The Influence of Wind Direction and Speed on Rainfall in Bengkulu City (2019-2023) Based on the Schmidt-Fergusson and Wind Rose Models

Rika Amelia Agustin[1], Riska Ekawita[1], Supiyati[1*], & Andre Alfando[2]
[1]Physics Study Program, University of Bengkulu, Indonesia
[2]Meteorology, Climatology and Geophysics Agency, Indonesia
*Corresponding author: supiyati_116@unib.ac.id

Received: 17th March 2025; **Accepted**: 20th May 2025; **Published**: 4h June 2025
DOI: https://dx.doi.org/10.29303/jpft.v11i1.8749

Abstract - *Increasingly extreme climate change has increased rainfall intensity and uncertainty of weather patterns in many parts of Indonesia, including Bengkulu City. This phenomenon affects rainfall patterns, the duration of the wet and dry seasons, and wind speed, all of which have an impact on various aspects of life. This study analyzes the effect of wind direction and speed on rainfall in Bengkulu City using the Schmidt-Fergusson, Wind Rose, and Multiple Linear Regression models, based on data from the Fatmawati Soekarno Bengkulu Meteorological Station in 2019-2023. The results of this study indicate that the dominant wind direction comes from the north, northeast, and southeast, with an average speed of 2.47 m/s, categorized as a weak wind according to the Beaufort scale. The highest annual rainfall was recorded in October 2022 at 600 mm. Based on the Schmidt-Fergusson classification, Bengkulu City is included in climate type A with a Q value = 0.1. Regression analysis shows that wind speed has a significant negative effect on rainfall indicating that wind speed has a negative effect, meaning that an increase in wind speed will cause a decrease in rainfall, while humidity has a positive effect, indicating that when air humidity increases, rainfall will also increase. The R^2 value of 32.7% indicates that the wind, temperature, pressure, and humidity variables explain some of the variation in rainfall. This finding emphasizes the importance of monitoring wind elements in the early warning system for extreme weather and supports hydrometeorological disaster risk mitigation planning in coastal areas vulnerable to climate change.*

Keywords*: Wind; Rainfall; Wind Rose; Schmidt-Fergusson Model; Bengkulu City*

INTRODUCTION

Bengkulu City is located on the west coast of Sumatra Island at coordinates 102°14′42″ E to 102°22′45″ E and 3°43′49″ S to 4°01′00″ S, with an area of 539.3 km². This area consists of 151.7 km² of land and 387.6 km² of sea. This city borders directly on the Indian Ocean, so its geographical characteristics are greatly influenced by the dynamics of the ocean's atmosphere (Rifai et al., 2020). Bengkulu Province is an area prone to changes in air pressure that can trigger heavy rain, lightning, and storms. In addition, this condition increases the potential for natural disasters such as floods, landslides, and seasonal droughts (Ummah, 2022).

The increasing intensity and uncertainty of weather patterns due to extreme climate change has affected many regions (Nur et al., 2024). This phenomenon has an impact on rainfall patterns, the duration of the wet and dry seasons, and wind speeds, all of which affect various aspects of life. According to the IPCC report (2021), climate change has caused an increase in global temperatures, changes in wind patterns, and an acceleration of the hydrological cycle. In coastal areas such as Bengkulu City, these changes often exacerbate the risk of natural disasters, especially those related to extreme rainfall and strong winds.

Rainfall

Rainfall is the amount of rainwater that falls on the earth's surface in a certain time unit, which is usually measured in millimeters (mm) per day, month, or year (Rakhmawati, 2024). Rainfall is measured using a device called an ombrometer or rain gauge, which collects rainwater and measures its volume (Febrianty et al., 2023). Rainfall plays an important role in various aspects of life, such as agriculture, water availability, and the potential for natural disasters such as floods (Purify et al., 2024). Factors that influence rainfall include temperature, humidity and movement of air masses (Kahar et al., 2024).

Surface wind is a meteorological element that can change both in terms of wind speed and wind direction (Firrizqi et al., 2023). Wind direction and speed affect the level of rainfall. If the wind blows from the Pacific Ocean or the Indonesian Ocean, then the wind carries high water vapor, thereby increasing rainfall (Simbolon et al, 2022). Meanwhile, wind direction affects the source of water vapor which then leads to the formation of rain patterns in an area (Kaseger et al., 2024). Wind speed and direction at the same height show significant annual cycle variations, influenced by geographic location, type of underlying surface, and differences in climate zones. In coastal areas, the dominant wind direction changes from east to south-southeast (Zhao et al., 2024). Based on the results of previous research, it shows that the wind convergence phenomenon significantly contributes to the formation of extreme rain, especially when the interaction between winds originating from the Indian Ocean and local winds is strengthened by topographic factors in the coastal areas of Bengkulu (Simbolon et al., 2023). The combination of these elements can produce specific rainfall patterns in each region. Research conducted by Angkotasan et al., (2024) shows that wind speed and direction play an important role in determining the intensity and distribution of rainfall in tropical regions.

Although studies on rainfall and the meteorological factors that influence it have been widely conducted in various regions of Indonesia, until now there has been no research that specifically examines the relationship between wind direction and speed and rainfall in Bengkulu City. This indicates a gap or vacuum in the scientific literature, especially those related to local atmospheric dynamics in the coastal areas of the west coast of Sumatra Island. In fact, wind direction and speed are meteorological parameters that play an important role in the process of cloud formation and precipitation distribution, especially in areas influenced by monsoon systems and complex topography such as Bengkulu.

In this study, there are three main approaches used to analyze the relationship between wind direction and speed with rainfall, namely the Wind Rose method, the Schmidt-Ferguson Model, and Multiple Linear Regression.

Therefore, the combination of these methods provides a deeper and more comprehensive understanding in identifying and analyzing the relationship between wind direction and speed to rainfall variations in Bengkulu City. This approach allows for a more accurate study in understanding weather patterns, so that it can be used as a basis for disaster mitigation planning or more effective water resource management.

RESEARCH METHODS

This study uses daily wind and rainfall data from the Fatmawati Soekarno Meteorological Station for the period January 2019 to December 2023. The

following is a diagram of the research flow.

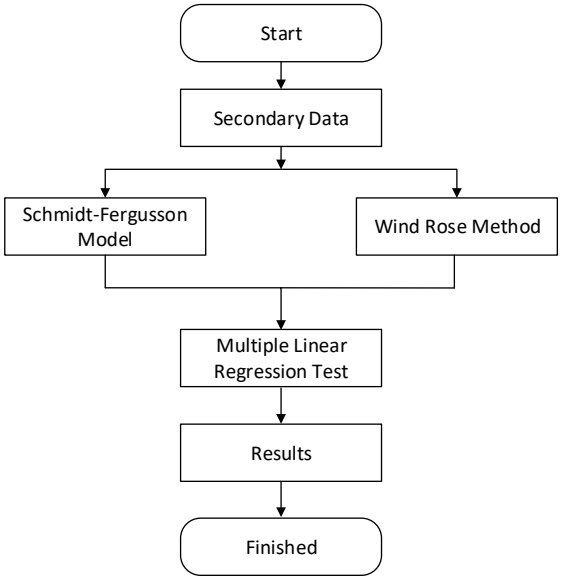

Figure 1. Research Flow Diagram

This study began with the collection of research data, namely rainfall and wind. Rainfall was analyzed using the Schmidt-Ferguson Model, a data-based method that groups the ratio of dry and wet months to study rainfall distribution patterns (Faisol et al., 2022). The first step is to group the months based on rainfall: dry months (maximum 60 mm), moderately wet months (between 60 and 100 mm), and wet months (minimum 100 mm). Next, the Q value is calculated by determining the proportion of wet months (rainfall of at least 100 mm) to the total 12 months. The Q value helps assess the level of climate humidity (Wahyuni, 2024). After obtaining the average value of monthly rainfall intensity each year, the data is then presented in the form of a graph. The processed graph is then analyzed using a descriptive approach to provide an overview of the pattern and variation of rainfall throughout the year.

Furthermore, daily data covering wind direction and speed were analyzed using the Wind Rose method with the help of WRPLOT View software version 8.0.2. WRPLOT View is a program designed for meteorological data processing, allowing users to create wind rose diagrams, analyze frequencies, and present diagrams based on various meteorological data formats (Gunasti et al., 2024).

To determine the influence of wind direction and speed on rainfall in Bengkulu City, a multiple linear regression analysis was carried out which was used to understand the linear relationship between one dependent variable and several independent variables (Fiola et al., 2024). In this study, the dependent variable is rainfall (Y), while the independent variables include temperature (X_1), humidity (X_2), wind velocity (X_3), and air pressure (X_4). The general equation of multiple linear regression can be written as follows:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon \quad (1)$$

Y : Dependent variable (rainfall)
X_1: The first independent variable (temperature)
X_2: Second independent variable (humidity)
X_3: The third independent variable (wind speed)
X_4: The fourth independent variable (air pressure)
B_0: Constant (intercept)
B_1, β_2, β_3, β_4: Regression coefficient for each independent variable
ε: Residual error (prediction error not explained by the model)

RESULTS AND DISCUSSION

Daily data covering wind and rainfall data for the period from January 2019 to December 2023, obtained from the Fatmawati Soekarno Meteorological Station in Bengkulu, provides an in-depth picture of the relationship between these parameters and their influence on weather patterns in Bengkulu City over the past five years. This information is very useful for analyzing climate change in the region, as well as supporting decision-making related to mitigation and adaptation to extreme weather conditions.

A. Wind Rose Method

As shown in Figure 2, wind speed is measured in meters per second (m/s), while

wind direction reflects the distribution of wind from various directions throughout the study period. The pattern of changes in wind direction and speed over time at the location can be visualized using a wind rose diagram. This diagram was created with the help of WRPLOT View software, which allows for a more detailed and accurate analysis of wind distribution, as well as its relationship to rainfall in Bengkulu City.

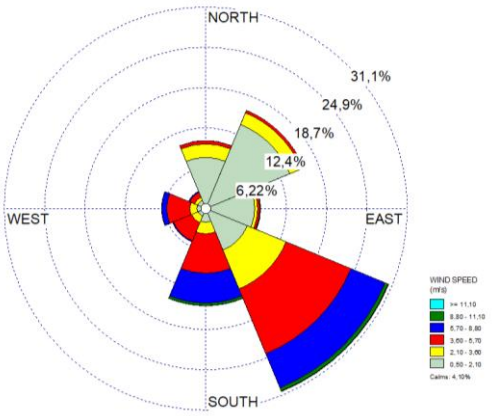

Figure 2. Wind Rose 2019

Based on Figure 2, the most frequent wind direction throughout 2019, the dominant wind blew from the southeast (31.1%). The average wind speed was 3.13 m/s, with most winds in the range of 2.80 - 8.80 m/s. The highest speed was recorded in September (4.70 m/s), while the lowest speed occurred in December (2.22 m/s). On the Beaufort scale, this wind is categorized as a weak wind (Light Breeze).

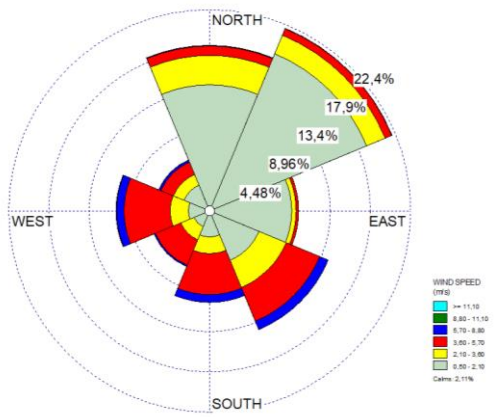

Figure 3. Wind Rose 2020

In Figure 3, the most dominant wind direction comes from the northeast (NE) with the highest percentage of 22.4%. The average annual wind speed is 2.42 m/s. Wind speeds range from 2.25 m/s (November) to 2.83 m/s (September). The month with the highest speed occurs in September (2.83 m/s). The month with the lowest speed occurs in November (2.25 m/s). With an average speed of 2.42 m/s, this wind is classified as Beaufort 2, namely Light Breeze.

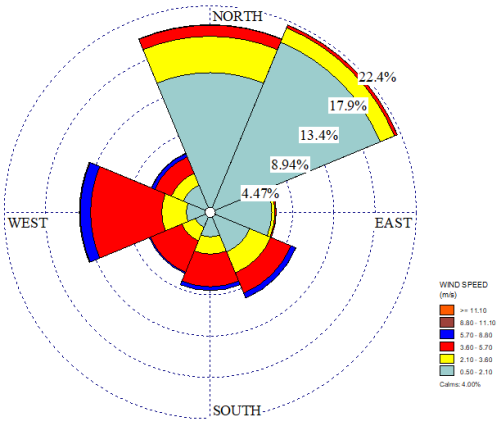

Figure 4. Wind Rose 2021

Based on Figure 4, the Wind Rose method analysis in 2021, the most significant winds came from the northeast (NE) with a percentage of 22.4%. The highest average wind speeds occurred in September and November, while January and August recorded the lowest speeds. The highest calm winds were in October (3.36%) and the lowest in August (2.28%). The average wind speed was quite low (2.37 m/s), but there were several occurrences of stronger winds, especially in the west. On the Beaufort scale, it is included in the weak wind category (Light Breeze).

In Figure 5, throughout 2022, the most frequent winds came from the north (N) with a percentage of 23.2%, followed by the northeast (NNE). The average annual wind speed is 2.21 m/s. Strong winds (>11.10 m/s) only occur in certain months, especially March and April.

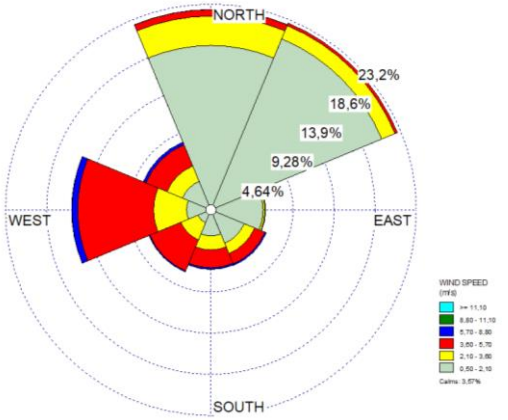

Figure 5. Wind Rose 2022

The average percentage of calm winds is 3%-4%, with the highest value recorded in September (5.42%). In general, wind activity shows a consistent pattern with a dominant direction from the north and moderate wind speeds that are stable throughout the year. With an average speed of 2.42 m/s, this wind is included in the Beaufort 2 category, namely Light Breeze.

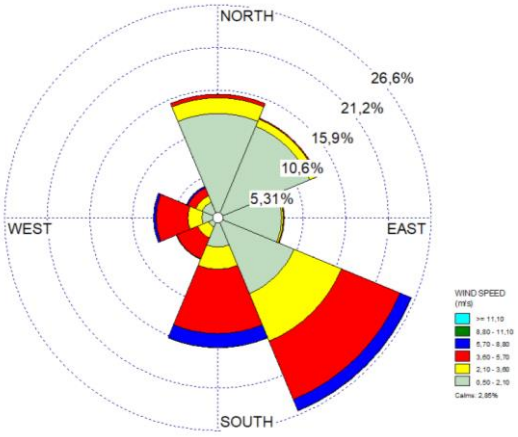

Figure 6. Wind Rose 2023

In Figure 6, the majority of winds blow from the southeast (SE) with a percentage of 26.6%. The average annual wind speed ranges from 2.24 m/s in December to 3.56 m/s in September. The highest percentage of calm winds occurs in November (6.11%), while the most active winds occur in September with a percentage of calm winds of only 0.69%. On the Beaufort scale, it is included in the category of weak winds (Light Breeze).

Schmidt-Fergusson Model

As shown in Figure 7, the annual rainfall amount is plotted in the form of a diagram.

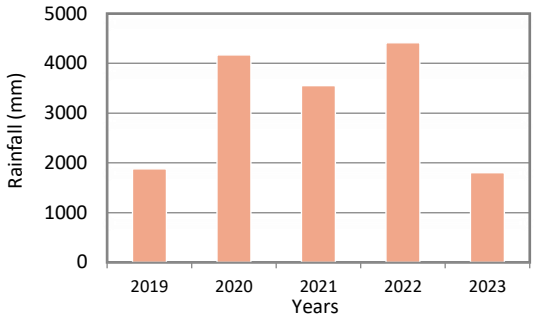

Figure 7. Rainfall Amount 2019-2023

From Figure 7, it can be seen that the volume of rainfall varies each year, where the highest amount was recorded in 2022 with 4415 mm. Meanwhile, the lowest amount of rainfall occurred in 2023 with 1800 mm. Based on rainfall data for 2022, October recorded the highest rainfall with an amount reaching 623 mm. In 2023, the dry months occurred in August, September and October. The humid months occurred in May, June and December. The highest rainfall occurred in April.

Table 1. Rainfall Characteristics

Year	Rainfall Characteristics	
	Wet month	Dry month
2019	9	3
2020	12	0
2021	12	0
2022	12	0
2023	9	3
Average	10,8	1,2
Q Value	0,1	
Type	A	
Characteristic	Very Wet	

Table 1 shows the characteristics of rainfall in Bengkulu City, which is included in the category of type A rainfall with the characteristic of "Very Wet" with a Q value obtained of 0.1.

B. Multiple Linear Regression

The regression results of wind speed, temperature, air humidity, air pressure on rainfall can be seen in table 2.

Table 2. Multiple Linear Regression Analysis

	Coeff.	Std. Error	t Stat	P-value
Intercept	21480,301	24727,612	0,869	0,389
Wind velocity	-86,421	32,506	-2,659	0,010
Temperature	-114,024	40,206	-2,836	0,006
Humidity	18,011	12,500	1,441	0,155
Air pressure	-19,130	24,854	-0,770	0,445

Table 3. Results of Determination Test (R^2)

Regression Statistics	
Multiple R	0.572591548
R Square	0.32786108
Adjusted R Square	0.27897825
Standard Error	132.7665639
Observations	60

In Table 2, the multiple linear regression equation is obtained, namely Y = 21480.301 - 86.421X1 - 114.024X2 + 18.011X3 - 19.130X4. Based on the regression equation, it is known that air humidity (X3) has a positive regression coefficient on rainfall (Y). This indicates that when air humidity increases, rainfall will also increase.

Based on Table 3, the R value is 0.572 which indicates that the relationship between air pressure, air humidity, wind speed, and air temperature to rainfall in Bengkulu City reaches 57.2%, so it can be categorized as a fairly close relationship. Meanwhile, the R Square value of 0.327 or 32.7%, indicates that the variables of air pressure, air humidity, wind speed, and air temperature are able to explain 32.7% of the factors that affect rainfall in Bengkulu City, while 67.3% is influenced by other factors.

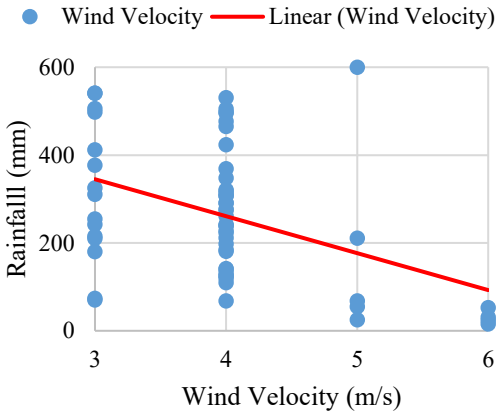

Figure 8. Scatter Plot of Wind Speed and Rainfall Regression

Based on Figure 8, the decreasing trend line indicates that the higher the wind speed, the lower the rainfall. The negative coefficient for wind speed (-86.421, p = 0.010) indicates that strong winds can disperse water vapor before it condenses, or increase the evaporation rate, which causes lower rainfall. This is in accordance with the research of Simbolon et al. (2022) in the Tangerang Regency area which noted that if the wind speed increases, rainfall will decrease.

Based on the results obtained, the wind that most often occurred in 2019 blew from the southeast (SE) with an average rainfall exceeding 100 mm, reaching 157 mm, which is classified as wet. The highest rainfall was recorded at 348 mm in January, while the maximum wind speed ranged from 8.8 to 11.1 m/s. In 2020, the most significant wind blew from the northeast (NE), with an average rainfall of 348 mm. The peak rainfall occurred in November, reaching 541 mm, and the maximum wind speed exceeded 11.10 m/s. In 2021, the wind from the northeast (NE) blew hard with an average rainfall of 296 mm, which is still included in the wet category. The highest rainfall was recorded in January, reaching 505 mm, while the maximum wind speed ranged from 8.8 to 11.1 m/s.

Meanwhile, in 2022, the dominant wind direction comes from the north (N), with an average rainfall reaching 368 mm, which is categorized as “high” rainfall. The highest rainfall occurs in October (600 mm) and the maximum wind speed ranges from 8.80 to 11.10 m/s. In 2023, the most significant wind blows from the southeast (SE) with an average rainfall of 150 mm, the highest rainfall occurs in April reaching 325 mm, while the maximum wind speed ranges from 8.80 to 11.10 m/s.

CONCLUSION

Based on the research results, it can be concluded that in 2019, 2020, 2021, 2022 and 2023 the dominant winds that occurred in Bengkulu City blew from the southeast (SE) and northeast (NE) with an average speed of 2.47 m/s. The rainfall pattern in Bengkulu City is included in category A (Very Wet) with a Q value of 0.1. The highest rainfall was recorded in October 2022, reaching 600 mm. Wind speed has a negative effect on rainfall. This means that the higher the wind speed, the rainfall will decrease.

Further studies can be conducted by combining mesoscale atmospheric modeling to verify the causal mechanisms behind wind-rainfall interactions in coastal microclimates.

ACKNOWLEDGMENT

Thanks to the Fatmawati Soekarno Bengkulu Meteorological Station for providing secondary data in this study.

REFERENCES

Angkotasan, M. A., Bemba, J., Tawari, R. H., & Natih, N. M. (2024). Hydro-oceanographic features of North Maluku archipelagic waters in January and July 2021. *Jurnal Sains Akuatik Indonesia*, 8(3), 269. https://doi.org/10.46252/jsai-fpik-unipa.2024.vol.8.no.3.269

Faisol, A., Paga, B. O., & Edowai, D. N. (2022). Schmidt–Ferguson climate zone update through utilization of Climate Hazards Group Infrared Precipitation With Stations data to support agricultural development in West Papua Province. *Proceedings of the National Seminar on Agricultural Development and Vocational Education*, 3(1), 546–556. https://doi.org/10.47687/snppvp.v3i1.338

Febrianty, D., Permana, M. A. B., & Pratama, A. P. (2023). Testing of rainfall data and surface air pressure from parallel observations from automatic and conventional instruments at the Banten Climatology Station. *Journal of Climatology*, 4, 34–42.

Fiola, E., Yulius, F., Mutia Risani, D., Alvionita, M., & Dwi Irawati, F. (n.d.). Variable selection method in linear regression modeling of rainfall data in Lampung Province. *National Seminar on Data Science*, 2024.

Firrizqi, I., Ilahi, N., Kajian, D., Arah, P., Permukaan, A., Tinggi, S., & Sekolah, G. (2023). Comparative study of surface wind direction on weather and climate elements in coastal and highland areas (case study: Soekarno-Hatta Meteorological Station and Citeko Meteorological Station). *Journal of Science and Physics Education*, 19, 1–12.

Gunasti, A., Wicaksana, K. A., Putri, T. G., Rozikin, A., Ridha, M., & Putra, A. (2024). Comparison of wind data using the Windrose method in Probolinggo City and Banyuwangi City with Independent Sample T-Test. *Jurnal Climate and Environmental Research*, 8(1). http://ojs.uma.ac.id/index.php/jcebt

Kahar, F. P., Abidin, K., & Ilham, R. (2024). Analysis of rainfall intensity levels, air pressure and air temperature in the Paotere Makassar area during the period of 2022. *Journal of Physical*

Science, 4.

Nur, I. T., Ullum, H., Fitria, A., & Widodo, W. (2024). Variation of El Niño–Southern Oscillation (ENSO) data analysis results on global climate. *Journal of Global Climate*, 2.

Purify, A., Teknik Elektronika Pertahanan, P., Militer, A., Kusman, A., Widodo, S., & Silitonga, F. (2024). Climate change and national security risks: A study of Indonesia's defense preparedness. *Journal of National Security*, 12(1).

Rakhmawati, G. (2024). Analysis of rainfall intensity and IDF (Intensity-Duration-Frequency) curve of Mononobe method in Salatiga City. *Journal of Engineering Science,* 3(3). https://salatigakota.bps.go.id/id

Rifai, A., Rochaddi, B., Fadika, U., Marwoto, J., & Setiyono, H. (2020). Study of the influence of monsoon winds on the distribution of sea surface temperatures (case study: Pangandaran Waters, West Java). *Indonesian Journal of Oceanography*, 2(1), 98–104. https://doi.org/10.14710/ijoce.v2i1.7499

Simbolon, C. D. L., Ruhiat, Y., & Saefullah, A. (2022). Analysis of Wind Direction and Speed on Rainfall Distribution in Tangerang Regency. Journal of Physics Theory and Applications, 10(01), 113–114.

Simbolon, M. (2023). Analisis Pengaruh Variabel Penduga Cuaca Ekstrem di Kota Bengkulu dengan Menggunakan Statistical Product and Service Solutions (SPSS). *Newton-Maxwell Journal of Physics*, *4*(2), 48–55. https://doi.org/10.33369/nmj.v4i2.24926

Ummah, M. S. (2022). Annual report: Atmospheric dynamics in Indonesia. Sustainability (Switzerland), 11(1), 1–14. Retrieved from http://scioteca.caf.com/bitstream/handle/123456789/1091/red2017-eng-8ene.pdf?sequence=12&isallowed=y

Wahyuni, M. (2024). Rainfall analysis and climate type classification using Schmidt-Ferguson method (case study: Lake Tempe). *Civil Engineering Media Journal*, 2.

Zhao, L., Wang, C., Jiang, Y., & Xu, J. (2024). Research on the characteristics of wind speed, wind direction, and wind profile based on ERA5 reanalysis data. *Aerospace Traffic and Safety*, 1(2–4), 131–140. https://doi.org/10.1016/j.aets.2024.12.007