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Research Article

Rainfall Conditions When Maden Julian Oscillation Strong and Weak in Jakarta, Bogor, and Tangerang

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Abstract: The Indonesian Maritime Continent has high rainfall variability with one of the causes, namely the *Madden Julian Oscillation* (MJO), especially in phases 3, 4, and 5. *Madden Julian Oscillation* (MJO) and rainfall have a correlation with one another. Therefore, this study aims to determine the effect of MJO on rainfall conditions in terms of intensity and frequency of occurrence every three months from 2013-2022 in Jakarta, Bogor, and Tangerang. The research method used is descriptive statistical analysis in the form of quarterly rainfall averages and anomalies as well as the Pearson correlation test. The data used is daily rainfall data for the 2013-2022 period. The results of the descriptive analysis show that the highest average rainfall occurs in the December-January-February (DJF) period and the lowest is in the June-July-August (JJA) period with the anomalies occurring in the December-January-February (DJF) and June-July-August (JJA) periods. On the other hand, the lowest frequency of strong and weak MJO events occurs during June-July-August (JJA), while the highest occurs during the December-January-February (DJF) period. The correlation test conducted between *the Madden Julian Oscillation* (MJO) and rainfall found that the highest positive correlation value was 0.197073 on March-April-May (MAM) and the highest negative correlation on September-October-November (SON) was -0.11866, so the relationship is weak.

Keywords: *Madden Julian Oscillation* (MJO), Real-time Multivariate (RMM) index, rainfall, correlation test

Introduction

The Indonesian Maritime Continent (IMC) has high rainfall variability. Many factors affect the variability of rainfall in BMI. The main factors include the Asian and Australian monsoons [1], El Nino Southern Oscillation [2]–[4]. One of these phenomena is the MJO.

Madden Julian Oscillation (MJO) is an intraseasonal oscillation or wave that occurs in the tropics and has a period of about 30 to 60 days and produces variations in several atmospheric and oceanic parameters which include cloudiness, wind speed and direction, sea surface temperature (SST*)*, precipitation rain and evaporation of sea level [5]. This MJO moves from west to east and occurs along the equator [5], [6].

The MJO determination uses *the All Season Realtime Multivariate MJO* (RMM) Index which is derived using the *Empirical Orthogonal Functions* (EOFs) method from wind parameters at an altitude of 850 hPa and 200 hPa and *Outgoing Longwave Radiation* (OLR). Weak MJO is characterized by an RMM amplitude value of less than one, while a strong MJO is characterized by an amplitude value of more than equal to one [7].

The MJO phase and amplitude in general can increase rainfall in the Indonesian region as it spreads from the Indian Ocean to the east [8]. In another study conducted by Peatman et al (2014), when the MJO was in phases 3, 4, and 5, there was an increase in the amount of rainfall above normal due to an overall positive rainfall anomaly in Indonesia.

In Indonesia, studies on MJO and rainfall have been conducted previously, for example in the Ngurah Rai region by Wendel Jan Pattipeilohy et al. The results showed that the percentage of positive rainfall anomalies was dominant during the MJO phase. The sea area is 36%. Then the dominant percentage of negative rainfall

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anomalies occurred when the MJO was in the Indian Ocean phase with a percentage of 33% [9]. Suhardi et al. in Sukabumi district, with the results of the study showing that the areas affected by the MJO include Jampang Kulon, Pelabuhan Ratu, and Lengkong with a positive correlation. The strong MJO phase that impacts extreme rainfall in the Sukabumi region occurs from December to February [10].

Adhary Ardian A et al. in Jakarta and surrounding areas, the analysis showed that the temporal distribution of rainfall decreased significantly during the MJO active period and after the MJO, especially in the early morning. Conversely, in the post-MJO season, rainfall increases by an average of more than 30 mm/hour [11]. In addition, there are also those who conduct studies in all regions of Indonesia, such as Purwaningsih et al, the results show that strong MJO phases 3, 4, and 5 are more frequent during DJF (50% more events than when MJO is weak). During JJA, the frequency of strong and weak MJO events is not significantly different. During DJF, rainfall intensity increases in western Indonesia during phases 3 and 4 of strong MJO. In eastern Indonesia, rainfall increased to almost 100% in some areas of Papua during the 5th DJF phase of strong MJO. In most parts of Sulawesi, rainfall doubled during the 4 months of the JJA strong MJO phase. Areas with higher rainfall during weak MJO include western Indonesia (Sumatra and Java) during MJO phase 3 in JJA [12]., and Hidayat & Kizu, with results showing that rainfall variability in Indonesia is strongly influenced by the phase of eastward MJO propagation. Excess rainfall occurs during the "wet" phase when convective activity peaks and low-level winds gather in the region [8].

The areas of Jakarta, Bogor, Depok, Tangerang, and Bekasi are very interesting to study because they have geographical areas that are vulnerable to the influence of the MJO. This is supported by the topography of Jakarta, Bogor, Depok, Tangerang, and Bekasi, which are hilly and surrounded by the sea. This varied topography has resulted in a variety of rainfall distribution patterns in the Jakarta, Bogor, and Tangerang areas [13].

Based on previous studies, the authors chose the Jakarta, Bogor, and Tangerang areas because they were affected by natural disasters in the form of floods with a total of 555 events in the 2012-2022 period (https://gis.bnpb.go.id/). Therefore, a study is needed to see at MJO conditions (strong and weak) on rainfall conditions, both intensity and frequency of occurrence by comparing the temporal conditions during the December-January-February period (DJF), March-April-May (MAM), June-July-August (JJA), and September-October-November (SON) from 2013-2022 that can be climatologically representative.

Materials and Methods

Materials

This type of research is quantitative research. The data used are daily rainfall data from BMKG monitoring stations in Jakarta, Bogor, and Tangerang as well as the daily RMM (*Real-time Multivariate MJO*) Index for 2013-2022.

Table 1. Station ID and Location (Author, 2023)

WMO ID	Station	Lo	La
96749	Jakarta / Soekarno-Hatta	106.65001	-6.116669
96739	Curug / Budiarto	106.65001	-6.233338
96741	Jakarta / Tanjung Priok	106.86668	-6.100002
96745	Jakarta / Observatory	106.83335	-6.183335
96751	Citeko / Puncak	106.93335	-6.700014

In this study, the study area covers Jakarta, Bogor, and Tangerang. This region is very interesting to study because it has a geographical area that is vulnerable to the influence of the MJO. This is supported by the topography of Jakarta, Bogor and Tangerang, and Bekasi which are hilly and surrounded by the sea. This varied topography has resulted in a variety of rainfall distribution patterns in the areas of Jakarta, Bogor, Depok, Tangerang, and Bekasi [13].

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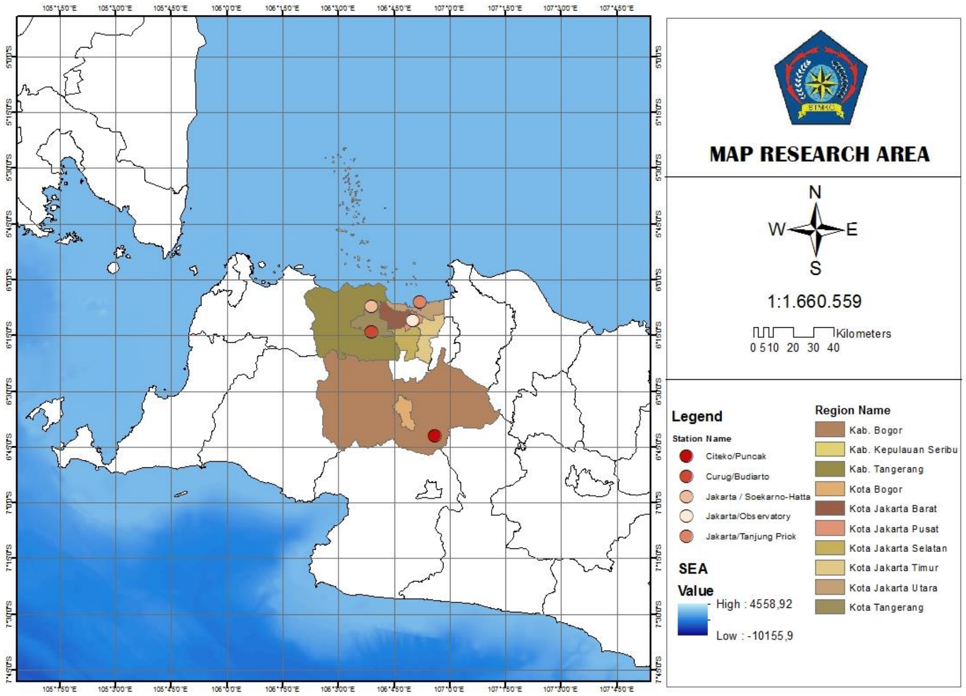

Figure 1. Map Of The Research Areas Of Jakarta, Bogor, and Tangerang (Author, 2023)

Data collection in the form of daily rainfall data is done by downloading data from the official Ogimet website (https://www.ogimet.com/home.phtml.en) and can also be done through a script in the R application. download data from the official website *of the Bureau of Meteorology Research Center* (BMRC; http://www.bom.gov.au/climate/mjo/).

Data Analysis

a. Convert daily rainfall data into quarterly (DJF, MAM, JJA, SON). Then the quarterly data is converted into a quarterly rainfall index by averaging the amount of data per quarter. Finding the quarterly rainfall index value with the first equation:

$$Y = \frac{1}{n}\sum_{i=1}^{n} Xi \quad (1)$$

Where Y is the quarterly rainfall, n is the number of days in the three months, and Xi is the total daily rainfall. Then look for the average quarterly rainfall over a certain period of time. Find the average rainfall basis with the second equation:

$$Y_{rerata} = \frac{1}{n}\sum_{i=1}^{n} X_i \quad (2)$$

Where $Y_{rerata}$is the average quarterly rainfall (average periods of DJF, MAM, JJA, and SON), n is the number of years used in the data, and $X_i$is the number of quarterly rainfalls (years 2012-2022).

b. Determine the quarterly rainfall anomaly with third equation:

$$Y_{anomali} = Y - Y_{rerata} \quad (3)$$

Where $Y_{anomali}$is the quarterly rainfall anomaly, Y is the quarterly rainfall (DJF, MAM, JJA, and SON), and $Y_{rerata}$is the average quarterly rainfall (the average period of DJF, MAM, JJA, and SON).

c. Displays the comparison or frequency of MJO events with rainfall in the DJF to SON periods. MJO frequency analysis in influencing rainfall in the period DJF to SON.

d. Pearson correlation analysis. This study uses a correlation analysis test to find the relationship between the independent variable (x), namely the element of weather (rainfall) and the dependent variable, (y)namely the RMM Index (Real-time Multivariate MJO). The analysis is calculated using the fouth equation:

$$r = \frac{n\sum XY-(\sum X)(\sum Y)}{\left(\sqrt{n\sum X^2-(\sum X^2)(n\sum Y^2)-(\sum Y^2)}\right)} \quad (4)$$

Where r is the correlation coefficient with the value of $(-1 \leq r \leq 1)$. If it $r = -1$ shows a perfect negative correlation (inversely proportional between the two variables), $r = 0$shows no correlation, and

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$r = 1$ shows a perfect positive correlation (directly proportional between the two variables). In interpreting this method in more detail, the following references are used [14]:

1) When the value of r(x, y) approaches +1, it shows that the relationship between the two variables is getting stronger and has a directly proportional nature.
2) If the value of r(x, y) is close to -1, it indicates that the relationship between the two variables is getting stronger and is inversely proportional.
3) If the value of r(x, y) has a value of ≥ +0.5 or ≥ -0.5, it indicates that the relationship between the two variables is considered quite strong.
4) When the value of r(x, y) has a value < +0.5 or < -0.5, it indicates that the relationship between the two variables is considered weak.

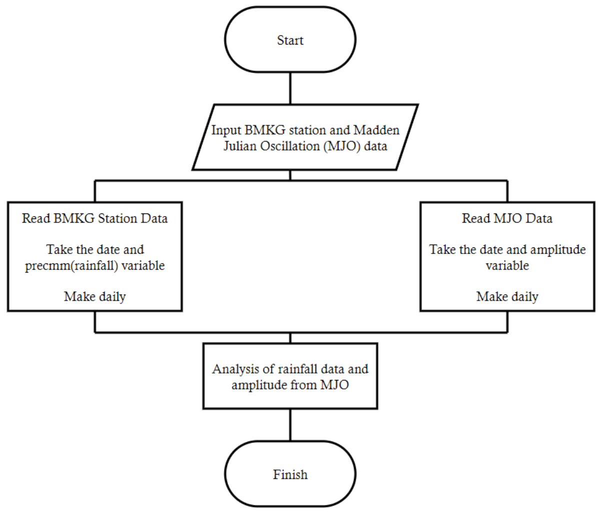

Figure 2. Flowchart

Results and Discussions

Average Seasonal Rainfall

The average quarterly rainfall in the Jakarta, Bogor, and Tangerang areas for the DJF-SON period can be seen in Figure 3.

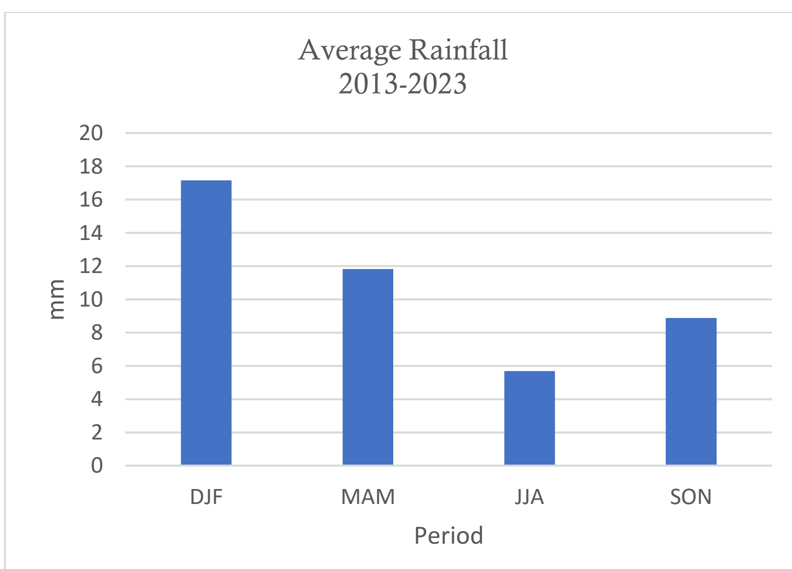

Figure 3. Average Rainfall 2013-2023

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From Figure 3, it can be seen that the highest rainfall rate during 2013-2022 was in the DJF period (December, January, and February) which was around 17.16 mm. The lowest level of rainfall is in the JJA period (June, July, and August) which is around 5.68 mm. Rainfall patterns are divided into three, namely monsoonal, equatorial, and local patterns. These three rain patterns can be explained as follows. the monsoonal rain pattern is the distribution of monthly rainfall following the monsoon season pattern, with one minimum rainfall period. This pattern can be depicted in graphic form resembling the letter "V" [15]. In the November-April period, there is an Asian monsoon which results in the rainy season [16], [17]. Rainfall levels in the western and central BMI are strongly influenced by the Asia-Australia Monsoon [16]. Meanwhile, the Australian Monsoon occurs in May-October, where several areas in Indonesia experience a dry season [17].

Precipitation Anomaly Percentage

Figure 4. Precipitation Anomaly Percentage

The rainfall anomaly from the DJF period (December-January-February) to SON (September-October-November) in Jakarta, Bogor, and Tangerang shows that the DJF and MAM periods have positive anomalies, while the JJA and SON periods have negative anomalies. This happens because the average rainfall of all periods is 10.88578 mm. Therefore, the percentage of anomalies in DJF and JJA periods have a greater value than the MAM and SON.The relation between averages rainfall and anomalies is linear.

Comparison The Frequency Rainfall

Frequency analysis of MJO events was performed to compare the number of strong (Active) and weak (Inactive) MJO events during the DJF-SON period. Based on existing data processing, an analysis of the number of events in the strong and weak MJO periods every quarter during the DJF-SON period is shown in the figure.5.

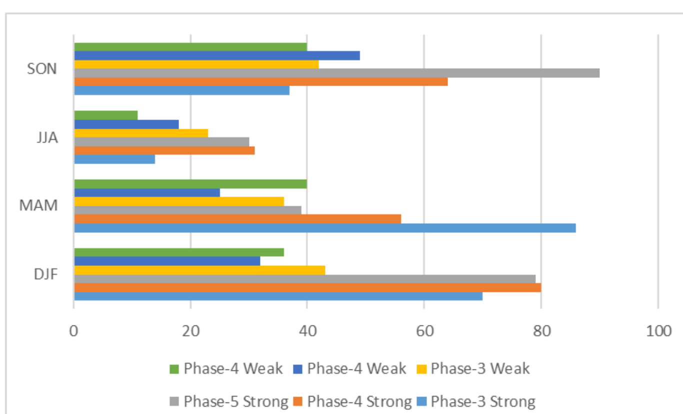

Figure 5. Madden Julian Oscillation Frequency In Influencing Rainfall

Based on the RMM index, during the 2013-2022 period, there were 1071 strong and weak MJO events in phases 3, 4, and 5. During the DJF period, a total of 229 strong MJO events and 111 weak MJO events. During this period, there were more cases of strong MJO in phases 3, 4, and 5 than weak MJO, with a presentation difference of up to 50%.

During the MAM period, a total of 181 strong MJO events and 101 weak MJO events. Furthermore, during the SON period, there were 191 strong MJO events and 131 weak MJO events. In the explanation above, the difference in the number of strong and weak MJO events is presented when it is still below 50%.

Unlike the other 3 periods, during the JJA period, the total number of strong and weak MJO events was not big as the other periods, namely 75 events in strong MJO and 52 events in weak MJO. It can be concluded, from this analysis the frequency of strong and weak MJO events in the JJA month is the lowest and in the DJF period is the highest.

Correlation Between Madden Julian Oscillation and Rainfall

The correlation test carried out using a mathematical approach through the Pearson correlation method, the results obtained between rainfall and the RMM MJO index in Jakarta, Bogor and Tangerang each period which can be seen in the table 2.

Table 2. Correlation Madden Julian Oscillation with Rainfall

	CORRELATION
DJF	-0.07216
MAM	0.197073
JJA	0.086687
SON	-0.11866

It can be seen in Table 2 that 0.197073 is the highest positive correlation value and occurs during the MAM period so it means that the correlation will be directly proportional between the variables. This correlation value indicates that the relationship between rainfall and MJO is weak. In addition, a value of -0.11866 in the SON period displays the highest negative correlation value, implying that the correlation will be inversely proportional between rainfall and MJO. The correlation value obtained in the SON period indicates that the relationship between rainfall and MJO is at a weak level. This is in line with other studies that discuss the influence of the Madden Julian Oscillation (MJO) on rainfall [9], [18].

Conclusion

The results of data analysis that has been carried out in Jakarta, Bogor, and Tangerang in 2013-2022 on rainfall and the *Madden Julian Oscillation* (MJO) that the average rainfall the highest occurred in the DJF period, which was around 17.16 mm and the lowest was in the JJA period, which was around 5.68 mm.

Rainfall anomalies in the Jakarta, Bogor and Tangerang areas during the DJF and MAM periods have positive anomalies, while the JJA and SON periods have negative anomalies. This occurs because the average rainfall for the entire period is 10.88578 mm. Therefore the percentage of anomalies in the DJF and JJA periods has a greater value compared to MAM and SON.

The analysis of the MJO frequency, it was found that the MJO affected the occurrence of rain in each period because when an active MJO occurs, the frequency of rainfall will increase. The highest frequency of events when the MJO was strong and weak occurred during the DFJ period with a total of 340 events. In the JJA period, the frequency of MJO that occurred in this period was the lowest with a total of 127 events. From the previous analysis, the DJF period had the highest average rainfall and the JJA period had the lowest, with this it was found that the MJO frequency affects the average amount of rainfall see at all periods when MJO is active, the amount of rainfall increases.

The results showed that the highest positive and negative values had a weak relationship between the variables so the Madden Julian Oscillation (MJO) did not affect rainfall intensity in Jakarta, Bogor, and Tangerang because the value is close to 0 and will have a strong relationship when the value is close to 1. However, does not rule out the possibility that this is caused by other factors such as monsoons, ENSO, topography, and others that affect rainfall conditions in Jakarta, Bogor, and Tangerang.

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