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Analysis of Madden-Julian Oscillation Phenomenon and its Effect on Rainfall Condition in New Capital City of Indonesia, IKN Nusantara

Anwar Budi Nugroho[1,*], Bai'at Alhadid[2], Yakubos Samoria[3]
[1]Stasiun Meteorologi Sangia Nibandera, Kolaka,
[2]Stasiun Meteorologi Aji Pangeran Tumenggung Pranoto Samarinda,
[3]Pos Meteorologi Dobo Jalan Protokol No. 1, Pomalaa, Kolaka 93562.

Corresponding author*
anwarbudi9945@gmail.com

Abstract: The development of the Indonesian Capital City (IKN) in Indonesia faces major challenges due to hydrometeorological disasters such as floods and landslides. High rainfall fluctuations, coupled with changes in land use, have the potential to increase the risk of hydrometeorological disasters. Therefore, a comprehensive mitigation strategy is needed, including adaptation through climate change and weather studies in determining the direction of infrastructure development, to ensure the resilience and safety of the IKN Nusantara area. MJO is one of the factors that can cause high rainfall fluctuations or extreme rain in the Indonesian region. Therefore, this study examines the influence of the MJO phenomenon on rainfall conditions, especially extreme rain events in the IKN area, with a focus only on MJO phases 3, 4, and 5. This study uses rainfall data for 30 years (1991–2020) from meteorological station observation data and the CHIRPS satellite. The results of the study show that MJO significantly affects rainfall conditions, especially extreme rainfall events in the IKN Nusantara region. In addition, this study also succeeded in identifying areas that have significant responses to MJO phases. Generally, the influence of MJO varies by phase and season, both in terms of monthly rainfall accumulation and extreme rainfall events. Some MJO phases increase the average extreme rainfall by up to 20% when the momentum coincides with humid atmospheric conditions that support the formation of convective clouds in the IKN Nusantara region, while other phases can reduce rainfall by up to 5% due to airflow that inhibits the formation of rain clouds in certain areas. This pattern shows a complex interaction between the MJO and local weather variability, which is influenced by seasonal factors and geographical characteristics of the IKN Nusantara region.

Keywords: IKN Nusantara, MJO, Rainfall Condition, Extreme Rainfall.

Introduction

The new capital city of Indonesia called Nusantara (IKN Nusantara) is a strategic national project located in North Penajam Paser, East Kalimantan, Indonesia. The Indonesian government has designed Nusantara as a modern and sustainable future residential area, adopting the concept of a "Smart and Green City." One of the significant challenges facing IKN Nusantara as a future residential area is its resilience to hydrometeorological disasters such as floods and landslides. This is influenced by the high rainfall in the IKN Nusantara location, which is an area frequently experiencing high/extreme rainfall with an occurrence interval of every 1-2 months (Setiawan, 2021). The high fluctuation in rainfall, coupled with changes in land use, has the potential to increase the risk of disasters. Therefore, a comprehensive mitigation strategy is needed, including adaptation through studies on climate and weather changes in determining the direction of infrastructure development, to ensure the resilience and safety of the IKN Nusantara region.

Extreme rainfall in a region can be influenced by various factors. One important factor affecting weather patterns and rainfall intensity in Indonesia is the Madden-Julian Oscillation (MJO) (Saragih et

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al., 2018). The MJO is a tropical weather phenomenon with a 30-60 day period, characterized by the movement of convective activity from the Indian Ocean to the Pacific Ocean (Madden and Julian, 1971). When the MJO is active, wind patterns and humidity in a region change, leading to increased cloud formation and rainfall. This condition can trigger extreme rainfall or extreme weather events (Vincent et al., 2014). As it progresses, the MJO goes through 8 phases, starting in the region near the Indian Ocean in Africa and moving eastward to phase 8 in the eastern Pacific Ocean (Higgins and Shi, 2001). In Indonesia, the MJO has the most significant impact when it is in phases 3, 4, and 5 (Purwaningsih et al., 2020).

Various studies have shown that the MJO has a significant impact on rainfall patterns and extreme rainfall events in Indonesia, especially during the rainy season (Hendon et al., 2007; Tadono et al., 2016). The MJO also increases the probability of extreme rainfall by up to 20% in some regions of Indonesia (Lim et al., 2017). During its active phase, the MJO triggers sea surface warming and increased humidity through water vapor transport into the atmosphere, which strengthens the formation of convective clouds (Hendon et al., 2007). The increased convective clouds can trigger extreme rainfall, which has the potential to cause hydrometeorological disasters (floods and landslides) (Sundararajan et al., 2020). Based on the background above, the MJO influences rainfall patterns and extreme rainfall events in Indonesia, increasing the risk of hydrometeorological disasters. Therefore, a study of the MJO's effect in the IKN Nusantara region is important to support disaster mitigation in this region.

This study will analyze MJO events and the effects on rainfall patterns and extreme rainfall in the new capital city, IKN Nusantara region. The analysis of MJO events will focus on phases 3, 4, and 5 (when the MJO is located near the Indonesian maritime continent) in relation to increased rainfall accumulation and extreme rainfall events (in this study, extreme rainfall defined as rainfall exceeding the 95th percentile of the daily data distribution over the 30-year period from 1991 to 2020). The ultimate goal of this study is to determine the magnitude of MJO's effects by mapping the significance of this phenomenon on spatial extreme rainfall accumulation in the IKN Nusantara region.

Materials and Methods

Study area

This research focuses on the new capital city of Indonesia, IKN Nusantara region, located in North Penajam Paser, East Kalimantan. This study was conducted by analyzing rainfall datas from 1991 to 2020. Furthemore, this study was also conducted at two meteorological observation stations of the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) located around the IKN Nusantara, namely Balikpapan Meteorological Station and Samarinda Meteorological Station. This station site was selected because there is no direct weather observation data in the IKN Nusantara. In more detail, the areas that are the focus of this research can be seen in Figure 1.

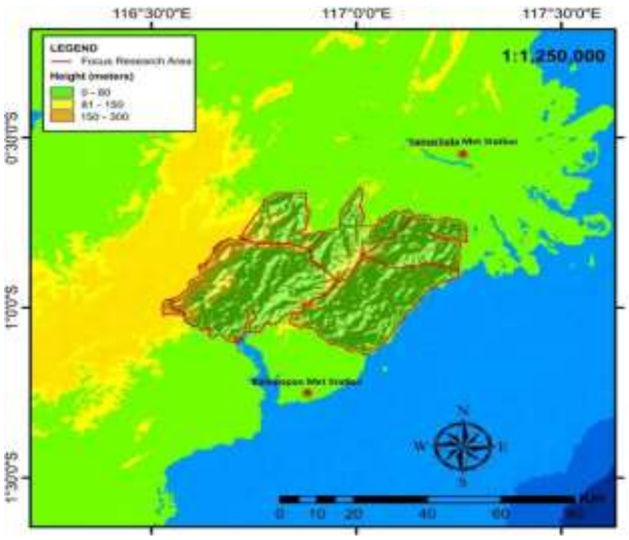

Figure 1. Map of the focus study area

Data

The data that will be used in this study are Realtime Multivariate MJO (RMM) index, rainfall observation data from BMKG, and CHIRPS satellite rainfall data. RMM index is used to determine the phase or movement of the MJO. Data processing and analysis in this study will be carried out based on the phase or movement of the MJO. Meanwhile, BMKG daily rainfall data and

CHIRPS satellite rainfall data are used to determine the effect of MJO on rainfall conditions in the IKN Nusantara and its surrounding area.

RMM data

The Real-time Multivariate MJO (RMM) index is an MJO index developed by the Bureau of Meteorology (BoM) to identify the timing and magnitude of MJO events (Wheeler & Hendon, 2004). The RMM index detects and monitors the Madden-Julian Oscillation (MJO) through two primary indices, RMM1 and RMM2, which are derived from the analysis of multivariate meteorological data. This data utilizes a number of parameters, such as surface pressure, rainfall, and atmospheric humidity, to provide a clear understanding of MJO activity. By mapping the position of the MJO in phase space, RMM allows for time series analysis that can predict weather changes and identify the relationship between MJO and weather phenomena. In this study, the MJO is identified based on whether it is active or not, it does not differentiate it according to a certain amplitude, thereby ruling out factors that might be caused by this differentiation.

Rainfall observation data

The rainfall observation data is derived from ground-based measurements at two meteorological stations operated by BMKG. Rainfall is measured directly using instruments like rain gauges. Rain gauges provide accurate point-scale precipitation data, their limited coverage and the increasing uncertainty with distance restrict their ability to capture large-scale precipitation patterns (Kidd et al., 2017). The rainfall observation data used in this study is daily and monthly rainfall data from 1991-2020 and was obtained from Balikpapan Meteorological Station and Samarinda Meteorological Station. Due to its proximity with the IKN Nusantara, the data from these stations is considered representative of the climatic conditions in the surrounding areas of the IKN Nusantara. However, additional observational data is needed to estimate precipitation across the study area and understand spatial variations induced by the MJO (Fadholi et al., 2020). Therefore, the observations data in this study serves as a valuable resource for analyzing the frequency of extreme rainfall events and for verifying the accuracy of CHIRPS satellite-based precipitation products.

CHIRPS satellite data

The other rainfall data that was used in this study is CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) satellite data. CHIRPS satellite data is a global precipitation dataset developed to provide accurate and consistent precipitation estimates. As a satellite-based precipitation product, CHIRPS is designed to address the limitations of sparse ground-based observation networks, which often suffer from significant measurement uncertainties due to large inter-station distances (Kidd et al., 2017). By leveraging satellite technology, we can overcome the challenges faced by traditional measurement systems and gain a better understanding of the global and continuous distribution of precipitation intensity (Kidd et al., 2012).

The CHIRPS satellite data used in this study has a spatial resolution of 0.05 degrees with daily and monthly temporal resolutions, covering the period from 1991 to 2020. The data was downloaded from https://data.chc.ucsb.edu/products/CHIRPS-2.0/.
The use of CHIRPS satellite precipitation data is justified by its demonstrated strong correlation with monthly rainfall in both Indonesia and globally (Pratama et al., 2022; Shen et al., 2020). This CHIRPS precipitation data is employed to investigate the spatial distribution of rainfall and to analyze the significance of MJO phases in the IKN Nusantara region.

Procedure

There are 3 main things that will be done in this research. Firstly, verifying the CHIRPS satellite rainfall data with rainfall observation data from BMKG, and then analyzing the MJO event based on the RMM index, and finally analyzing the effects of MJO on rainfall condition in the IKN Nusantara and its surrounding area.

This study specifically focused on spatial identification within the IKN area, covering the range from 116.5°E to 117.3°E and from -1.2°S to -0.6°S. Rainfall data for spatial analysis was developed using CHIRPS satellite data, which were statistically validated against station-observed rainfall data to assess the accuracy and reliability of the satellite data for the region (Huffman et al., 2007; Shen et al., 2020). The data verification method refers to Shen et al. (2020) include Pearson correlation coefficient (CC), Mean Error (ME), Root Mean Square Error (RMSE), and BIAS.

After that, identification of MJO events was conducted using RMM index. The RMM index analysis was performed to identify the movement or phases of the MJO phenomenon. Additionally, the RMM index data analysis was utilized to determine the timing and frequency of occurrences for each MJO phase. This study focuses only on MJO phases 3, 4, and 5, as during these phases, the MJO is positioned near the Indonesian region (Purwaningsih et al., 2020).

And finally, the effect of the Madden-Julian Oscillation (MJO) on rainfall conditions is analyzed through several quantitative steps, through the analysis of monthly rainfall accumulation and the frequency of extreme rainfall events. In this study, the extreme rainfall threshold was determined based on the 95th percentile of daily rainfall data from 1991-2020 (Equation 1). This threshold is grounded in the statistical theory of data rarity and recurrence interval for rainfall events within a specific recording period (WMO, 2023). Subsequently, extreme rainfall events were categorized based on MJO phases, separating periods active MJO (amplitude > 1) with inactive (weak) MJO (amplitude ≤ 1) for phases 3, 4, and 5. This approach allows an assessment of the extent to which MJO phases impact extreme rainfall.

$$P^{95} = \frac{n \times p}{100} \quad (1)$$

The significance of MJO's effect on rainfall is evaluated using the Spearman Rank correlation (r), which measures both the strength and direction of the relationship between MJO phases and daily rainfall (Equation 2). In practice, however, direct identification of this correlation (r) between MJO and rainfall can be distorted by Type I errors (false positives/negatives), where relationships may appear statistically significant without reflecting a true causal connection.

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

where: *r= spearman rank correlation coefficient; d= difference between two rangking (extreme rainfall event and MJO event); and n= number of observation*

Several factors contribute to false alarms in correlation analysis, including non-normal data distribution and small sample sizes (Bishara and Hitner, 2012). In the context of MJO, non-normality may arise due to lag effects between MJO phases, which can introduce bias in recording the relationship between MJO phases and rainfall in a region. To minimize the risk of error and mitigate spurious influences on correlation significance, this study normalizes correlation values (r) according to the standard normal Z distribution. The fisher-z transformation method (Equation 3) is applied to convert correlation (r) values into Z-scores, with a significance threshold set at Z=±1.96 as the acceptance region (Lehmann & Gorsuch, 2010). This the method that used to transform correlation into Zscore:

$$z' = 0.5ln\frac{(1+r)}{(1-r)}$$

Z-score:

$$Z = \frac{z'}{(SE)}$$

where:

$$SE = \frac{1}{(\sqrt{(n-3)})}$$

then:

$$Z = z'\sqrt{(n-3} \quad (3)$$

where: *z'= transformed r to z value; Z= Z-score ; SE= Standart Error; n=amount of data*

The spatial visualization of mathematical calculations was conducted using Python programming. A shapefile overlay of regional boundaries was applied to ensure that rainfall patterns and their significance can be geographically interpreted. Through this process, the study not only identifies significant relationships between MJO phases and extreme rainfall events but also reveals how seasonal variations (DJF and JJA) influence these patterns.

Results and Discussion

CHIRPS satellite data verification

The limitation of point data in representing spatial areas presents a major issue in this research for obtaining spatial analysis. Advanced statistical methods exist for converting point data into spatial fields; however, the limited availability of point data presents an additional challenge. Therefore, the use of satellite observation data serves as an alternative that provides better results (Fadholi et al., 2020), but this data must first be verified. From the scatterplot results in Figure 2, it is observed that most of the clustered data points are close to the 1:1 line. This is evident at both verification points (Balikpapan Meteorological Station and Samarinda Meteorological Station), indicating that the observation algorithm used by CHIRPS is capable of representing the systematic fluctuations of rainfall observation data around IKN. Several observed data outliers indicate the occurrence of extreme rainfall phenomena that can be identified.

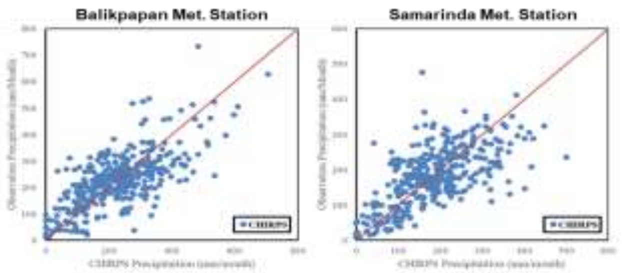

Figure 2. Scatterplots of mean monthly rainfall data comparison of CHIRPS and Meteorological Station

Additionally, Table 1 shows the statistical analysis using metrics such as Pearson correlation coefficient (CC), Mean Error (ME), Root Mean Square Error (RMSE), and BIAS also demonstrates that the verification of CHIRPS satellite rainfall data against surface observation data in Balikpapan Meteorological Station and Samarinda Meteorological Station shows fairly good results, although there are still some variations and biases that need to be addressed.

For the Balikpapan region, the Mean Error (ME) of 1.269 indicates a small average difference between satellite estimates and surface observations. The Root Mean Square Error (RMSE) value of 87.77 suggests significant fluctuations, likely due to extreme rainfall events that are difficult to measure accurately by satellites. The correlation coefficient of 0.695 indicates a strong relationship between satellite data and surface data, although there is still room for improvement. A bias of 15.2% indicates a tendency for satellite data to slightly overestimate rainfall compared to surface observations.

In the Samarinda region, the verification produced a Mean Error of -3.174, indicating that the satellite data slightly underestimates compared to surface data. The RMSE of 72.29 is lower than that of Balikpapan, suggesting a more stable difference between satellite and surface data. The correlation coefficient of 0.659 indicates a still fairly strong correlation, albeit slightly lower than in Balikpapan. A bias of 13.1% indicates a small tendency for underestimation in the satellite data.

Table 1. Statistical verification results of monthly rainfall data comparison of CHIRPS and Meteorological Station.

Met Station	CC	ME (mm)	RMSE (mm)	Bias (%)
Balikpapan	0.695	1.27	87.7	15.2
Samarinda	0.659	-3.17	72.3	13.1

Overall, in both Balikpapan and Samarinda, CHIRPS satellite data estimates provide fairly representative results with some minor biases and deviations. While CHIRPS satellite data can be relied upon for rainfall estimation, some adjustments may be necessary due to limitations in historical CHIRPS data and the insufficient number of observation stations used in developing the CHIRPS dataset in the research area. However, considering the good correlation, minor bias, and deviations, CHIRPS data is deemed suitable for use in this research.

Frequency of MJO events from 1991 - 2020

Figure 3 below is a graph of the frequency of MJO events phases 3, 4, and 5 during 1991-2020 based on RMM Index data. Based on the RMM index, it was found that during the period from 1991 to 2020, the highest number of days or occurrences of the MJO occurred in December, totaling 302 events. In contrast, the fewest days or occurrences of the

MJO were recorded in August, with only 129 events. Overall, the MJO occurrences were most frequent during the December, January, and February (DJF) period, amounting to 759 events, whereas the least occurrences were noted during the June, July, and August (JJA) period, with only 439 events.

Meanwhile, during the other periods, specifically March, April, and May (MAM) and September, October, and November (SON), the occurrences of the MJO were recorded at 623 and 703 events, respectively. This is consistent with previous research indicating that MJO events are most frequent during the DJF period and least frequent during the JJA period (Purwaningsih et al., 2020). The lower occurrence of the MJO during the JJA period may be attributed to interactions between the MJO and other intraseasonal phenomena, which weaken the eastward propagation of the MJO, making it less effectively explained by the RMM index (Fu et al., 2013).

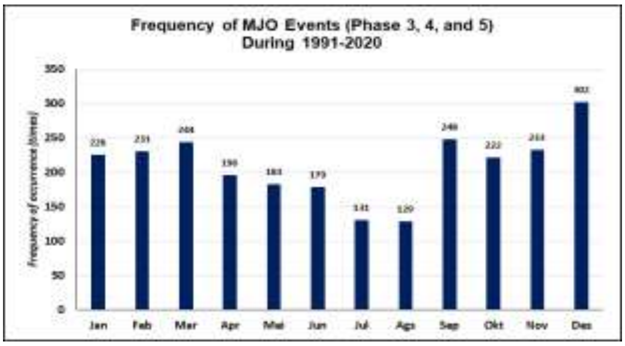

Figure 3. Frequency of MJO events during 1991-2020.

Analysis of the effects of MJO on rainfall condition in IKN Nusantara

In this study, the effects of the MJO on rainfall conditions in the IKN Nusantara is analyzed using a combined data approach, that are temporal and spatial analysis. Temporal analysis utilizes data from observation stations that provide direct recordings of daily and monthly rainfall variability around the IKN area, allowing for the detection of changes in rainfall patterns that may occur cyclically or seasonally in response to MJO activity. And then, spatial analysis will be drawn to represent the effects of MJO to spatial distribution on rainfall conditions in IKN Nusantara area based on the processing and plotting of CHIRPS data. There are 2 main things that will be analyzed to determine the effects of MJO on rainfall conditions, that are effects of MJO on monthly rainfall conditions and extreme rainfall events (>95th percentile from rainfall data 1991-2020).

The first analysis is an analysis of the effects of MJO on monthly rainfall conditions around the IKN area, this analysis uses monthly rainfall data from Balikpapan Meteorological Station and Samarinda Meteorological Station. Figure 4 shows the percentage of monthly rainfall anomalies in the Balikpapan and Samarinda regions during MJO events from 1991 to 2020 compared to normal conditions. From that figure, it can be observed that each MJO phase has a different effect on the monthly rainfall conditions in the Balikpapan and Samarinda regions.

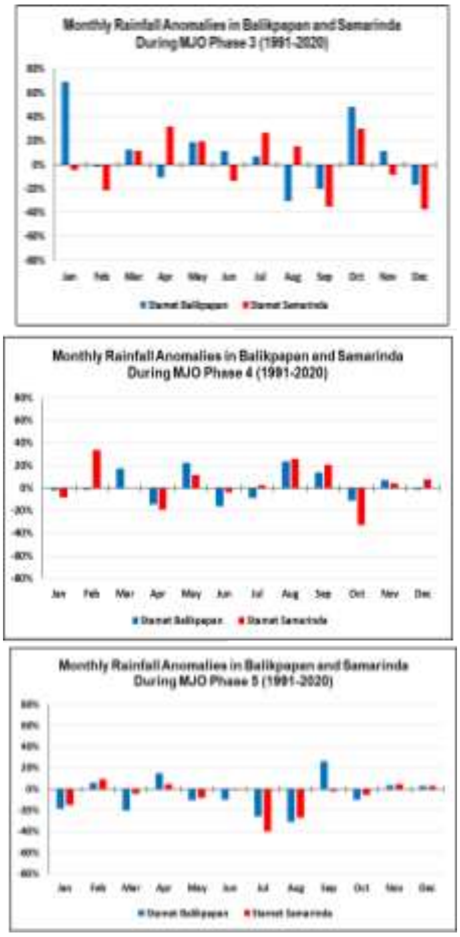

Figure 4. Graph of percentage of monthly rainfall anomalies when the MJO is active in Balikpapan and Samarinda.

Generally, MJO phase 3 has a more significant effect on increasing monthly rainfall compared to phases 4 and 5. During MJO phase 3, the highest increase in rainfall in Balikpapan occurs in January, reaching 60% compared to normal conditions, while in Samarinda, the highest increase occurs in April and October, only reaching 30%. An increase in monthly rainfall compared to normal condition also occurs during MJO phase 4, with the highest monthly rainfall increase in Samarinda reaching 32%, and in Balikpapan the highest increase only reaching 23%.

Overall, the increase in monthly rainfall is more pronounced during MJO phases 3 and 4. The increase in monthly rainfall occurs more frequently during the DJF and MAM periods compared to the JJA and SON periods. Meanwhile, MJO phase 5 generally does not have a significant effect on increasing monthly rainfall in Balikpapan and Samarinda. The absence of increased monthly rainfall, especially during MJO phase 5, may be due to the fact that this study does not analysis the other phenomena (such as El Niño/La Niña events) that could influence monthly rainfall fluctuations. Additionally, this may also be attributed to the interaction between MJO phenomena and local/diurnal cycles in East Kalimantan, leading to "opposite phenomena/impacts" in East Kalimantan during the MJO (whereas the increase in rainfall due to MJO influence typically observed in other regions does not occur in East Kalimantan) (Permana, 2021).

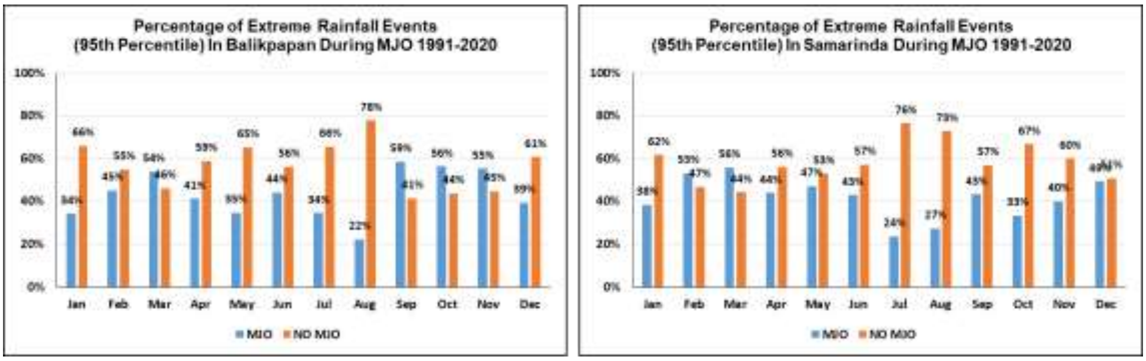

Figure 5. Percentage of Extreme Rainfall Eventgs In Sepinggan (Balikpapan) and APT Pranoto (Samarinda) Met. Station.

The next analysis is an analysis of the effect of MJO on extreme rainfall events. Figure 5 shows the percentage of extreme rainfall (>95th percentile) events during MJO and no MJO events in Balikpapan and Samarinda regions from 1991 to 2020. From that figure, it is evident that the percentage of extreme rainfall events due to the MJO correlates with the frequency of MJO occurrences, as illustrated in the previous Figure 1. An increasing number of MJO events each month leads to a higher percentage of extreme rainfall occurrences.

Additionally, the figure indicates that the MJO has a varying influence across different regions and times. Generally, the MJO does not significantly affect the increase in extreme rainfall events in the two areas surrounding the IKN Nusantara. Extreme rainfall can occur both during MJO or no MJO events. The increase in extreme rainfall events attributed to the MJO occurs only in certain months. In the Samarinda region, the MJO influences the increase in extreme rainfall events in February and March, reaching 6-10%. Meanwhile, in the Balikpapan region, the MJO has a more pronounced effect on the increase in extreme rainfall events compared to Samarinda. In Balikpapan, the MJO influences the increase in extreme rainfall events in September, October, and November, reaching 10-18%.

Although the increase in extreme rainfall events due to the influence of the MJO occurs most in February, March, September, October, and November. From the image above, it can also be seen that extreme rainfall events around the IKN Nusantara area have the potential to occur every month so that in the future, good mitigation and urban planning readiness are needed to avoid hydrometeorological disasters such as floods and landslides. Extreme rainfall events around the IKN Nusantara area have the potential to occur without being caused by the MJO. Extreme rainfall events that occur around the IKN area can be caused by other factors that need to be studied further. MJO is a non-seasonal factor related to extreme rainfall events, although there are other non-seasonal factors such as the interaction between La Nina and tropical disturbances, La Nina and local circulation, and El Nino and local circulation which also affect extreme rainfall events (Safril et al., 2020).

Subsequently, a general analysis of the MJO's effect in the IKN Nusantara area was conducted through the spatial identification of extreme rainfall (>95th percentile) during active and inactive MJO periods. The results show an increase in the extreme rainfall threshold value across the entire GRID area during MJO activity in the phases 3, 4, and 5. Areas with the most significant threshold increases tend to be in the western and southern parts of the IKN. This pattern reflects the effects of convection patterns caused by the MJO, which enhance rainfall in the western and southern areas, particularly during active phases associated with intensified tropical convecti.on (Zhou et al., 2012). These results specifically indicate that the presence of active MJO conditions increases the ris0.0k of high rainfall in several regions of the IKN Nusantara, which is useful for hydrometeorological disaster planning and mitigation, as shown in Figure 6.

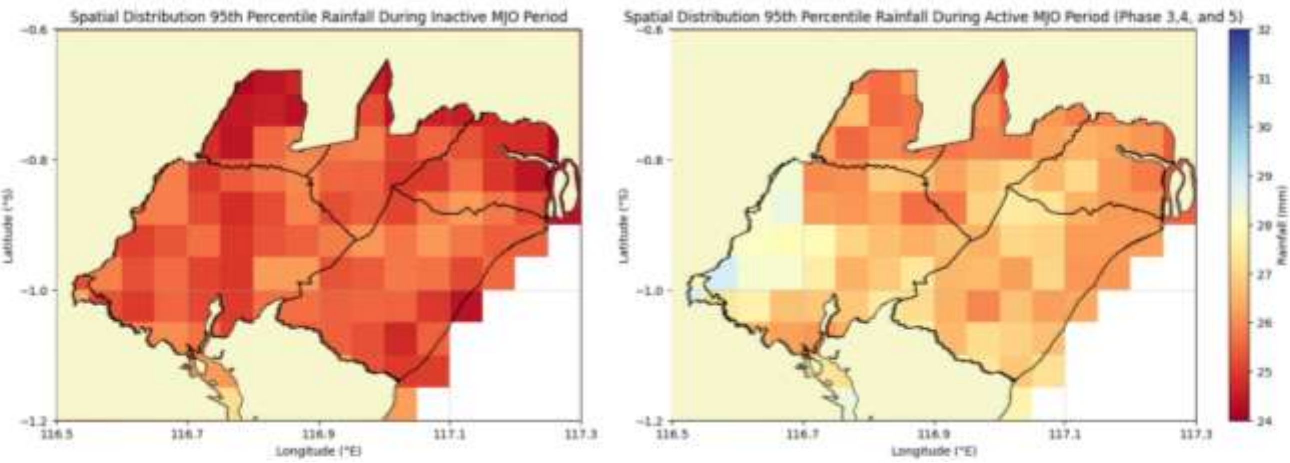

Figure 6. Spatial distribution extreme rainfall threshold on IKN Nusantara.

Based on the spatial distribution of extreme rainfall in the previous figure, it is evident that each phase of the MJO may have varying effects on the rainfall patterns in the IKN Nusatara region. Several studies indicate different effects due to the nature of convection propagation and the interactions between MJO phases and the tropical atmosphere, as well as the surrounding regions (Permana, 2021; Fadholi et al., 2020).

Meanwhile, different results are shown in Figure 7 regarding seasonal variations due to the MJO in the IKN region concerning changes in extreme rainfall. In the DJF period, MJO phase 4 is the most dominant, showing an increase in the average extreme rainfall up to 20% compared to when the MJO is inactive, followed by phase 5, which has a less significant effect. In contrast, for phase 3, most of the IKN region experiences a decrease in average extreme rainfall, recorded at up to 5%. Statistically, this analysis indicates that the intensity of rainfall is more likely to increase during MJO phases 4 and 5, while intensity decreases during phase 3.

In the JJA period, the results are the opposite of those in the DJF period. MJO phase 3 shows an increase in average extreme rainfall compared to phases 4 and 5, which experience a decline. This interpretation suggests that the presence of the MJO does not always uniformly increase the intensity of extreme rainfall but has varying impacts depending on the season and phase, which influence the interaction between the MJO and atmospheric patterns such as monsoon winds, topographic effects, and local conditions in the area.

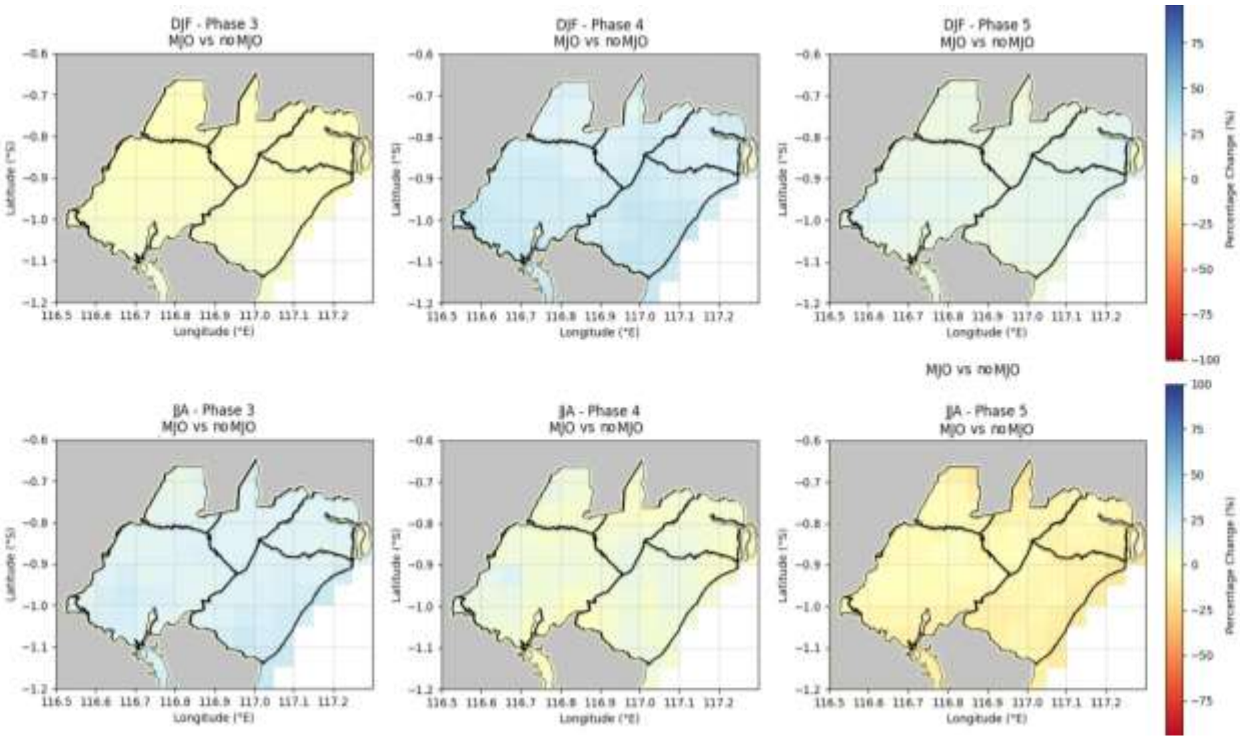

Figure 7. Percentage change in extreme rainfall during MJO active and inactive

The next analysis is a distribution map of Z scores (Figure 8) to determine the significance of MJO phases 3, 4, and 5 on extreme rainfall (95th percentile). It is evident that the influence of the MJO on extreme rainfall events shows specific variations both spatially and by phase. In phase 3 (top left map), areas shaded in green indicate a significant negative influence, suggesting a reduction in extreme rainfall, particularly in the southwestern and southern regions of the IKN Nusantara. In contrast, phase 4 (top right map) shows a significant increase in several distinct areas. In phase 5 (bottom map), there is a significant spatially varying influence, with the northern and eastern regions showing significant increases in extreme rainfall (red areas), while some southern regions experience reductions (green areas).

This variation indicates that the response of extreme rainfall to MJO phases is local and not uniform across the entire region. Overall, this analysis demonstrates that not all areas respond to the MJO uniformly, and certain MJO phases may enhance or reduce extreme rainfall depending on their geographical location. Local factors, such as local atmospheric conditions and interactions with local to regional circulation, may also influence how these MJO phases modify extreme rainfall in each location.

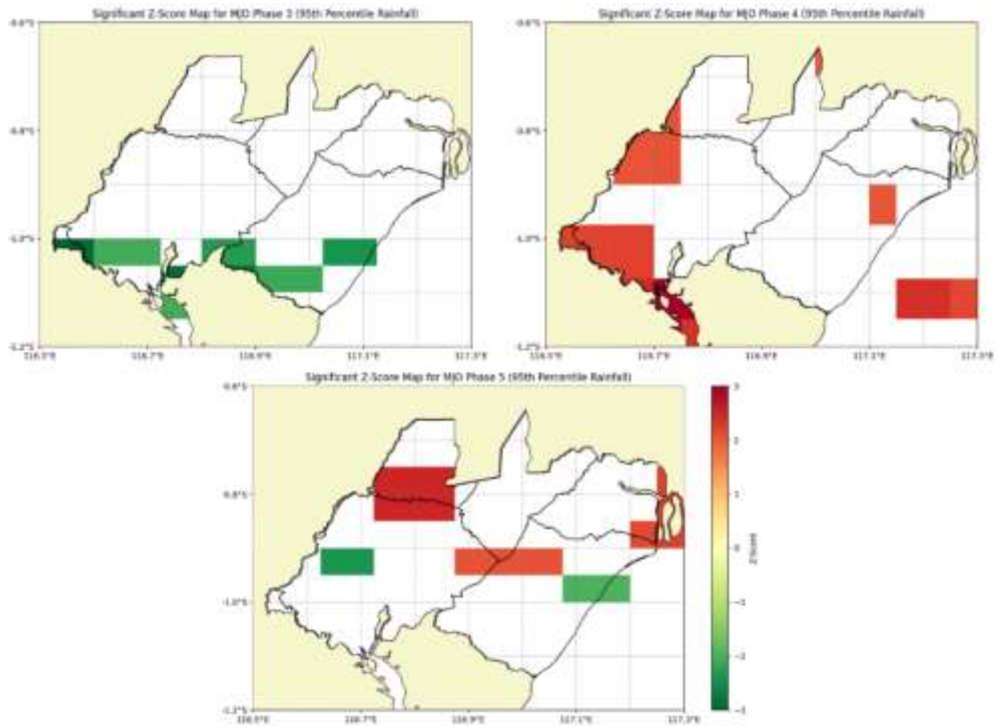

Figure 8. Significant map of MJO (Z scores) in the IKN Nusantara region.

Discussion

The limitations of the observational station network, potential errors in manual measurements, and the scarcity of historical data pose challenges in selecting data for this study. Nevertheless, direct rainfall measurements still yield more precise data at the point scale, although accuracy diminishes outside the observation station area. With the advancement of technology, many studies have shown that satellite data, which have been validated with field data, can help address these spatial coverage limitations (Tang et al., 2015; Funk et al., 2015). This method has been applied in this research and indicates that the satellite observation dataset, CHIRPS, has a good correlation with observational data and is considered capable of representing rainfall in the IKN Nusantara region as a whole.

However, it is important to note that satellite data also has limitations. While satellite data provide advantages in spatial coverage, their accuracy still relies on the validation and correction methods used to reduce bias against observational data. The differences in temporal and spatial resolution between satellite and ground data can also affect interpretations, especially regarding extreme rainfall patterns that require high precision. Therefore, the integration of satellite data and thoroughly validated observational data becomes a crucial strategy for obtaining a more accurate and reliable representation of rainfall in the IKN Nusantara region.

Furthermore, the influence of the MJO on rainfall patterns in the IKN Nusantara region and its surroundings has been analyzed in depth. Using advanced statistical methods, areas showing significant responses to the MJO have been successfully grouped. The combination of validated observational data and satellite data indicates that rainfall responses to the MJO vary throughout the IKN region and its surroundings. This analysis encompasses two main aspects: total rainfall accumulation and extreme rainfall (the 95th percentile). The results indicate that both aspects are influenced by the MJO phases and their seasonal variations.

Overall, this study emphasizes the importance of understanding the interactions between tropical phenomena such as the MJO and local weather variability in the IKN Nusantara region. The use of satellite data validated with field observational data allows for a deeper understanding of rainfall patterns within the geographical context of the IKN Nusantara. These findings also highlight the need for more precise weather prediction models in the future, particularly concerning the potential risks of disasters caused by extreme rainfall, as climate change may exacerbate rainfall responses to the MJO.

Conclusions

The study reveals that the Madden-Julian Oscillation (MJO) phenomenon has an effect on rainfall conditions in the IKN Nusantara region and its surroundings. MJO has a more significant influence on extreme rainfall events compared to monthly rainfall conditions. By combining validated observational data and CHIRPS satellite data, the scope of the research is expanded spatially, allowing for a more comprehensive analysis of the influence of the MJO on rainfall in the IKN Nusantara region. This research successfully identifies areas with significant responses to the MJO phases. The results show that the influence of the MJO varies according to phase and season, both in terms of monthly rainfall accumulation and extreme rainfall events. Some MJO phases increase average extreme rainfall by up to 20% when momentum coincides with humid atmospheric conditions that support convection cloud formation in the IKN Nusantara region, while other phases may decrease rainfall by up to 5% due to airflows that hinder rain cloud formation in certain areas. This pattern demonstrates the complex interaction between the MJO and local weather variability, influenced by seasonal factors and the geographic characteristics of the IKN Nusantara region.

Conflict of Interest: The authors declare that there are no conflicts of interest concerning the publication of this article.

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