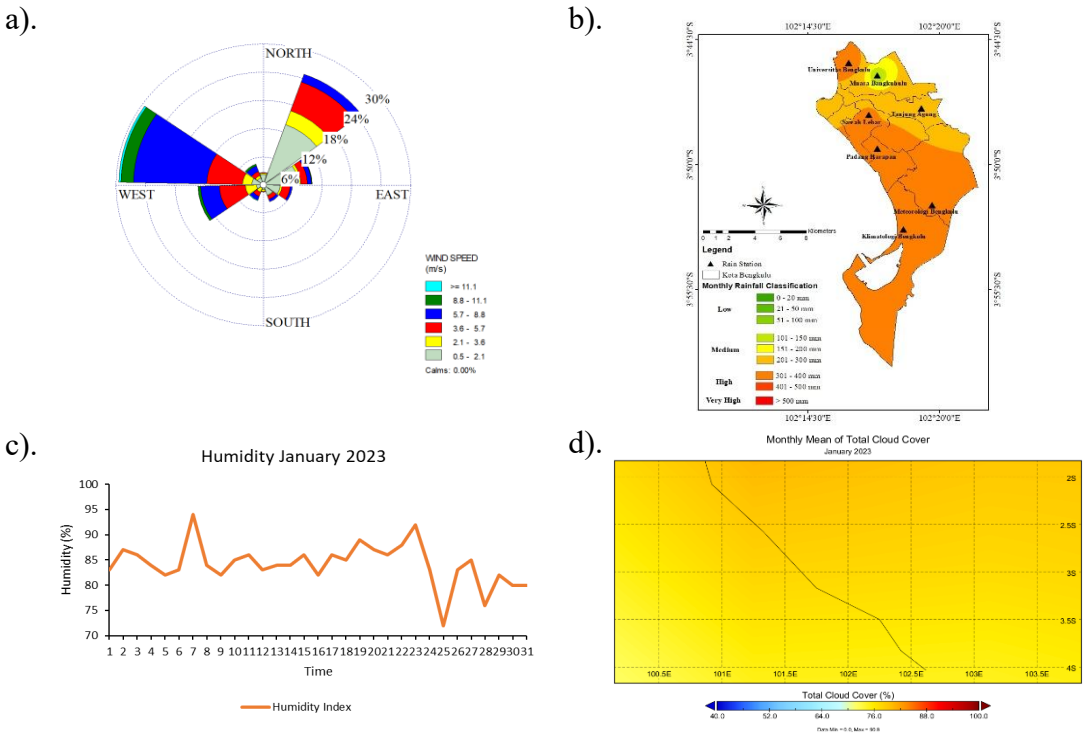

Figure 3. Results of Processing (a) Windrose Graph of Wind Direction and Speed, b) Rainfall Distribution Map, c) Air Humidity, d) Cloud Cover) in January 2023 in Bengkulu City.

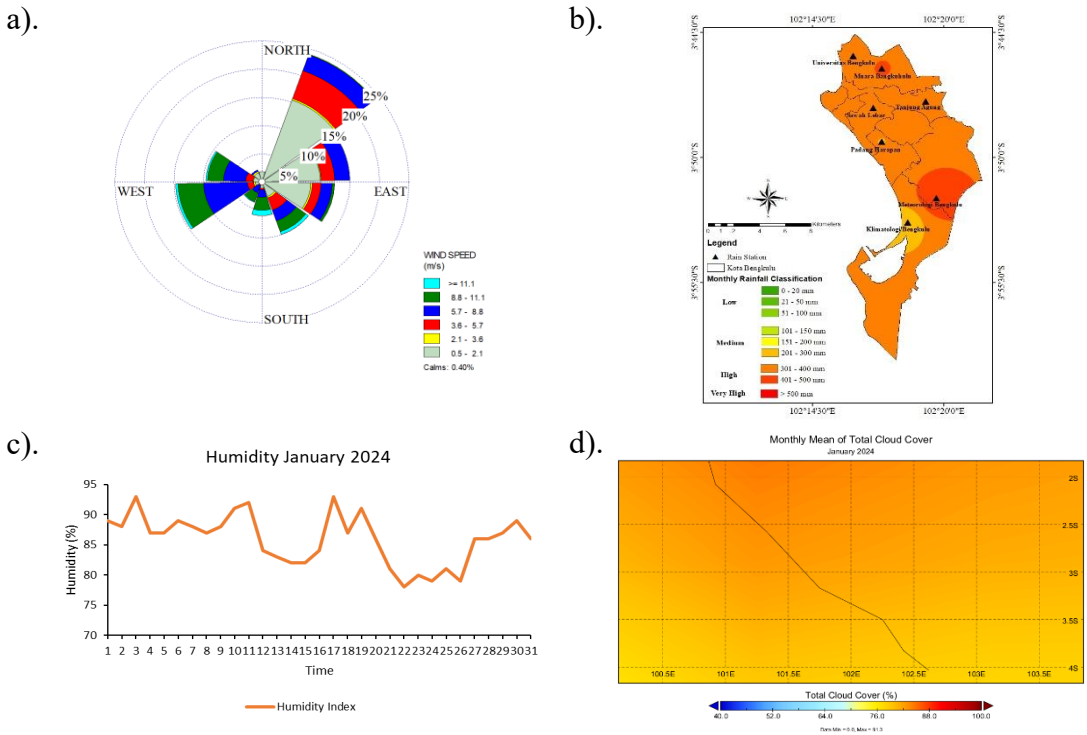

Figure 4. Results of Processing (a) Windrose Graph of Wind Direction and Speed, b) Rainfall Distribution Map, c) Air Humidity, d) Cloud Cover) in January 2024 in Bengkulu City

2. Transitional Monsoon I

During the Transition Monsoon I, dominant winds from the northwest and west contribute to moderate to high rainfall and increased humidity, accompanied by consistently high cloud cover. Figures 5 and 6 show the dominant winds from the northwest (20%) and west (15%), with a speed of 3.6 – 8.8 m/s. The rainfall map shows medium to high rainfall intensity

(orange-yellow). Daily air humidity ranges from 75% to 90%. While the average cloud cover (>70%).

Wind direction and speed (Figure 7a) vary greatly, causing an even distribution of cloud cover (75 – 85%) in Bengkulu City (Figure 7d). This also increases humidity and rainfall. Figure 7b shows that rainfall is moderate to high and evenly distributed in the Bengkulu City area. The highest humidity is 91% and the lowest is 80% (Figure 7c).

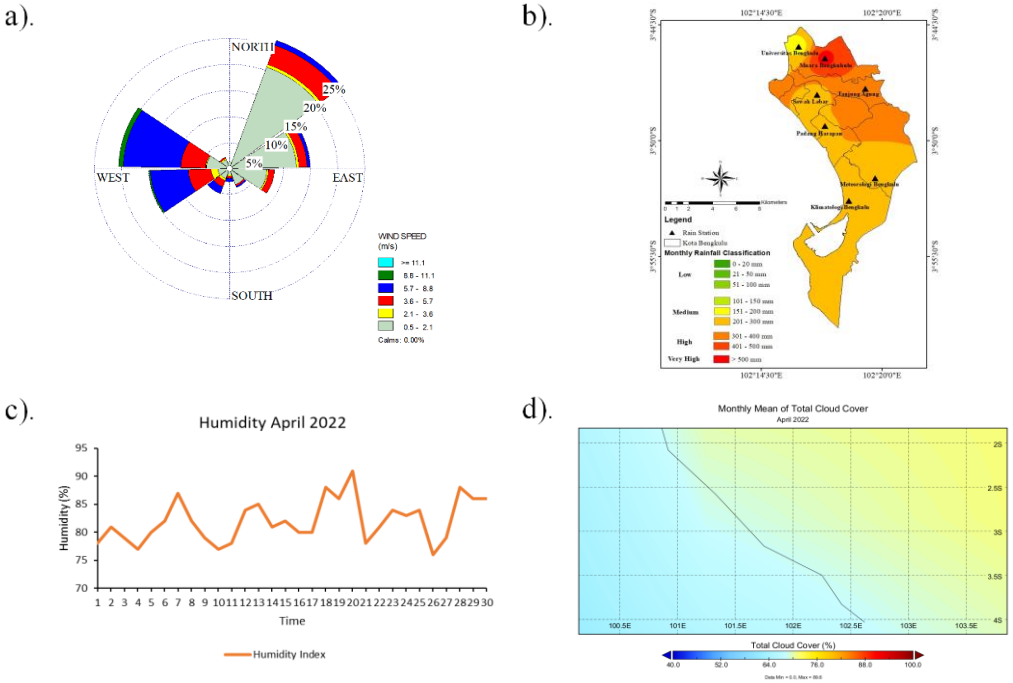

Figure 5. Results of Processing (a) Windrose Graph of Wind Direction and Speed, b) Rainfall Distribution Map, c) Air Humidity, d) Cloud Cover) in April 2022 in Bengkulu City.

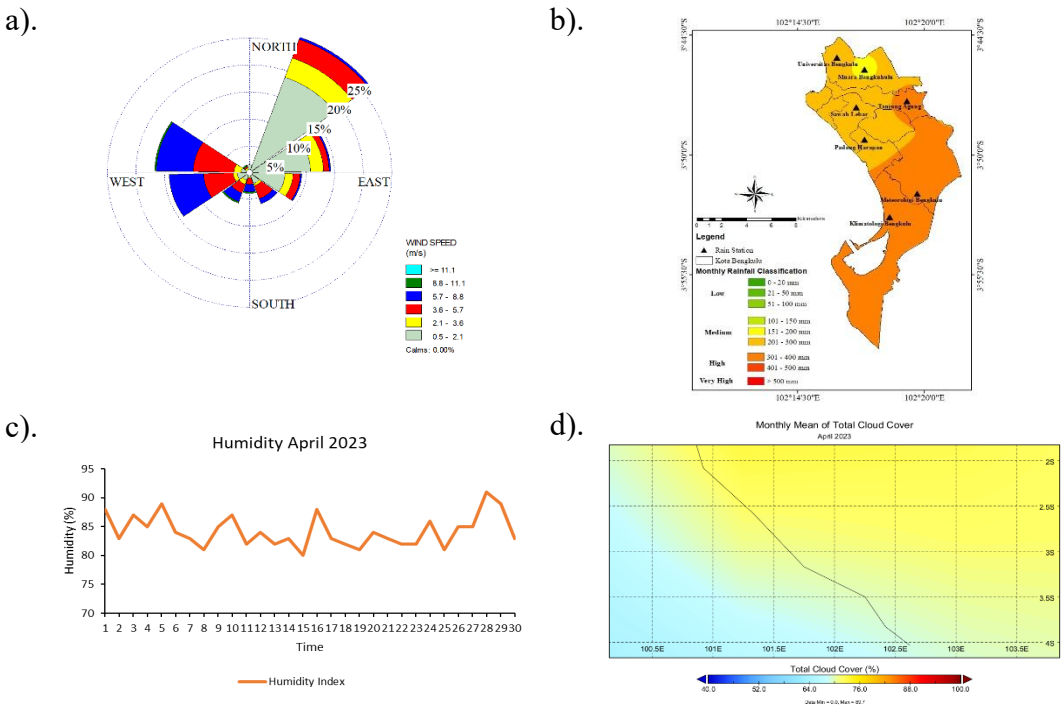

Figure 6. Results of Processing (a) Windrose Graph of Wind Direction and Speed, b) Rainfall Distribution Map, c) Air Humidity, d) Cloud Cover) in April 2023 in Bengkulu City.

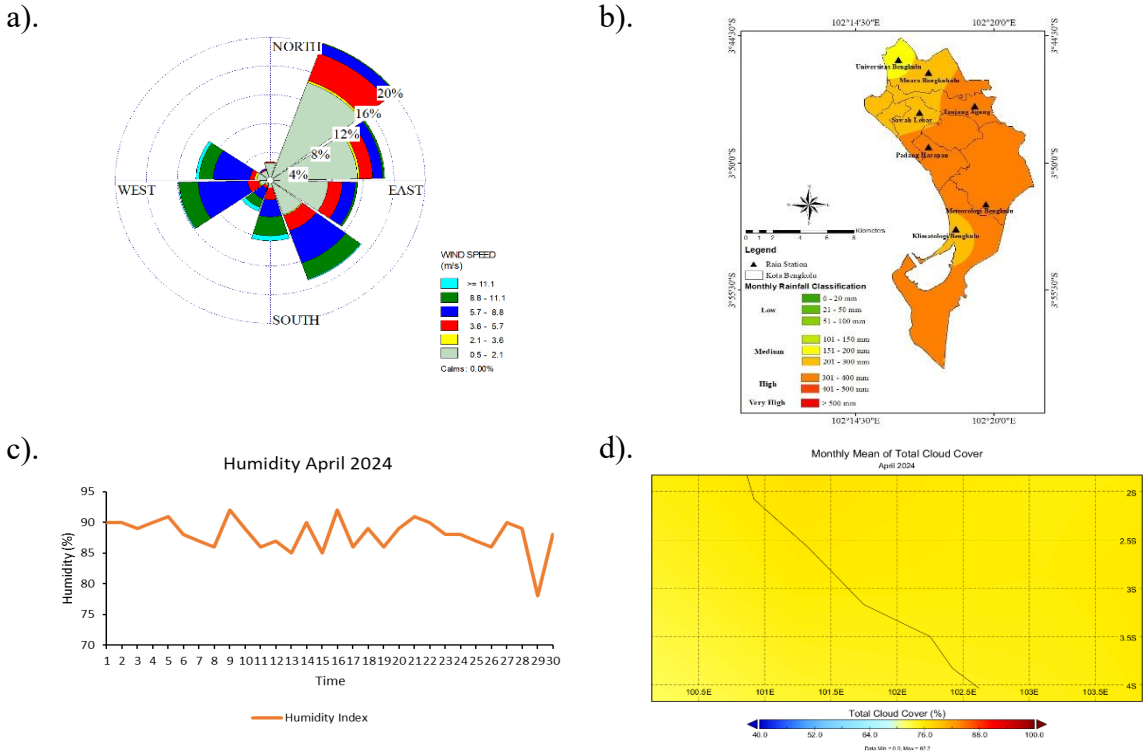

Figure 7. Results of Processing (a) Windrose Graph of Wind Direction and Speed, b) Rainfall Distribution Map, c) Air Humidity, d) Cloud Cover) in April 2024 in Bengkulu City.

3. Southeast Monsoon

Figure 8a shows the wind direction varies, southeast (16%), west and northwest (12%) with a speed of 3.6 - 8.8%, and northeast (20%). This pattern causes an even distribution of cloud cover (Figure 8d) and high to very high rainfall (Figure 8b), with high humidity (75 - 95%) (Figure 8c).

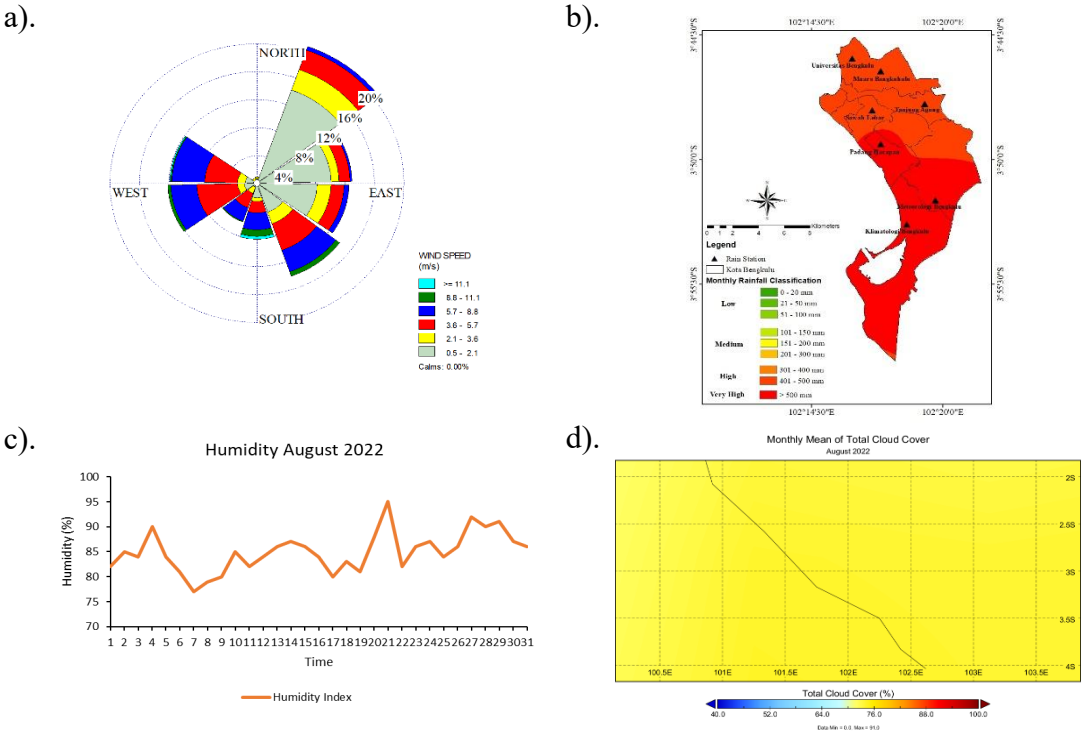

Figure 8. Results of Processing (a) Windrose Graph of Wind Direction and Speed, b) Rainfall Distribution Map, c) Air Humidity, d) Cloud Cover) in August 2022 in Bengkulu City.

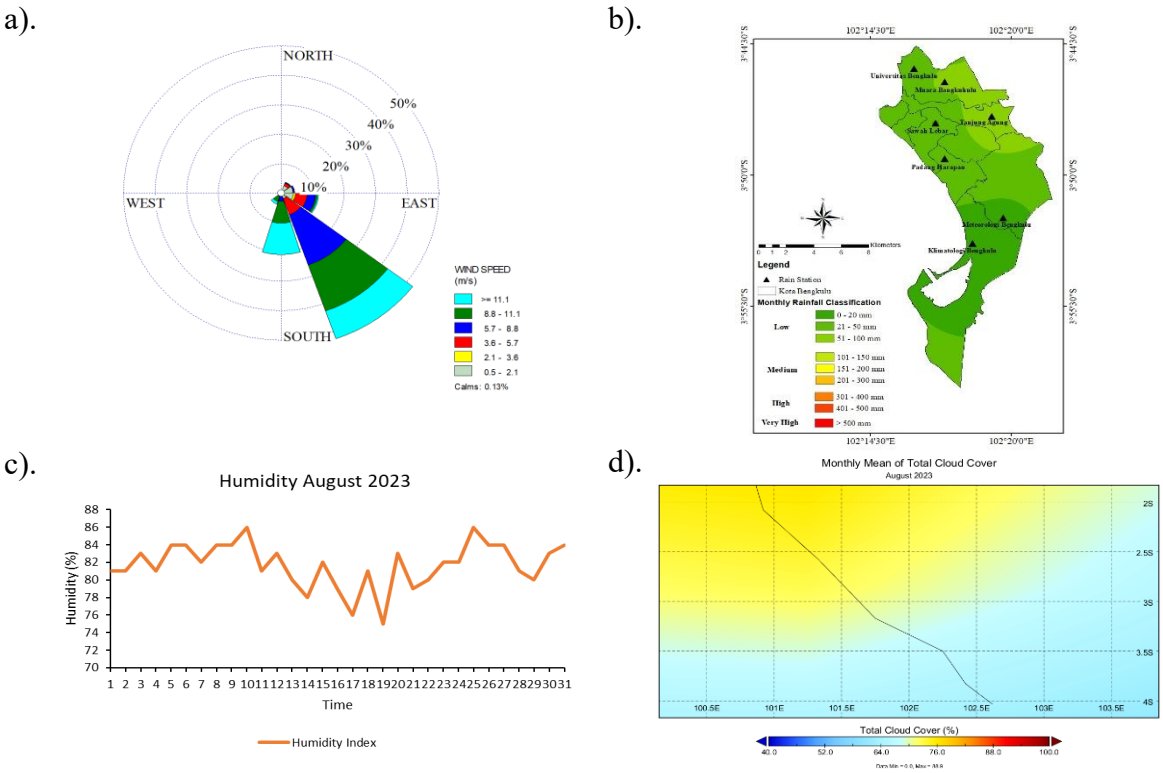

Figure 9. Results of Processing (a) Windrose Graph of Wind Direction and Speed, b) Rainfall Distribution Map, c) Air Humidity, d) Cloud Cover) in August 2023 in Bengkulu City.

In Figures 9 and 10, the dominant wind direction is consistently from the southeast with speeds ranging from 3.6 to 11 m/s. During this period, rainfall is low, while humidity ranges from 75% to 87%. Cloud cover is moderate, varying between 55% and 65%. This suggests that the dominant wind from the southeast is associated with reduced rainfall, moderate humidity, and relatively lower cloud cover.

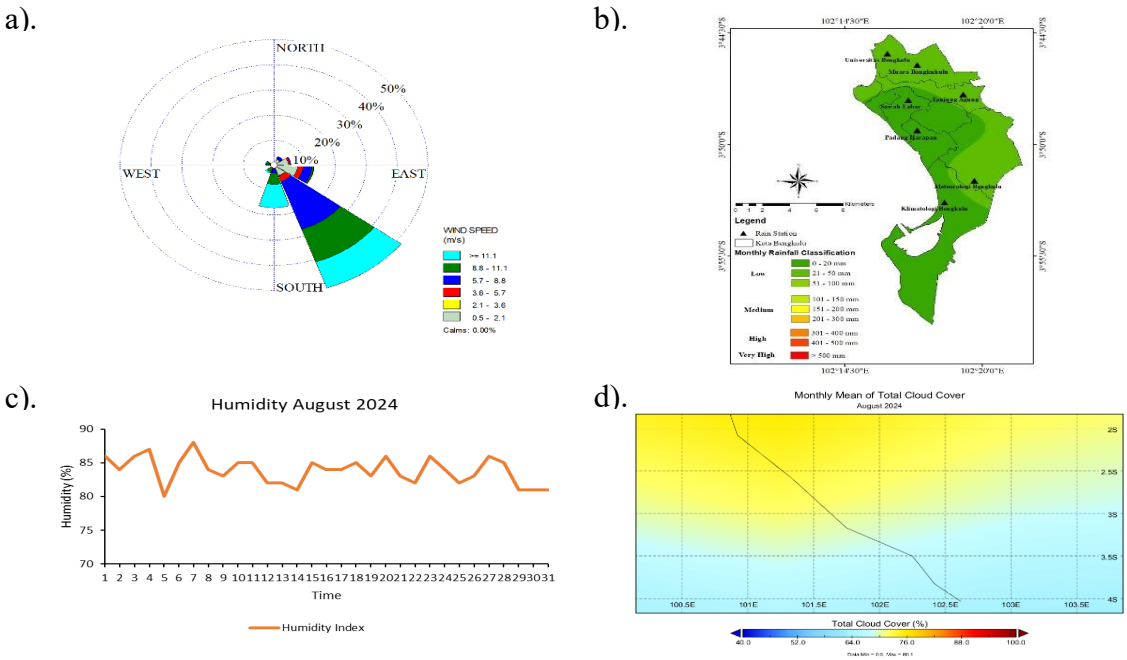

Figure 10. Results of Processing (a) Windrose Graph of Wind Direction and Speed, b) Rainfall Distribution Map, c) Air Humidity, d) Cloud Cover) in August 2024 in Bengkulu City.

4. Transitional Monsoon II

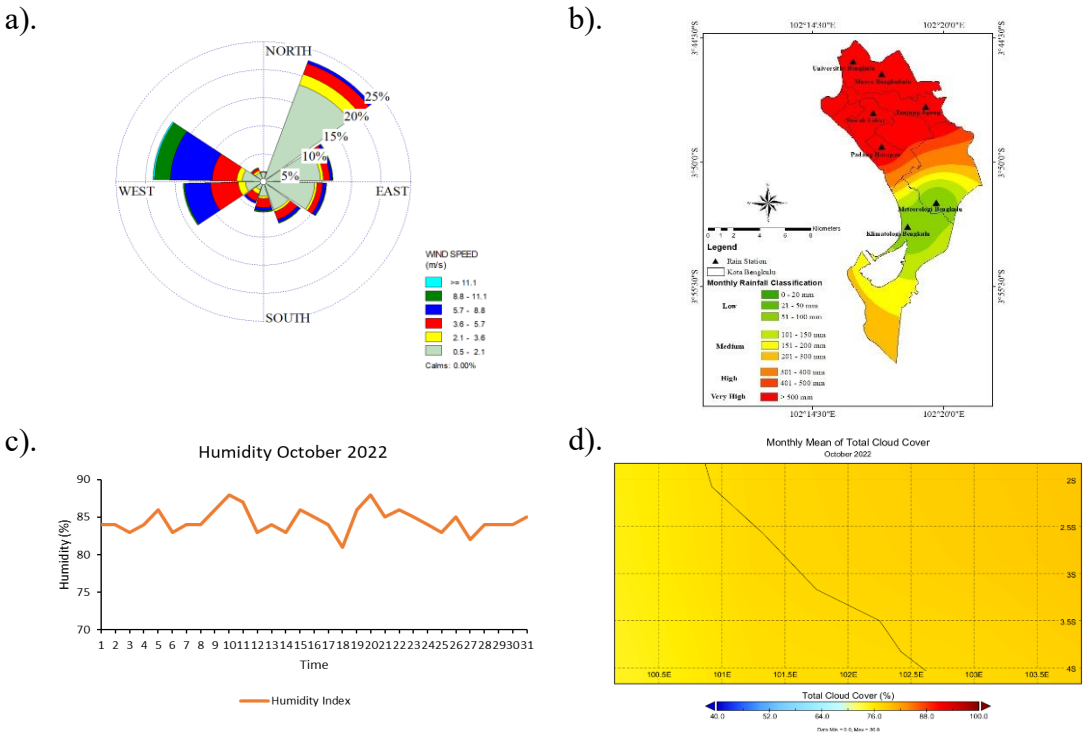

Figure 11. Results of Processing (a) Windrose Graph of Wind Direction and Speed, b) Rainfall Distribution Map, c) Air Humidity, d) Cloud Cover) in October 2022 in Bengkulu City.

Figure 11 shows the dominant wind pattern comes from the northwest (18%), with a wind speed of 2.1 - 8.8 m / s, with rainfall distribution in the Bengkulu region varying from low to high. Areas in North Bengkulu tend to have higher rainfall than the South. Fluctuations in air humidity range from 75% to 90%. The distribution of cloud cover ranges from 75 - 85%.

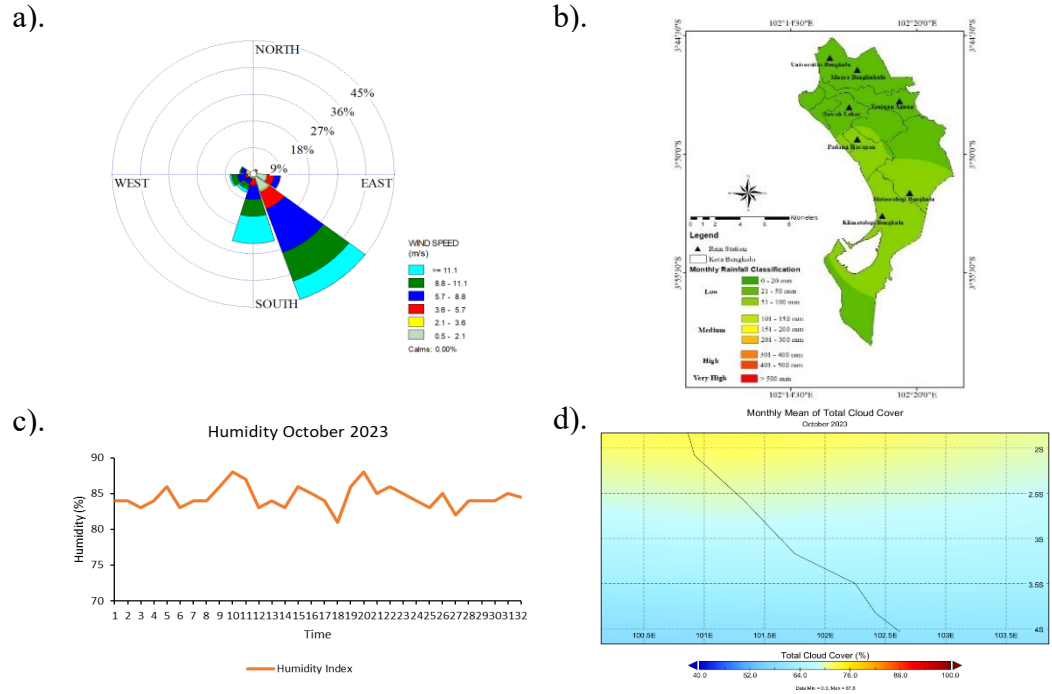

Figure 12. Results of Processing (a) Windrose Graph of Wind Direction and Speed, b) Rainfall Distribution Map, c) Air Humidity, d) Cloud Cover) in October 2023 in Bengkulu City.

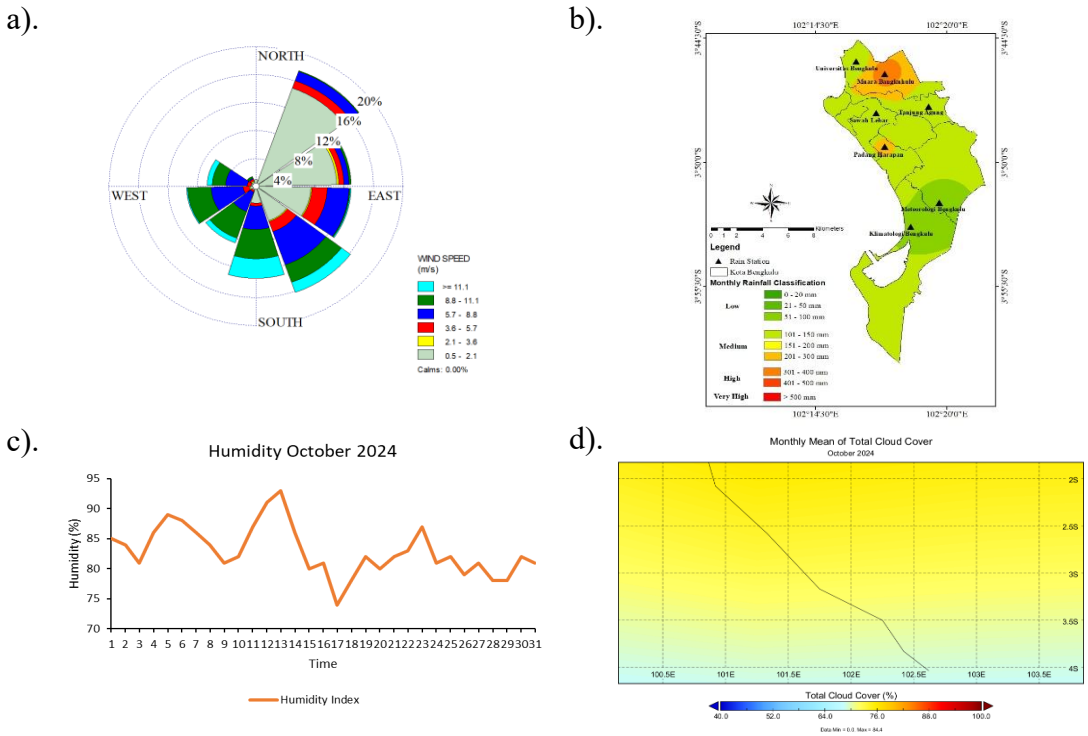

Figure 13. Results of Processing (a) Windrose Graph of Wind Direction and Speed, b) Rainfall Distribution Map, c) Air Humidity, d) Cloud Cover) in October 2024 in Bengkulu City.

Figure 12 shows the dominant wind from the southeast (45%) with a speed of 5.7 - 11 m / s. Low rainfall is 31 - 59 mm / month. The average humidity is 84%. Cloud cover is 60 - 70%.

Figure 13a shows the wind comes from the southeast (16%), north (14%) and west (8%). Medium to high rainfall (Figure 13b). The highest humidity is 93% and the lowest is 74% (Figure 13c). In Figure 13d, the cloud cover in the northern part of Bengkulu City is higher than in the southern part, this is in accordance with the distribution of rainfall.

During the transitional monsoon period II, mixed wind directions from the southeast, north and west correspond to moderate to high rainfall, high humidity and moderate to high cloud cover consistent with the rainfall distribution.

Table 1. Correlation between Rainfall (R) with Air Humidity (AH) and Cloud Cover (CC) in Bengkulu City

Station	Correlation R vs AH	Correlation R vs CC
Meteorologi Bengkulu	0.43	0.55
Muara Bangkahulu	0.25	0.64
Padang Harapan	0.35	0.60
Sawah Lebar	0.36	0.66
Klimatologi Bengkulu	0.45	0.53
Tanjung Agung	0.31	0.67
Universitas Bengkulu	0.22	0.66

Table 1 shows the highest correlation between rainfall and humidity at Bengkulu Climatology Station (0.45) and the lowest at Bengkulu University Station (0.22). The highest correlation between rainfall and cloud cover was at Tanjung Agung Station (0.67) and the lowest at Bengkulu Climatology Station (0.53).

Discussion

Wind speed affects the process of transporting water vapor in the atmosphere. Strong winds can carry water vapor from the sea to land, which is one of the main factors in the formation of cloud cover and rain (Muzaki et al., 2021). In addition, the ITCZ also plays a role in regulating the movement of monsoon winds and the distribution of rainfall in the Indo-Australian region, as well as the migration of the ITCZ to the south during the Heinrich Stadial 1 (HS1) period which caused a decrease in rainfall in Southeast Asia including Sumatra, and increased rainfall occurred in southeastern Africa, the southern Indian Ocean, southern Indonesia, and northern Australia (Lu et al., 2024).

The wind blowing from the west to the northwest is called the Northwest Monsoon. Because it passes through the Indian Ocean and the Pacific Ocean, this wind carries a lot of water vapor, which is the cause of high rainfall in Indonesia, especially in western regions such as Sumatra (Madinah et al., 2025). Air humidity is directly related to rainfall. When humidity is high, the potential for rain also increases because water vapor condenses into rain clouds (Al-Azkia et al., 2019). This can be seen in Figures 2, 3, 4, 5, 6, 7 where in January and April the dominant wind direction is from the West and Northwest, causing medium to high rainfall, the highest humidity is 95% and the lowest is 74%, and an average cloud cover of 80% in Bengkulu City.

Firdaus et al., (2024) detected a rotating wind pattern in the West Indian Ocean of Bengkulu City in the 2022 dry season, this phenomenon is suspected to be a vortex storm that triggers heavy rain. This indicates an atmospheric anomaly that affects weather patterns in the Bengkulu City area observed in Figure 8. This atmospheric anomaly peaked on August 20, 2022, which caused the Bengkulu City area to experience flooding and landslides on August 21, 2022. Based on data recorded at the Fatmawati Bengkulu Meteorological Station, rainfall reached 154.3 mm/day, categorized as "very heavy" according to the BMKG classification (>100 mm/day) (Paski, 2022).

In Figure 9, it can be seen that the dominant wind direction is from the southeast (50%). Low rainfall (10 - 84 mm / month), this rainfall intensity is lower than the average monthly value for the last 5 years (2020 - 2024) from the BMKG Bengkulu Climatology data of 183 mm / month. The influence of the southeast wind on rainfall in Bengkulu is very strong, especially because this wind brings humid air from the Indian Ocean. However, the influence of global phenomena such as the ENSO phenomenon can also affect the intensity of rainfall in the Bengkulu region (Wardani et al., 2023). Based on research by Baharrizky et al., (2024) in 2023 there was an increase in the Nino index of 3.0 ° C throughout the year. Overall, the rainfall anomaly along the Pacific Ocean region in August weakened.

In October 2023 (Figure 12) shows almost the same conditions as August 2023, influenced by global phenomena (Wardani et al., 2023). Low rainfall is 31 – 59 mm/month. The rainfall intensity is far from the monthly average of the last 5 years (296 mm/month). Based on what was published in the BMKG bulletin in the October 2023 edition, ENSO is in the Moderate El Niño phase (+1.57) and Positive Dipole Mode (+2.15). This causes a decrease in rainfall intensity in Bengkulu City.

Table 1 shows the correlation between rainfall and humidity, the highest at Bengkulu Climatology Station (0.45) and the lowest at Bengkulu University Station (0.22). Coastal areas generally have high air humidity due to evaporation from the sea.

However, even though the humidity is high, the rainfall that occurs is not always comparable, because other factors such as sea and land breezes affect the distribution of rain (Kusuma et al., 2024). This can cause a lower correlation between air humidity and rainfall. The correlation between rainfall and cloud cover is highest at Tanjung Agung Station (0.67) and lowest at Bengkulu Climatology Station (0.53). Areas with higher elevations tend to experience high rainfall because clouds containing water vapor are forced to rise when they encounter hills or mountains, leading to condensation and precipitation. This orographic lifting causes the windward side of the terrain to receive abundant rainfall, while the area behind the hills, known as the rain shadow region, experiences significantly lower rainfall due to the blocking effect of the mountains (Houze, 2012; Islami et al., 2024). This causes a closer relationship between cloud cover and rainfall, resulting in a higher correlation value.

CONCLUSION

The results of the study show that monsoon winds have a significant effect on air humidity, cloud cover, and rainfall in Bengkulu City. In the Northwest Monsoon (January 2022-2024), the dominant winds are from the northwest and northeast. Cloud cover is above 80%, the highest humidity is 94% and the lowest is 77%, and the highest rainfall is 449 mm/month and the lowest is 208 mm/month. During Transitional Monsoon I (April 2022-2024), the dominant wind direction is from the northwest, the highest humidity is 95%, cloud cover (75%) and rainfall is classified as medium to high. In the Southeast Monsoon, August 2022, the wind comes from the southeast, northwest and west, the highest humidity (95%) and the lowest (77%) and rainfall is very high reaching 558 mm/month. The El Niño phenomenon was observed in August and October 2023, there was a decrease in rainfall intensity. In Transitional Monsoon II (October 2022 and 2024), variations in wind direction resulted in differences in rainfall, with the northern part of Bengkulu City experiencing moderate to high rainfall, while the southern part was relatively low. The highest correlation coefficient of rainfall with humidity was 0.45 at the Bengkulu Climatology Station and the lowest was 0.22 at the Bengkulu University Station. The highest correlation with cloud cover was 0.67 at Tanjung Agung Station and the lowest was 0.53 at the Bengkulu Climatology Station. This study confirms that monsoon winds and global atmospheric phenomena play an important role in shaping climate dynamics and rainfall distribution in Bengkulu City.

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