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Analysis of Extreme Rainfall in Padang City Based on The Influence of MJO and IOD in The Period 1991-2020

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Abstract: Rainfall above normal can be categorized as extreme rainfall. Extreme rainfall can be caused by various factors, such as global, local, and regional factors. Some regional factors that influence rainfall are the Madden Julian Oscillation (MJO) and the Indian Ocean Dipole (IOD). Padang City has high rainfall intensity which can result in extreme rainfall. The lack of adequate disaster mitigation results in flood disasters when extreme rainfall occurs. Therefore, this research aims to determine normal rainfall, extreme rainfall trends and the relationship between the MJO and IOD phenomena with the frequency of extreme rainfall in Padang City. This information is needed for future disaster mitigation planning. The method used is the time series method and statistical correlation test. Based on the results of the analysis, it is known that Padang City is an area with an equatorial rain type, where the highest rainfall occurs in November with a value of 512 mm and the lowest in May with a value of 268 mm. The trend in extreme rainfall tends to decrease with regression coefficient values of 0.0412 and 0.0708. There is a significant relationship between the number of negative IOD events and the frequency of extreme rainfall with a correlation coefficient of 0.483 and 0.403 which indicates a moderate correlation. There is no significant correlation between the number of strong MJO events in Phases 3 and 4 and the frequency of extreme rainfall, with a correlation coefficient of -0.038 – 0.105.

Keywords: Extreme Rainfall; Indian Ocean Dipole; Madden Julian Oscillation

1. Introduction

The changes in climate conditions are closely related to the change in rainfall patterns and intensity which will have an impact on seasonal changes [1]. Climate is a statistical probability of various atmospheric conditions, including temperature, pressure, wind, and humidity, occurring in an area over a long period. Climate is not only the average of the atmospheric conditions or

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the average weather for that location [2]. Rain is a drop in the form of water particles (hydrometeor) with a diameter of 0.5 mm or more [3]. Rain will only occur if the water molecules have reached > 1mm [4]. Rainfall is an estimate of rain that falls from a certain height in a flat location and is not expected to be affected by evaporation, does not seep and does not flow [5]. Based on the general pattern of occurrence, Rainfall in Indonesia can be divided into 3 types namely, equatorial type, monsoon type, and local type [6]. Rainfall intensity is the amount of water that falls on the surface of the earth per unit of time which can be measured with a rain gauge with units of mm [7]. Rainfall patterns can be influenced by geographic location, topography, altitude, slope, wind direction, and latitude [8]. Based on the type of Schmidt-Ferguson rainfall, rainfall can be categorized as in Table 1.

Table 1. Rainfall Category [7]

No	Comparison of rainfall to average	Category
1.	>115%	Above Normal (AN)
2.	85% - 115%	Normal (N)
3.	<85%	Below Normal (BN)

Above normal rainfall can be categorized as extreme rainfall, as shown in Table 1. Extreme rainfall is in the form of heavy rain and hail [9]. Extreme rainfall can be caused by various factors, such as global, local and regional factors. Several global factors that affect rainfall are MJO and IOD. [9]. Extreme rainfall can be caused by various factors, such as global, local and regional factors. Several global factors that affect rainfall are MJO and IOD.

Madden Julian Oscillation (MJO) is characterized as a large-scale atmospheric perturbation with intra-seasonal time scales, moving eastward at a speed of about 5 m/s in the tropical belt, and originating from the Indian Ocean, then passing through Indonesian territory and finally crossing the date line in the Pacific Ocean [10]. The MJO is a disturbance of the eastward movement of clouds, precipitation, wind, pressure, and convective phase that crosses the Indian Ocean along the equator and returns to its initial starting point within 40 to 60 days. MJO can affect sea surface temperature, which increases with the passage of sea currents to the east so it has an impact on the high evaporation of sea water. The next process occurs when water vapor moves vertically and forms several clusters of rain clouds moving eastward at 5–10 m/s [11]. Meanwhile, the Indian Ocean Dipole (IOD) is a phenomenon of deviation from sea surface temperature in the Indian Ocean near the equator which causes certain circulation variations in the atmosphere and oceans. The Indian ocean dipole is one of the dominant drivers of rainfall variability on Earth [12]. During the IOD (-), the western region of Sumatra including West Sumatra experienced a surplus of rainfall and the eastern region of Africa experienced drought, and vice versa.

Padang City is on the west coast of Sumatra which has high rainfall intensity. The reason for the high rainfall in the city of Padang is due to the geographic, astronomical location, and also the hills around the city of Padang. Astronomically, the city of Padang is between 0° 44'00" and 1° 08'35" south latitude and between 100° 05' 05" and 100° 34'09" east longitude. Apart from its geographic and astronomical location, the high rainfall in Padang City can also be caused by global phenomena such as MJO and IOD. The high intensity of rainfall can result in extreme rainfall. Extreme rainfall can cause various kinds of disasters, such as floods, landslides, and damage to facilities and infrastructure. The flood and landslide disaster index issued by BNPB places Padang City at high risk of these disasters. Therefore, in this research, we will analyze normal rainfall and extreme rainfall trends in Padang City which will be used for future disaster mitigation. Also, an analysis was carried out whether on the MJO and IOD phenomena had an impact on increasing extreme rainfall in Padang City considering the disturbance and increase in rain surplus when these phenomena occurred. MJO events are defined based on the Real-time Multivariate MJO Index (RMM). These indices are then used to calculate the amplitude of MJO events as RMM12 and RMM22.

MJO is considered weak if the RMM index value is <1 and is considered strong if the value is >1 [10]. The MJO consists of 8 phase diagrams, for the Padang City area, the investigation of the MJO effect uses real-time MJO information in Phase 3 and Phase 4 [13]. This is because during the MJO in phase 3 there was a period of oscillation in the eastern Indian Ocean, and in phase 4 there was a period of oscillation in western Indonesia, one of which was the city of Padang. The oscillation period causes the formation of areas of convective cloud formation which can result in increased rainfall. Meanwhile, the investigation of the effect of IOD is based on real-time information with a small IOD value of -0.5. This is because, if the IOD value is less than -0.5 then it identifies a significant contribution to cloud formation around Indonesia [14]. The IOD index occurs due to differences in sea surface temperature between the tropical West Indian Ocean and the tropical Southeast Indian Ocean [15].

2. Materials and Method

The data used in this study are daily rainfall data from BMKG Teluk Bayur Maritime Meteorology Station (Sta-met Maritim Teluk Bayur) for the period 1994 - 2020 and BMKG Minangkabau Meteorological Station, Padang Pariaman (Sta-met Minangkabau) for the period 1991 - 2020. Rainfall data is processed using the Microsoft Excel application to determine the average and intensity of rainfall. Monthly rainfall, as well as extreme rainfall trends. Rainfall intensity is calculated using formula 1 [13].

$$\text{Pb} = \sum_{i=1} Pi \qquad (1)$$

Whereas: Pb = the amount of rainfall in the i-month (mm), Pi = precipitation it rains on a certain day in the i-month. The average monthly rainfall intensity for each year can be calculated using the algebraic average technique with formula 2 [13]:

$$\text{Cb} = \sum_{i=1}^{n} Ci \,/ n \qquad (2)$$

Whereas: Cb = precipitation monthly average rainfall for n years (mm), Ci = precipitation certain month of rain in the i-year, n = number of years of observation.

Extreme rainfall can be seen from the intensity value of monthly rainfall which is more than 115% of the average value. In analyzing the trend of extreme rainfall used the linear regression method [14]. Extreme rainfall can be seen from the intensity value of monthly rainfall which is more than 115% of the average value. In analyzing the trend of extreme rainfall used linear regression analysis [14]. Formula 2 is used in the extreme rainfall trend analysis [2].

$$\Upsilon = \alpha + \beta\, x \qquad (3)$$

Whereas: β = regression Constant, α = Y-intercept, ϒ = regression line/response variable (frequency of extreme rainfall), x = independent variable (period/year). The negative (-) or positive (+) sign on the regression coefficient value is a statement of the direction of the relationship or also emphasizes the influence of the independent variable (X) on the dependent variable (Y). Correlation test was conducted to determine the relationship between extreme rainfall on MJO and IOD. The research instrument used is the IBM SPSS application which is used to perform normality tests and correlation tests with data interpretation. The procedure for conducting a correlation test can be seen in Figure 1.

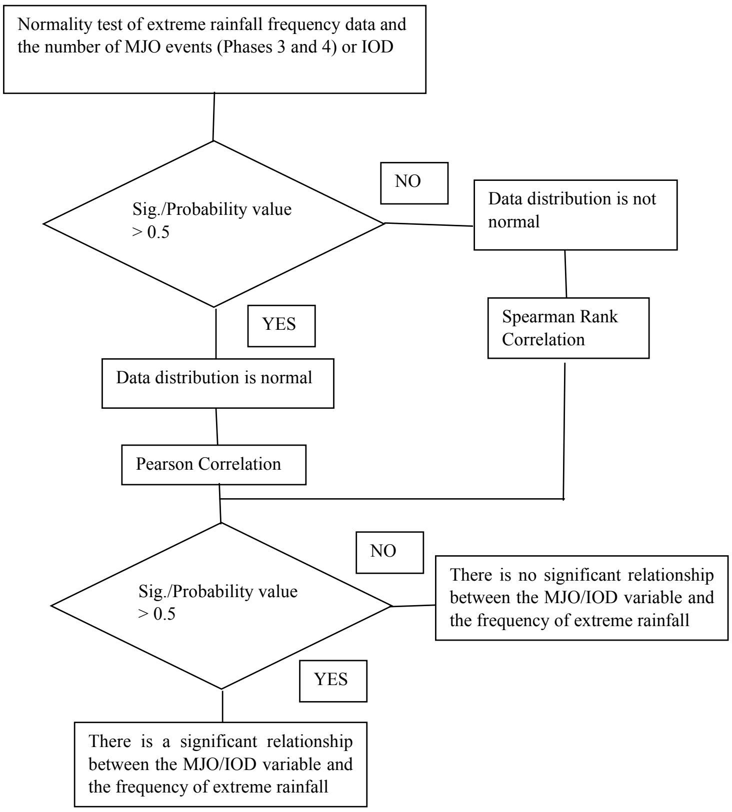


Figure 1. The procedure for conducting a correlation test

Based on Figure 1, an analysis of the relationship between the frequency of extreme rainfall and the number of strong MJO events (phases 3 and 4) or IOD was carried out using the IBM SPSS application. If the probability value obtained is > 0.5, this indicates that there is a significant relationship between the extreme rainfall frequency variable and the many strong MJO events (phases 3 and 4) or IOD. Then, to determine the closeness of the relationship between the two variables, it is seen from the value of the correlation coefficient. The interpretation of the correlation coefficient values was on Table 2.

Table 2. Interpretation of Correlation Value [16]

No	r value	Correlation Interpretation
1	0,00-0,20	Very low
2	0,21-0,40	Low
3	0,41-0,60	Currently
4	0,61-0,80	Strong
5	0,81-1,00	Very strong

Based on the interpretation of the correlation coefficient values in Table 2, the degree of closeness of the relationship between variables from the correlation results is strengthened by calculating the average daily rainfall each month, namely connecting the average daily rainfall value each month with the total strong MJO event phase 3.4 and negative IOD. Daily average rainfall can be calculated by formula 4 [13]:

$$\text{CHr} = \frac{\sum_{i=1} CHi}{HH} \qquad (4)$$

Whereas: CHr = Precipitation daily average rainfall in month i, CHi = Precipitation rainy day I, HH = A lot rainy day. Meanwhile, to calculate the average daily rainfall of the i-th month for n years using the algebraic average method/technique with the formula 5 [13]:

$$\text{CHT} = \frac{\sum_{i=1}^{n} CHr}{n} \qquad (5)$$

Whereas: CHT = precipitation the i month's average daily rainfall for n years, CHr = precipitation daily average rainfall in month i, n = number of years of observation. We conducted a descriptive analysis of the number of strong MJO events of phase 3,4 and negative IOD on the frequency of extreme rainfall. This analysis aims to prove whether during extreme rainfall events there is a strong MJO phenomenon or a negative IOD.

3. Results and Discussion

Normal rainfall intensity is obtained from the average monthly rainfall intensity for 30 years from the data of the two stations. Rainfall intensity is calculated using formula 1. The results of these calculations are then averaged to obtain the average rainfall each month. Table 3 is the average monthly rainfall for Padang City for the period 1991 – 2020.

Table 3. Monthly Average Rainfall Intensity of Padang City Period 1991 - 2020

Month	Teluk Bayur Maritime Meteorology Station	Minangkabau Meteorology Station	Average
January	323	311	317
February	255	308	281
March	306	352	329
April	309	329	319
May	277	259	268
June	340	291	316
July	312	285	298
August	318	300	309
September	372	336	354
October	401	405	403
November	537	486	512
December	478	426	452

Based on Table 3, there are differences in the data of the two stations, this difference is due to the hills around the Teluk Bayur Maritime Meteorological Station area which makes sea breezes hit the hills and causes orographic rain. Orographic rain is rain that occurs in mountainous areas, air containing water vapor moves up the mountains causing a decrease in temperature and condensation so that rain falls on the slopes of the mountains facing the wind. Normal rainfall is the average rainfall intensity value from the two stations which can be seen in Figure 2.

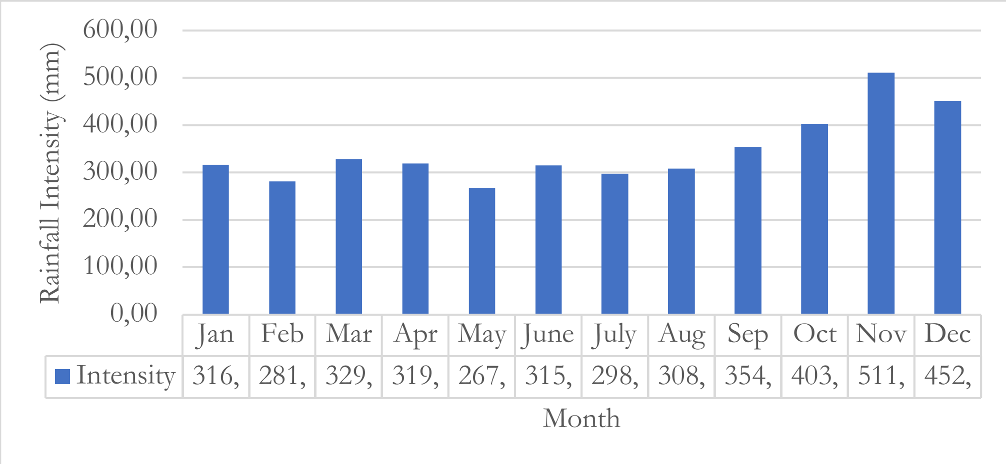


Figure 2. Average monthly rainfall intensity for Padang City for the period 1991 – 2020

The type of rainfall intensity in Padang City is the equatorial type shown in Figure 2. This type is characterized by two peaks of the rainy season, namely March and November. The highest rainfall intensity occurs in November with an intensity of 512 mm and the lowest in May with 268 mm. Normal rainfall is rainfall that has an intensity of 85% - 115% of the average value for 30 years. Table 4 is the result of the analysis, the normal rainfall for Padang City for the period 1991 – 2020.

Table 4. Padang City Normal Rainfall Intensity Period 1991-2020

Month	Intensity	
	Minimum	Maximum
January	269	364
February	239	324
march	280	378
April	271	367
may	227	308
June	268	363
July	253	343
August	263	355
September	301	408
October	343	464
November	435	588
December	384	520

Table 4 determines the rainfall intensity threshold for each month, if the rainfall intensity exceeds the maximum value, then it is called above normal rainfall, and if it is less than the minimum intensity value then it is called below normal rainfall. The extreme rainfall used is rainfall that has an intensity value of > 115% of the average value. The trend for extreme rainfall is calculated from the number of extreme rainfall events or above normal rainfall each year. Figure 3 is the trend of extreme rainfall obtained using linear regression analysis.

(a) (b)

Figure 3. (a) Extreme Rainfall Trend in Sta-met Minangkabau and (b) Extreme Rainfall Trend in Sta-met Maritim Teluk Bayur

Based on Figure 3, it can be seen that the regression coefficient (β) is negative (-), this indicates an inverse relationship between the independent variable and the dependent variable. Or the trend value tends to fall. This indicates that the frequency of extreme rainfall events will decrease every year. The regression coefficient value is -0.0412 (Minangkabau meteorological station data) and -0.0708 (Teluk Bayur meteorological station data), this indicates a significant level of trend of decreasing extreme rainfall of 4.12% and 7.08%.

Positive IOD events generally have an impact on reduced rainfall in Indonesia, especially in the western part. While the IOD value is negative, it has an impact on increasing rainfall in western Indonesia. Negative IOD that can affect the rainfall cycle in West Sumatra is IOD with an index value < -0.5. The graph of the IOD index for the period 1991 - 2020 can be seen in Figure 4.

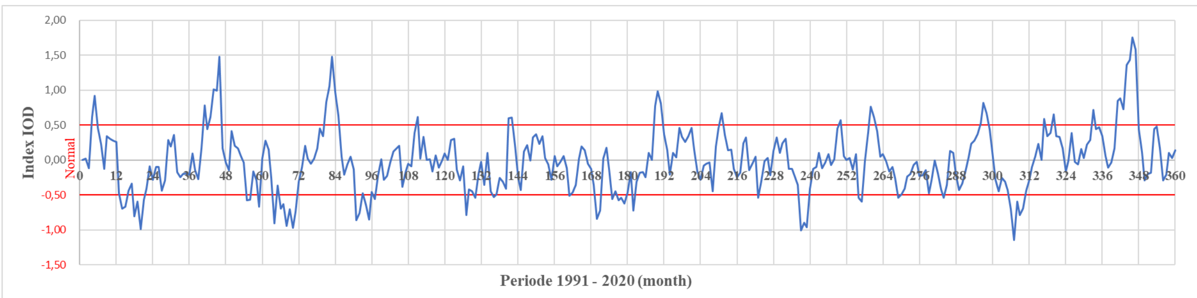
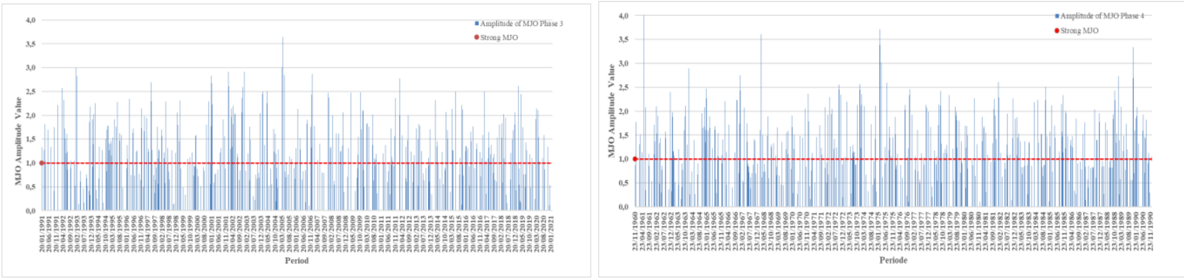


Figure 4. IOD Index Graph for the Period 1991 - 2020

Based on Figure 4, it can be seen that the negative IOD return period occurs every 2-3 years [12]. However, in the 1991 - 2020 period there were several IOD return period anomalies, namely in 2012-2014 where IOD appeared every year in a row and in 2017-2020 where IOD did not appear for 4 years. The effect of negative IOD on extreme rainfall can be determined by conducting a correlation test between the frequency of extreme rainfall and the number of negative IOD events. Based on the results of the analysis, it was found that there was a relationship between the frequency of extreme rainfall and the number of negative IOD events from the data of the two stations. The correlation coefficient value of the Teluk Bayur Maritime Meteorological Station data is 0,483 which indicates a moderate relationship/correlation between the frequency of extreme rainfall and the number of negative IOD events with a closeness level of 4,83%. Whereas at the Minangkabau Meteorological Station the correlation coefficient was 0,403 which indicates a moderate relationship/correlation between the frequency of extreme rainfall and the many negative IOD events with a closeness level of 40,3%. The effect of MJO on extreme rainfall can be determined by conducting a correlation test between the frequency of extreme rainfall and the number of MJO events. The MJO that affect rainfall in Padang City are MJO phases 3 and 4. Figure 5 is a graph of the MJO for the 1991-2020 period based on the amplitude.



(a) (b)

Figure 5. (a) MJO phase 3 period 1991-2020 (b) MJO phase 4 periods 1991-2020

Based on Figure 5 it can be seen that strong MJO events in phases 3 and 4 often occur. However, the results of the analysis show that there is no relationship between the frequency of extreme rainfall and the number of MJO events. Table 5 is the value of the correlation coefficient of the strong MJO variable phases 3 and 4 with frequency of extreme rainfall.

Table 5. Correlation of Multiple Strong MJO Events with Frequency of Extreme Rainfall

Phase/Quadrant	Station	Correlation coefficient
3	Teluk Bayur Maritime Meteorological Station	-0,11
	Minangkabau Meteorological Station	-0,236
4	Teluk Bayur Maritime Meteorological Station	0,105
	Minangkabau Meteorological Station	-0,38

Based on Table 5, the value of the correlation coefficient between the strong MJO event variables phases 3 and 4 with the frequency of extreme rainfall is -0,215 to 0,133. The minus sign on the correlation coefficient indicates the phase difference and lag. Physically, the different phases and delays mean that when a strong MJO enters the Padang City area, a cloud growth process occurs and after a strong MJO leaves the area, the clouds that form turn into rain [17].

Calculation of daily average rainfall was carried out to strengthen the correlation results, then connected with MJO phase 3.4 and the incidence of Negative IOD. Table 6 is the average daily rainfall value for Padang City for the period 1991 – 2020. Based on Table 6, the highest average daily rainfall is in June and July which is the dry or dry season. The high average daily rainfall in June is caused by the many strong MJO events which can increase the formation of rain clouds, but there is a different phase delay which causes when a strong MJO enters the Padang City area a process of cloud growth occurs and after a strong MJO leaves the area then clouds are formed, turned into rain. In July due to the many negative IOD phenomena which can cause deviations in sea surface temperature thereby increasing rainfall intensity.

Table 6. Padang City Daily Average Rainfall Period 1991 - 2020

Station/Month	Teluk Bayur Maritime Meteorological Station	Minangkabau Meteorological Station	Average
January	22,9	21,8	22,4
February	24,3	26,5	25,4
March	20,3	21,5	20,9
April	19,2	19,3	19,3
May	21,1	19,4	20,3
June	27	24,6	25,8
July	27	24,3	25,7
August	22,6	20,9	21,8
September	24.,9	21,4	23,2
October	21,2	20,9	21,1
November	25,4	22,8	24,1
December	25,4	22,4	23,9

The daily average rainfall pattern for the City of Padang for the 1991-2020 periods can be seen in Figure 6. Based on Figure 6, above normal/extreme rainfall events in January occurred 11 times with many negative IOD events 1 time, and strong MJO events (> 1) phase 3 as many as 78 times and phase 4 as many as 70 times. In February, extreme rainfall events occurred 9 times, with many negative IOD events 3 times. Meanwhile, strong MJO events (> 1) phase 3 was 62 times and phase 4 were 77 times. In March, extreme rainfall events occurred 8 times, with many negative IOD events 2 times. As for strong MJO events (> 1) phase 3 was 102 times and phase 4 was 89 times.

In April, extreme rainfall events occurred 10 times, with many negative IOD events 3 times. As for strong MJO events (> 1), phase 3 was 76 times and phase 4 was 77 times. In May, normal/extreme rainfall events occurred 10 times, with many negative IOD events 3 times. As for strong MJO events (> 1), phase 3 was 60 times and phase 4 was 50 times. In June, extreme above rainfall events occurred 8 times, with many negative IOD events 3 times. Meanwhile for strong MJO events (> 1) phase 3 was 56 times and phase 4 was 65 times.

In July, extreme rainfall events occurred 10 times, with many negative IOD events 6 times. Meanwhile, there were 36 strong MJO events (> 1) phase 3 as 36 times and phase 4 as 38 times. In August, extreme rainfall events occurred 12 times, with many negative IOD events 6 times. Meanwhile, strong MJO events (> 1) phase 3 was 45 times and phase 4 as much as 32 times. In September, extreme rainfall events occurred 7 times, with many negative IOD events 4 times. As for strong MJO events (> 1) phase 3 as 48 times and phase 4 as 89 times.

In October, extreme rainfall events occurred 9 times, with many negative IOD events 5 times. As for strong MJO events (> 1) phase 3 were 39 times and phase 4 as much as 67 times. In November, extreme rainfall events occurred 9 times, with many negative IOD events 5 times. Meanwhile, strong MJO events (> 1) phase 3 was 85 times and phase 4 was 87 times. In December, extreme rainfall occurred 9 times, there were no negative IOD events. Whereas for strong MJO events (> 1) phase 3 was 99 times and phase 4 was 99 times.

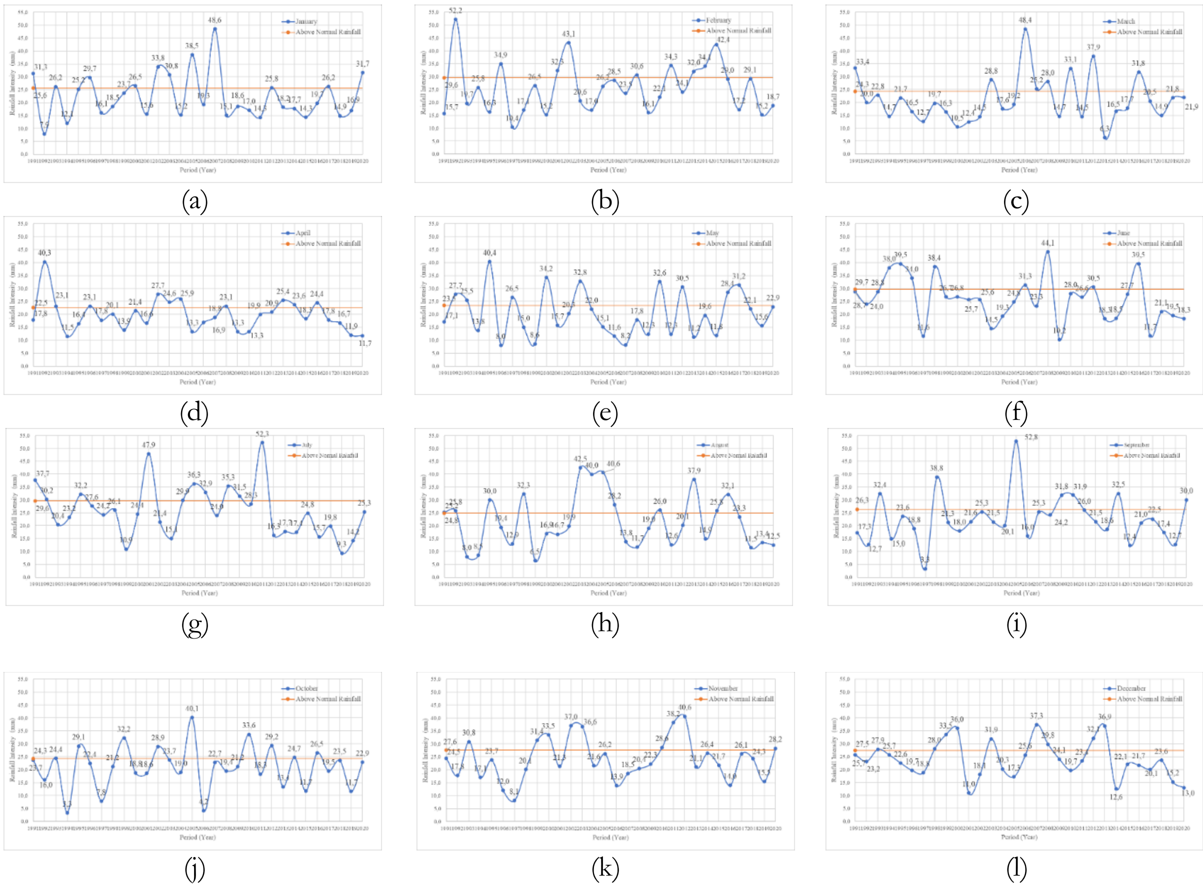


Figure 6. Daily average rainfall for the period 1991- 2020 (a) January (b) February (c) march (d) April
(e) May (f) June (g) July (h) august (i) September (j) October (k) November (l) December

During the last 30 years (1991-2020), the most IOD occurred in August which caused a high frequency of rainfall above normal in that month, as can be seen in Figure 6. This is in accordance with the results of the analysis where a negative IOD has a significant effect on increasing frequency of extreme rainfall. The relationship between negative IOD and extreme rainfall frequency is moderate. This means that the more negative IOD events the frequency of extreme rainfall will also increase.

The strong MJO event did not significantly affect the increase in extreme rainfall in Padang City. These results are in accordance with previous research [17] where the value of the correlation coefficient is negative. This indicates that when a strong MJO event occurs the formation of rain clouds but still has a different phase or delay which causes rain to fall when the MJO has come out of phase 3 or 4.

The increase and decrease in rainfall intensity in Padang City is not only influenced by the Madden Julian Oscillation and Indian Ocean Dipole phenomena, but is also largely influenced by local factors such as the Bukit Barisan mountains which surround Padang City. The wind moving from the east over Bukit Barisan makes the Padang City area a place where winds meet (convergence), which accelerates the process of cloud formation. If sea breezes converge with winds from different directions, “sea breeze fronts” often form which can cause the formation of local clouds and rain. Clouds grow in the convergence zone between these opposing synoptic and local scale systems. Over islands and peninsulas converging sea breeze systems from opposing coasts can cause maximum rainfall [18].

4. Conclusion

Based on the results of the analysis, it can be concluded that: (1) the intensity of normal monthly rainfall in Padang City ranges from 227 mm/month to 588 mm/month, with the lowest average intensity occurring in May at 268 mm and the highest in November of 512 mm. (2) the trend of extreme rainfall in Padang City for 30 years has decreased with a regression coefficient of -0.0412 and -0.0708. The value identifies a decrease in extreme rainfall events each year with a decrease percentage of 4.12% and 7.08%. (3) there is a significant correlation between the number of negative Indian Ocean Dipole (IOD) events and the frequency of extreme rainfall for Minangkabau Meteorological Station and Teluk Bayur Maritime Meteorological Station data. The correlation coefficient value is 0.403 -0.483 which indicates a moderate correlation. There are differences in correlation values for the Bayur Bay Maritime Meteorological Station data due to the location of the station around the hills which causes orographic rain. (4) There is no significant relationship between the numbers of MJO phases 3 and 4 events and the frequency of extreme rainfall. This is because when a strong MJO enters the Padang City area, a cloud growth process occurs and after a strong MJO leaves the area, the clouds that form turn into rain.

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