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The Effect of Triple Dip La Niña on Rainfall in Lombok During 2020–2023

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Abstract: *Triple Dip La Niña* is a term that describes the *La Niña* phenomenon that lasts for 3 consecutive years. History records that this phenomenon last occurred in 1973–1976 and 1998–2001 which influenced the regional weather system through the mechanism of atmosphere-ocean interaction, one of which was in Lombok. This study was conducted to analyze the impact of the emergence of the *Triple Dip La Niña* phenomenon on rainfall variability in Lombok from 2020 to 2023, as well as to test the correlation of the ENSO relationship indicated by the ONI (*Oceanic Niño Index*) indicator with rainfall variables. The data used in this study were monthly rainfall data from 55 rain posts and ONI data from NOAA. The results showed that the influence of *Triple Dip La Niña* on rainfall variability was observed most significantly in the dry season (JJA) with an increase in rainfall >100%. A strong relationship between the ONI index and rainfall was identified in Senaru, Bayan, Janapria, and Pringgabaya.
Keywords: Triple Dip La Niña, rainfall, correlation

1. Introduction

ENSO (*El Niño Southern Oscillation*) is a phenomenon characterized by an increase in sea surface temperatures above normal in the eastern Pacific Ocean (known as *El Niño*) while *La Niña* has the opposite condition [1]. The warming and cooling patterns that occur in the Pacific Ocean form the main cycle in ENSO. The *El Niño* and *La Niña* phase is an extreme phase in the ENSO cycle and between these two phases there is a neutral phase.

Determination of the ENSO phase can be shown using one of the indices, namely the *Oceanic Niño Index* (ONI) [2]. This ONI index refers to the *Niño* 3.4 region located between 5°N to 5°S and 170°W to 120°W and is considered to represent the average SST in the equatorial Pacific region and has a strong correlation with SST in the central and eastern tropical Pacific [3]. In the ONI index, one period or cycle in ENSO is counted if the SST anomaly in the *Niño* 3.4 region exceeds the threshold of ±0.5°C for a minimum of 5 consecutive 3-month periods. *El Niño* or also known as the warm phase occurs when the SST anomaly in the Niño 3.4 region exceeds +0.5°C, in contrast to *La Niña* (cold phase) occurs when the SST anomaly in the *Niño* 3.4 region is less than -0.5°C. Neutral conditions (normal phase) occur when the SST anomaly is in the range of -0.5°C to +0.5°C.

Based on NOAA (United States Oceanic and Atmospheric Administration) monitoring, in mid-2020 to early 2023 the ONI Index value was <-0.5°C which indicated the occurrence of *La Niña*. However, the duration of La Niña that occurred is considered an anomaly because the La Niña period generally lasts for only 9-12 months (single year *La Niña*) [4]. The duration of La Niña that occurred for three consecutive years is known as *Triple Dip La Niña*.

Triple dip La Niña is a rare climatological phenomenon where the *La Niña* phase lasts for three consecutive years, marked by the *Niño* 3.4 index below the threshold of -0.5°C. This indicates the occurrence of continuous sea surface temperatures cooling in the central and eastern Pacific below normal values (negative anomalies) for three years. The frequency of consecutive *La Niña* events (*multi-years La Niña*) has increased in the 21st century due to changes in global warming patterns that cause easterly wind anomalies, thus supporting the persistence of La Niña [5].

The Triple Dip La Niña that occurred in 2020-2023 is not a new phenomenon, previously similar events were recorded in 1973-1976 and 1998-2001. In these two periods, the *Triple Dip La Niña* developed after a strong *El Niño* [6]. However, this statement was refuted by the emergence of the *Triple Dip La Niña* in 2020-2023. The *Triple Dip La Niña* in 2020-2023 is unique because it was not preceded by a strong *El Niño* condition. Zonal advection is the largest contributor in maintaining the persistence of the *Triple Dip La Niña* in the 2020-2023 period despite the relatively weaker subsurface cooling [7]. The presence of subsurface Kelvin waves also plays a role in maintaining the *Triple Dip La Niña* conditions [8]. These Kelvin waves contribute to heat accumulation and thermocline deepening in the Western Pacific. During multi-year *La Niña*, the *Indonesian Throughflow* (ITF) experiences increased transport volume that flows more heat from the Western Pacific Ocean to the Eastern Indian Ocean. As a result, there is a temperature anomaly in the Indian Ocean that triggers subsurface Kelvin waves that transfer heat back to the

Western Pacific Ocean.

The emergence of the *Triple Dip La Niña* phenomenon has an impact on global weather patterns. In the Indonesian region, there are changes in atmospheric dynamics such as strengthening zonal winds, increasing relative humidity, and increasing rainfall [9]. The impact of the *Triple dip La Niña* has also spread widely to Pakistan and China. Floods in Pakistan and drought in South China in the summer of 2022 were caused by the *Triple dip La Niña* phenomenon associated with a very strong negative IOD (*Indian Ocean Dipole*) and negative PDO (*Pacific Decadal Oscillation*) forming a rainfall pattern where Pakistan experiences a rainfall surplus and a rainfall deficit occurs in South China [10].

ENSO is a natural phenomenon involving ocean temperature fluctuations in the central and eastern equatorial Pacific Ocean followed by atmospheric changes [11]. The dynamics in the Pacific Ocean are related to the Indian Ocean which is connected through the circulation of the ITF. The interaction of these two oceans also affects the dynamics of the atmosphere in the Indonesian region, one of which is in the Lombok region [12]. Through the waters of the Lombok Strait as one of the ITF output routes that carry water mass and heat from the Pacific Ocean to the Indian Ocean, it causes variations in sea surface temperatures in the region [13][14]. These variations in sea surface temperatures have a significant effect on rainfall intensity. The increase in sea surface temperature has implications for increasing rainfall because the increase in sea surface temperature indicates an increase in energy in the ocean which provides the possibility of increasing evaporation rates in the atmosphere [15].

Previous studies have analyzed the impact of *La Niña* on rainfall anomalies in the NTB region using data from 2010-2020 which showed that rainfall increased evenly and with high intensity at the peak of the rainy season in the NTB region [16]. However, this study only focused on changes in rainfall during the rainy season. The *Triple Dip La Niña* phenomenon that occurred in the 2020-2023 period is a rare event that has not been included in the analysis of this study. Given the large implications of the *Triple Dip La Niña* phenomenon, especially in influencing the variability of rainfall and sea surface temperature, it is necessary to conduct research that examines changes in rainfall and sea surface temperature during the *Triple Dip La Niña* phenomenon. In addition, this study took the location of Lombok referring to the characteristics of the region with its dynamics and there has been no research discussing this topic in the Lombok region.

2. Material and Methods

2.1. Materials

The monthly rainfall data used is observational rainfall data from 55 rainfall posts spread throughout the Lombok region. The data comes from the West Nusa Tenggara Climatology Station rainfall database. Monthly rainfall data from 2004 to 2023 will be processed to obtain rainfall anomaly data. Meanwhile, the ONI Index data was obtained from the *Climate Prediction Center (CPC) - NOAA* (https://origin.cpc.ncep.noaa.gov) during the 2020-2023 period. The ONI Index data is used to review the *Triple Dip La Niña* period and as a parameter tested in the verification that represents the *Triple Dip La Niña* conditions in their influence on rainfall.

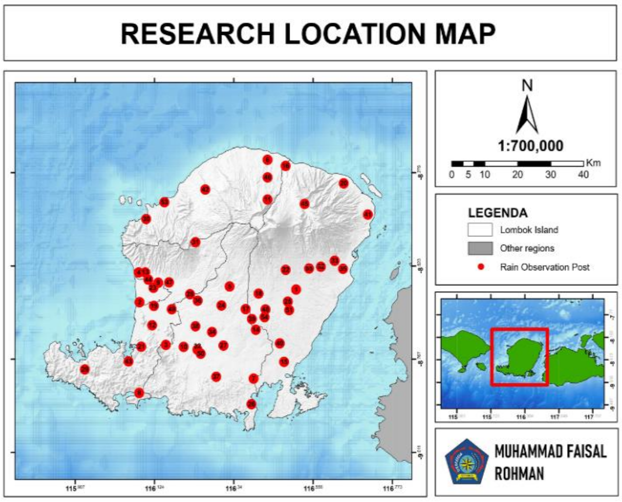


Figure 1. Research Location

2.2. Methods

This study will discuss the impacts caused by the *Triple Dip La Niña* phenomenon on rainfall parameters. Based on this, this study uses a combination of qualitative and quantitative approaches, namely comparative causal and descriptive methods. The comparative causal method is used to identify and analyze the causal relationship between independent variables (influencing variables) and dependent variables (influenced variables). This study will examine changes in rainfall associated with the emergence of the *Triple Dip La Niña* phenomenon. Meanwhile, the descriptive method is used to present a clear and accurate picture of the material and phenomena being investigated based on data that has been collected and compiled, then analyzed using analytical techniques [17].

2.3. Data Analysis

2.3.1. Spatial analysis of rainfall variability

Spatial analysis will show the distribution pattern and rainfall anomalies in the Lombok region. The magnitude of the rainfall anomaly is expressed in the form of a percentage of anomalies whose values can be positive (indicating an increase in rainfall) and negative (indicating a decrease in rainfall). To calculate the rainfall anomaly, the rainfall anomaly percentage formula is used, which is formulated as follows [18]:

$$Anomaly = \frac{x - x_0}{x_0} \times 100\% \quad (1)$$

Information:

x : Average rainfall during *Triple Dip La Niña*

x_0 : average rainfall during the period 2003 to 2004 (normal data)

2.3.2. Analysis of correlation results

The influence of *Triple Dip La Niña* as a trigger for changes in rainfall is shown through the correlation coefficient which describes the relationship and interaction of the two variables. The correlation coefficient shows the level of closeness of the relationship between two or more variables. This study uses the Pearson correlation coefficient method to test the strength of the influence of *Triple Dip La Niña* in influencing rainfall. The Pearson correlation coefficient can show positive and negative values with intervals from +1 to -1. The direction of the correlation coefficient relationship is expressed in the form of a positive or negative relationship, while the strength of the relationship is expressed in magnitude [19]. If the correlation coefficient is +1, it indicates a perfect positive correlation (a relationship that is directly proportional/unidirectional), a correlation coefficient of -1 indicates a perfect negative correlation (an inversely proportional/non-unidirectional relationship), while a correlation coefficient of 0 indicates no correlation or no relationship at all [20]. The Pearson correlation coefficient equation is expressed through the following equation [19]:

$$r = \frac{n\sum(XY) - (\sum X)(\sum Y)}{\sqrt{[n\sum X^2 - (\sum X)^2] - [n\sum Y^2 - (\sum Y)^2]}} \qquad (2)$$

Information:

r : correlation coefficient between X and Y

X : Nino index 3.4

Y : parameter value (rainfall)

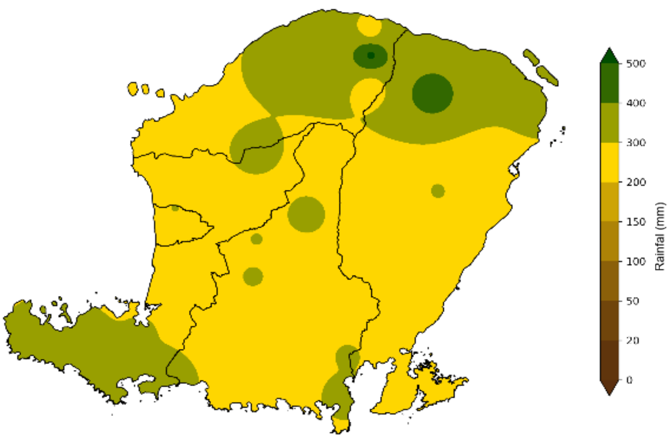
n : amount of data

3. Results and Discussion

3.1. Result

3.1.1. Rainfall

a. Rainfall for DJF Period (December-January-February)



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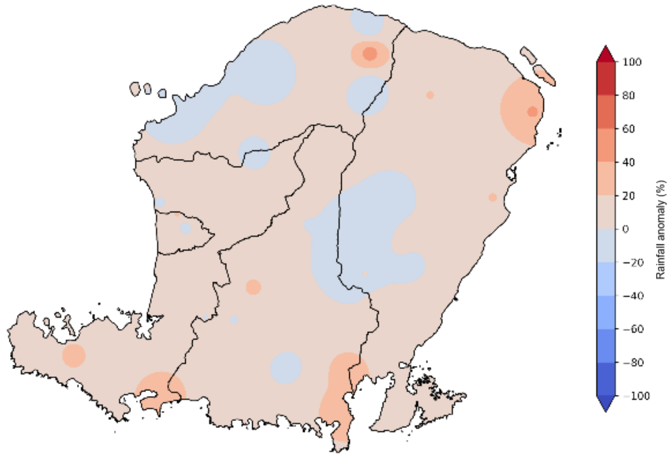
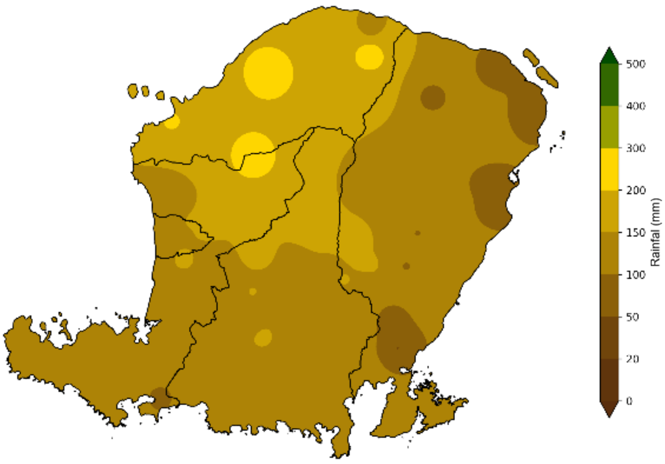


(b)

Figure 2. Spatial patterns of a) rainfall distribution and b) rainfall anomalies in DJF during the *Triple Dip La Niña* period 2020-2023.

Based on Figure 2.a, variations in rainfall distribution on Lombok Island during the DJF period are visible. Spatially, the northern region of Lombok shows higher rainfall intensity compared to other regions with rainfall reaching 400-500 mm, especially in Senaru and Sembalun which are marked with dark green. Meanwhile, the central to southern part of Lombok is dominated by yellow indicating lower rainfall intensity compared to the northern region with rainfall ranging from 200-400 mm. Several areas in the central and southern parts of Lombok are also observed to have moderate/medium rainfall intensity indicated by light green such as in North Batukliang, Pelangan, Sekotong, and Bilelando.

Anomalies shown in Figure 2.b, the distribution of positive anomalies appears more dominant than negative anomalies. The large increase in rainfall during this period can reach 40% which is seen in several areas in the northern and southern parts of Lombok as shown by the distribution of pale pink and orange colors in the image. The Senaru area located in the northern part of Lombok was observed to experience the most significant increase in the DJF season during the *Triple dip La Niña* period 2020-2023. Meanwhile, there are areas marked in light blue which are spread across the eastern and northern parts of Lombok indicating negative anomalies. This decrease in rainfall was observed in areas such as Sikur (eastern part), Bayan, and Gangga (northern part) with rainfall decreasing by 20% as shown in light blue. This distribution pattern also shows that areas with high rainfall intensity do not always indicate a positive anomaly *b. Rainfall MAM Period (March-April-May)*



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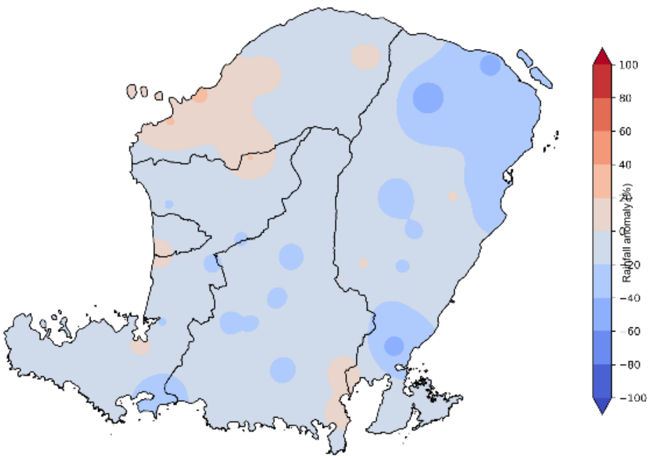


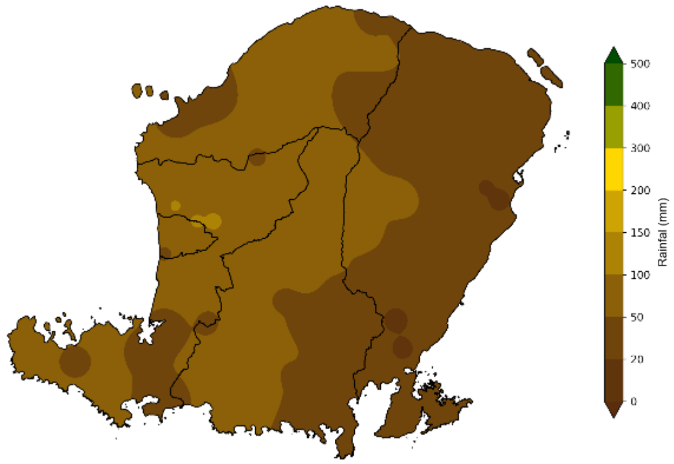
(b)

Figure 3. Spatial patterns of a) rainfall distribution and b) rainfall anomalies in MAM during the *Triple Dip La Niña* period 2020-2023

From Figure 3.a, it can be seen that the rainfall intensity in Lombok during the MAM period was lower compared to the previous DJF season. During this period, rainfall was recorded ranging from 40-300 mm with minimum rainfall occurring in the eastern part of Lombok such as in the Sakra, Sambelia, and Pringgabaya areas which are indicated by the dark brown color. Meanwhile, the highest rainfall was observed in the Gangga, Senaru, and Pemenang areas (northern part) with rainfall reaching 200-400 mm which is indicated by the bright yellow color. When viewed spatially, the highest rainfall distribution is still concentrated in the northern region, especially around northwest Lombok which is indicated by the dominant yellow color.

The rainfall anomaly shown in Figure 3.b shows that most of Lombok experienced negative anomalies with a decrease in rainfall reaching -20 to -50% in the MAM season during the *Triple dip La Niña* period. The area showing the largest negative anomaly was observed in Sembalun with rainfall decreasing by up to 50% from normal conditions which is shown in the image by the dark blue color gradation. Followed by the Jerowaru area (southern part) and Labuhan Pandan (eastern part) which experienced the second largest decrease in rainfall of 40% which is marked by a lighter blue color. This pattern is inversely proportional to the previous period which was dominated by positive anomalies. Positive anomalies were observed to be spread only in coastal areas, especially in the northwest and a small part of the southern part of Lombok which includes the Pemenang, Tanjung, and Bilelendo areas which are shown in pink.

c. Rainfall Period JJA (June-July-August)



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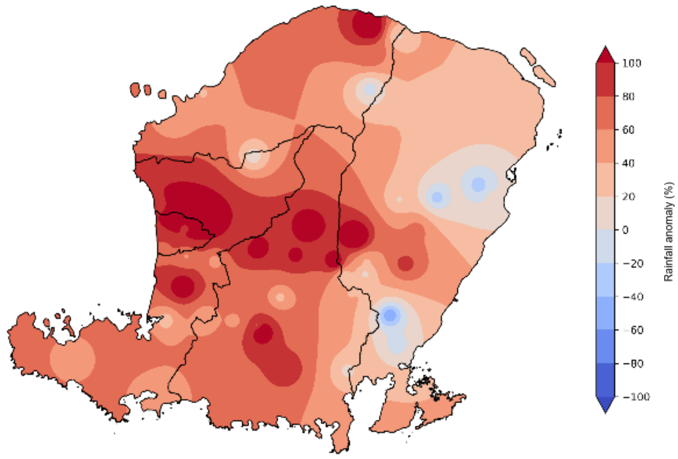


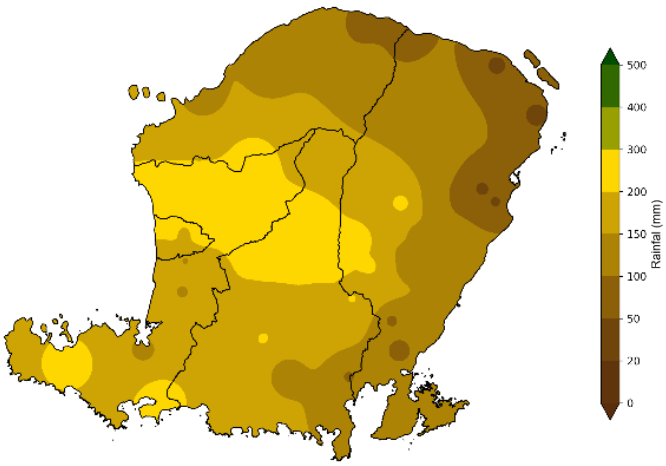
(b)

Figure 4. Spatial patterns of a) rainfall distribution and b) rainfall anomalies in SON during the Triple Dip La Niña period 2020-2023.

Based on Figure 4.a shows the distribution of rainfall in Lombok during the dry season (JJA) with low rainfall. In this season, rainfall is observed to range between 5-100 mm. The eastern part of Lombok Island shows lower rainfall intensity compared to the western region which is marked with a darker brown color. Areas such as Sakra, Jerowaru, and Pringgabaya which are located in the eastern part of Lombok have low rainfall (>20 mm) which can be seen in the image with a dominant dark brown color in the area. While in the western part, the highest rainfall is concentrated in the Cakranegara, Sigerongan, and Gunung Sari areas with rainfall intensity reaching 100 mm as shown in the image with a lighter brown color.

The rainfall anomaly map presented in Figure 4.b shows significant spatial variations that can be seen from the difference in color contrast. In the western and central parts of Lombok, there are strong positive anomalies. In several areas in the region, there are positive anomalies with an increase in rainfall reaching >100% as observed in Cakranegara, Sigerongan, Gunung Sari, Gerung, and North Batukliang which are indicated by the dark red color on the map. The high rainfall observed in Cakranegara, Sigerongan, and Gunung Sari during the JJA season indicates a significant trend of increasing rainfall in the region. Not only in the western and central areas of Lombok, strong positive anomalies are also observed in the northern part of Lombok, precisely in the Bayan area which is also marked by the dark red color. The anomaly map shows a spatial pattern dominated by positive anomalies, although there are several areas in the eastern part of Lombok that are observed to experience a decrease in rainfall represented by the light blue color.

d. Rainfall SON Period (September-October-December)



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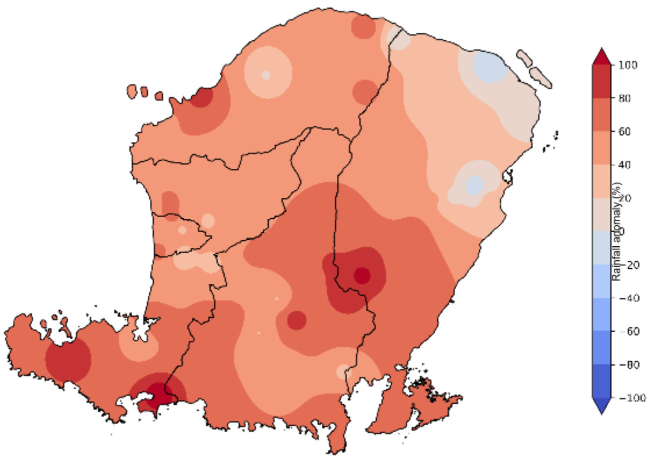

(b)

Figure 5. Spatial patterns of a) rainfall distribution and b) rainfall anomalies in SON during the *Triple Dip La Niña* period 2020-2023

The distribution of rainfall during the SON period shown in Figure 5.a shows a tendency for a pattern similar to the JJA period, but the observed rainfall intensity is higher with rainfall ranging from 40-300 mm. The western and central parts of Lombok show higher rainfall intensity as indicated by the bright yellow color. Meanwhile, rainfall intensity decreases in the eastern part of Lombok as indicated by the increasingly dark brown color gradation. The Sambelia, Pringgabaya, and Labuhan Pandan areas located in the northeastern part of Lombok are recorded to have the lowest rainfall during the SON period with rainfall of 40-45 mm as indicated by the dark brown color.

From Figure 5.b which describes the distribution of rainfall anomalies, it shows that there are still strong positive anomalies in several areas such as Terara (eastern part) and Buwun Mas (southern part) with an increase in rainfall of >100% which is marked by dark red. Meanwhile, other areas that were also observed to experience positive anomalies experienced an increase in rainfall of 20-90% which is indicated by a gradation of pink to red. Areas that experienced a significant increase in rainfall in this period tended to be fewer than the JJA period, but the dominance of positive anomalies and negative anomalies in the east was also observed in the SON period.

3.1.2. *Correlation of ONI Index and Rainfall*

a. *Correlation of ONI Index and DJF Period Rainfall*

Based on Table 1 which contains Pearson correlation data between two variables (rainfall and ONI index) along with the p-value stating the significance of the relationship for each location, it can be seen that there is a dominant negative relationship between the ONI index and rainfall which indicates an inverse relationship. This means that rainfall is higher when the ONI index is lower (indicating *La Niña*). While a positive correlation indicates a unidirectional relationship which means that there is a decrease in rainfall along with the low ONI index. This was observed at the Batulayar rainfall post ($r = 0.461$) and the Zainuddin Abdul Madjid Meteorological Station ($r = 0.452$) which had a positive correlation with a moderate relationship level.

During the DJF period, the Senaru rainfall station showed a very strong correlation ($r = -0.839$) and was the only location that had a significant relationship with a p-value of 0.009 (p-value <0.05). A strong correlation was also observed in Perigi ($r = -0.618$), but was not statistically significant (p-value = 0.102). Meanwhile, other locations such as Jerowaru, Mertak, Bilelando, Pringgabaya, West Sakra, Sambelia, and Swela showed a negative correlation with a moderate level of relationship that was identified as not significant.

Table 1. Significance of moderate-very strong correlation levels between rainfall and the ONI index during the DJF period.

Location	R	Relationship Level	P-Value	Significance
Batulayar	0.46144	Currently	0.24976	Not Significant
Jerowaru/Sepapan	-0.46760	Currently	0.24265	Not Significant
Mertak	-0.52548	Sedang	0.18107	Not Significant
Mujur2/Bilelando	-0.48832	Currently	0.21954	Not Significant
Perigi	-0.61819	Strong	0.10234	Not Significant
Pringgabaya	-0.46944	Currently	0.24056	Not Significant
Sakra Barat	-0.49762	Currently	0.20954	Not Significant
Sambelia	-0.51742	Currently	0.18908	Not Significant
Senaru	-0.83935	Very strong	0.00915	Significant
Stasiun Meteorologi Zainuddin Abdul Madjid	0.45167	Currently	0.26124	Not Significant
Swela	-0.53107	Currently	0.17562	Not Significant

Figure 6 presents the spatial pattern of the relationship between rainfall and ENSO in the DJF season. In the figure, the blue color shows a negative correlation, meaning that ENSO conditions (in the *La Niña* phase) are related to increased rainfall. While the red color shows a positive correlation, indicating a decrease in rainfall. The darker the blue/red color, the stronger the correlation.

From the map in Figure 6, it can be seen that the northern and northeastern areas of Lombok show a strong correlation marked in dark blue. This indicates that during *La Niña* conditions the area shows a response to increased rainfall. On the other hand, a positive correlation is observed spread across several areas in the central and western parts of Lombok indicating a decrease in rainfall in the area.

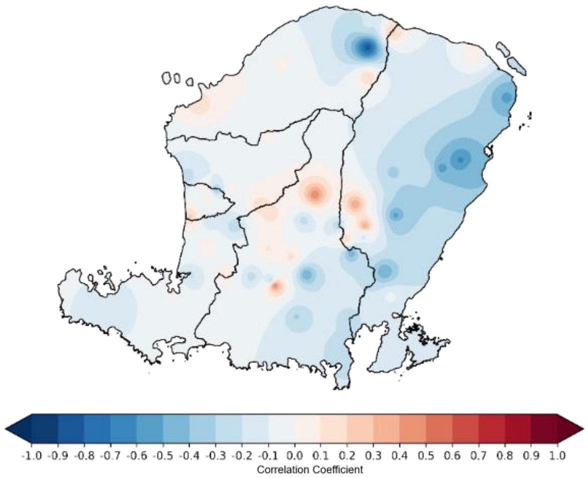

Figure 6. Spatial pattern of correlation coefficient between rainfall and ONI for the DJF period

b. *Correlation of ONI Index and Rainfall in MAM Period*

During the *Triple dip La Niña* period in the MAM season there was no significant correlation between rainfall and the ONI index as shown in Table 2. The correlation of rainfall and the ONI index in almost all rainfall observation posts showed a negative correlation and only the Ampenan area was observed to have a positive correlation (r = 0.471) with a moderate level of relationship. The strongest negative correlation was observed at the Zainuddin Abdul Madjid Meteorological Station rainfall post (r = -783) followed by Pelangan (r = -0.763) and Banyu Urip (r = -0.746). Although these locations showed a strong correlation, it was still not significant with a p-value > 0.05.

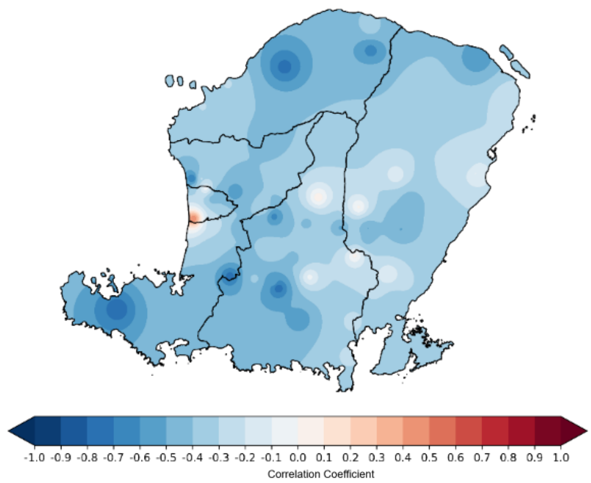

Figure 7. Spatial pattern of correlation coefficient between rainfall and ONI MAM period

Table 2. Significance of moderate-strong correlation levels between rainfall and the ONI index during the MAM period

Location	R	Relationship Level	P-Value	Significance
Aikmel	-0.48953	Currently	0.32435	Not Significant
Ampenan	0.47111	Currently	0.34560	Not Significant
Banyu Urip/Banter	-0.74556	Strong	0.08887	Not Significant
Batukliang Utara	-0.69283	Strong	0.12703	Not Significant
Cakranegara	-0.41115	Currently	0.41801	Not Significant
Darek	-0.49572	Currently	0.31731	Not Significant
Gerung	-0.40826	Currently	0.42162	Not Significant
Kopang	-0.47897	Currently	0.33647	Not Significant
Kotaraja/Montong Gading	-0.51128	Currently	0.29989	Not Significant
Lembar	-0.57604	Currently	0.23150	Not Significant
Lenek Duren	-0.43314	Currently	0.39091	Not Significant
Mantang	-0.43948	Currently	0.38321	Not Significant
Masbagik	-0.41497	Currently	0.41327	Not Significant
Mertak	-0.48711	Currently	0.32711	Not Significant
Pelangan	-0.76340	Strong	0.07734	Not Significant
Pemenang Timur	-0.46681	Currently	0.35064	Not Significant
Penujak	-0.56907	Currently	0.23853	Not Significant
Praya	-0.41415	Currently	0.41428	Not Significant
Pringgarata	-0.63300	Kuat	0.1773	Not Significant
Pujut	-0.57407	Currently	0.23348	Not Significant
Sambik Bangkol	-0.73733	Strong	0.09442	Not Significant
Sekotong	-0.48171	Currently	0.33331	Not Significant
Senaru	-0.64241	Strong	0.16893	Not Significant
Sigerongan	-0.60067	Strong	0.20734	Not Significant
Sikur	-0.50146	Currently	0.31084	Not Significant
Stasiun Klimatologi Nusa Tenggara Barat	-0.44161	Currently	0.38064	Not Significant
Stasiun Meteorologi Zainuddin Abdul Madjid	-0.78354	Strong	0.06520	Not Significant
Sukamulia/Dasan Lekong	-0.50190	Currently	0.31036	Not Significant
Terara	-0.44617	Currently	0.37515	Not Significant

Figure 7 shows the spatial correlation map between rainfall and ONI index during the MAM season in Lombok. The dominance of blue color indicating negative correlation with varying intensity is observed in almost all areas of Lombok Island. Strong negative correlation is marked by darker blue color observed in several areas in the western and central parts of Lombok.

c. *Correlation of ONI Index and Rainfall in JJA Period*

From Table 3, it can be seen the strength of the correlation and the significance of the relationship between the ENSO index and rainfall during the JJA season. In terms of the strength of the correlation, most areas show a dominant negative correlation. Only one location, Tanjung, has a positive correlation (r = 0.441) which is included in the moderate category. Bayan is an area with a very strong correlation (r = -0.816) followed by Janapria which has a strong correlation (r = -0.759).

In terms of the significance of the relationship, the locations that showed significant results were Bayan (p-value = 0.025) and Janapria (p-value = 0.048). This indicates that the correlation that occurred can be considered statistically significant. Meanwhile, other areas showed results that were not statistically significant even though they were observed to have a correlation.

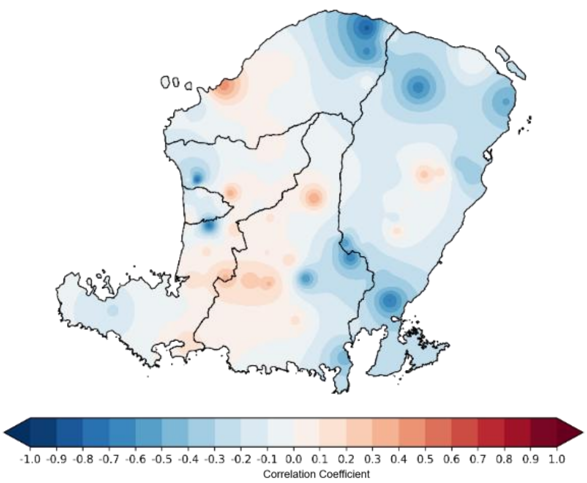

Figure 4.8 Spatial pattern of correlation coefficient between rainfall and ONI for the JJA period

Judging from the spatial pattern of the relationship between rainfall and ENSO in the JJA season as presented in Figure 8, the distribution of negative correlations is spread across almost all areas of Lombok. The northern and northeastern regions show a strong correlation dominance marked by a darker blue color. Meanwhile, positive correlations tend to be concentrated in the western and central parts of Lombok, although negative correlations are still observed in several areas.

Table 3. Significance of moderate-very strong correlation levels between rainfall and the ONI index in the JJA period

Location	R	Relationship Level	P-Value	Significance
Bayan	-0.81671	Very strong	0.02495	Significant
Janapria	-0.75920	Strong	0.04776	Significant
Jerowaru/Sepapan	-0.69951	Strong	0.08022	Not Significant
Kokok Putih/Sembalun	-0.70400	Strong	0.07745	Not Significant
Labuhan Pandan	-0.72880	Strong	0.06316	Not Significant
Mujur	-0.44964	Currently	0.31142	Not Significant
Mujur2/Bilelando	-0.58580	Currently	0.16696	Not Significant
Rarang Selatan	-0.57236	Currently	0.17932	Not Significant
Sambelia	-0.50870	Currently	0.24366	Not Significant
Sembalun	-0.64363	Strong	0.11879	Not Significant
Senaru	-0.62058	Strong	0.13700	Not Significant
Tanjung	0.44191	Currently	0.32083	Not Significant

d. *Correlation of ONI Index and SON Period Rainfall*

The analysis of the correlation results in Table 4 shows that during the SON period, the ONI index has a fairly strong correlation with the variation in rainfall observed in Lombok. During the SON period, for the moderate-very strong relationship level, the correlation between rainfall and the ONI index at almost all rainfall posts shows a negative correlation, but only the Gangga area is observed to have a positive correlation (r = 0.473) with a low relationship level. A very strong correlation was observed in the Pringgabaya area and the correlation coefficient value was 0.8615 and the p-value was at 0.003, which means that the correlation that occurred in the area was significant. Other locations such as Banyu Urip, Bayan, Labuapi, Lembar, Pelangan, Sambelia, Sekotong, and Selaparang showed a moderate negative correlation with a range of correlation coefficient values between -0.40 and -0.599.

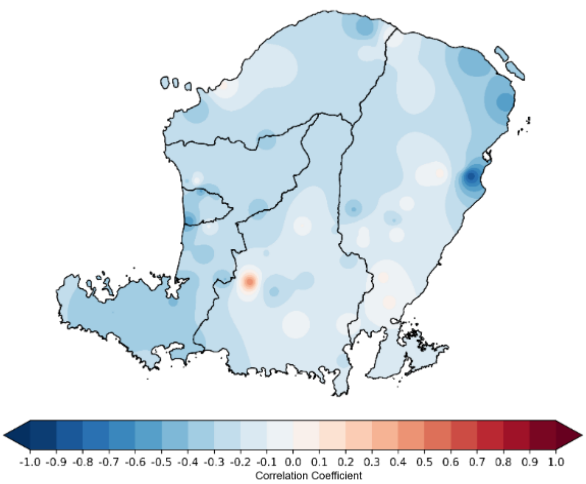

Figure 9. Spatial pattern of correlation coefficient between rainfall and ONI SON period

The correlation of rainfall in Lombok with the ONI index during the SON season shows a negative correlation with a very low to very strong correlation level in most areas in Lombok (Figure 9). Along the central to eastern Lombok region, a weak and neutral negative correlation is observed, even a reddish orange color is seen indicating a positive correlation in the region. The northeastern region of Lombok, especially the coastal area, shows a strong correlation compared to other regions.

3.2. Dicussion

3.2.1. Rainfall

a. *DJF Period Rainfall*

The peak of the rainy season in Indonesia is the DJF period (December-January-February) which is influenced by the movement of the *Intertropical Convergence Zone* (ITCZ) to the south of the equator. When the ITCZ moves south, areas in Indonesia generally experience increased humidity and convection which causes high rainfall. The high rainfall during this period is associated with the active Asian monsoon and depends on topographic conditions [21].

Based on Figure 2.a, the distribution of rainfall in the Lombok region during the DJF period is relatively high with the northern region of Lombok showing very high rainfall intensity. This is influenced by the topography of the northern region which is relatively flat and open so that the west monsoon winds that bring moisture are not orographically disturbed. The second influencing factor is the orographic effect of the presence of Mount Rinjani which causes the northern and western regions of the mountain to receive more rainfall with maximum rainfall reaching 400 mm/month [22].

Table 4. Significance of medium-strong correlation level between rainfall and ONI index in the SON period

Location	R	Relationship Level	P-Value	Significance
Ampenan	-0.57014	Currently	0.10896	Not Significant
Banyu Urip/Banter	-0.40434	Currently	0.28041	Not Significant
Bayan	-0.49775	Currently	0.17270	Not Significant
Gangga	0.473902	Currently	0.19749	Not Significant
Labuapi	-0.4151	Currently	0.26656	Not Significant
Lembar	-0.47415	Currently	0.19722	Not Significant
Pelangan	-0.4002	Currently	0.28584	Not Significant
Pringgabaya	-0.8615	Very strong	0.00283	Significant
Sambelia	-0.53603	Currently	0.13685	Not Significant
Sekotong	-0.41435	Currently	0.26752	Not Significant
Selaparang	-0.52064	Currently	0.15069	Not Significant

The formation of orographic clouds that trigger high rainfall in the region occurs when moist air masses from the sea rise and interact with the mountain slopes. The combination of these two local factors is further strengthened by the emergence of the *Triple Dip La Niña* phenomenon as a trigger for rainfall that synergistically modulates high rainfall variability. In several areas of southern Lombok that border the waters also show high rainfall. This indicates that there is a strong response from the atmosphere-ocean interaction so that it becomes one of the factors causing increased rainfall by providing a supply of water vapor from the waters [23]. However, not all coastal areas are observed to experience increased rainfall. This is influenced by the lag time between SST changes and atmospheric response [24].

From Figure 2.b, in general, during the DJF period there was a slightly higher increase in rainfall compared to normal conditions. This increase is related to the *Triple Dip La Niña* phenomenon of 2020-2023 which has an impact on rainfall variability, although not very significant. During the DJF period, *La Niña* did not have a significant impact on increasing rainfall in central and western Indonesia [25]. The decrease in rainfall tends to be more significant in western Indonesia. The anomaly map also shows that several areas experienced a decrease in rainfall compared to normal which was unevenly distributed. During this DJF period, the rainfall pattern tends to still follow climatological conditions with several areas experiencing an increase and decrease in rainfall. The trend of changes in rainfall tends to be weak with small, insignificant fluctuations. The rainfall anomaly in Lombok during the DJF period generally has a value of at least ≥40% with the North Lombok and northern East Lombok areas tending to experience a higher increase in rainfall than other areas [16]. This spatial pattern indicates the strong influence of local factors such as topography and local wind circulation which modify the impact of *La Niña* on rainfall distribution [26].

b. *Rainfall MAM Period*

The MAM period (March-April-May) is the first transition season or better known as the transition period from the rainy season to the dry season in Indonesia. During this period, the influence of the western monsoon gradually weakens and the initial influence of the eastern monsoon begins to enter. The movement of rain to the north does not occur gradually following the Australian monsoon wind pattern [27]. In addition, several factors that inhibit the movement of rain to the north during the MAM period include the absence of a strong pressure gradient between land and sea, weak Kelvin currents in the Equatorial Western Pacific, divergence zones, and subsidence in the sea area.

The spatial pattern of rainfall distribution in Figure 3.a shows the highest rainfall concentration in the northwest region which includes North Lombok, parts of West and Central Lombok. This area with higher rainfall intensity is still influenced by the remaining wet air mass from the rainy season which is starting to end and is supported by warmer SST conditions in northwest Lombok causing increased evaporation and the formation of convective clouds. Meanwhile, the decrease in rainfall in the eastern region of Lombok is due to the influence of dry air from the Australian monsoon winds which are starting to appear in the MAM season.

Figure 3.b shows changes in rainfall during the MAM season leading to a decrease in rainfall intensity that almost hit all areas of Lombok. In the transition season I, the influence of *Triple Dip La Niña* on rainfall in Lombok tends to weaken and even appears to disappear during this season. The MAM period is the season with the weakest influence of ENSO on rainfall variability as evidenced by the results of the correlation of the ENSO index and rainfall which are not significant in most areas in Indonesia [28]. As the global climate phenomena is minimum during the season, the rainfall variability during this season probably caused by regional or even local climate variability. From Figure 3.b, it can also be seen that several areas still experience positive anomalies during the MAM season in the *Triple Dip La Niña* period. This complexity is associated with the local convection system which plays a greater role in the formation of rain compared to ENSO as a triggering factor. The

existence of Super Cloud Cluster (SCC) cloud formation activity which is influenced by warming and topography as well as interseasonal variations, such as MJO, has a significant effect on rainfall patterns in this period [29]. The emergence of cyclones in the Southern Hemisphere, especially those formed in the southern waters of Lombok, also modulates rainfall variability during this period. As in the case of Cyclone Quang that occurred in April 2015. The occurrence of heavy to extreme rainfall triggered by this cyclone was caused by the deflection of winds to the south which caused a convergence area between the winds deflected by the cyclone and the easterly winds [30]. The study also explained that the opportunity for heavy to extreme rainfall is very large when the cyclone is in the tropical depression phase, so it has the potential to increase rainfall intensity.

c. *Rainfall Period JJA*

Lombok is included in Region A with clear seasonal differences where the dry season occurs in the JJA period (June, July, August) [31]. During this period, the lowest rainfall was recorded in August. This is due to the position of the sun in the northern hemisphere which causes the southern part of Indonesia to be influenced by the movement of the east-southeast monsoon winds from Australia which bring dry air [21]. However, during the La Niña period, this pattern can change because the increase in sea surface temperatures around the Indonesian region strengthens the walker circulation and increases convection and rainfall [24].

Figure 3.a shows that during the JJA season, the Lombok region experiences a rainfall deficit, especially in the eastern part of Lombok. The low rainfall in the region is related to the movement of the southeast monsoon winds originating from Australia where dry air masses will first interact with the eastern region of Lombok Island, causing minimal rainfall. As the monsoon moves northwestward, the effect of the monsoon winds weakens in the west and north. The warmer SST conditions in the western part of Lombok Island and topographic effects are also factors that cause higher rainfall in the western and central parts of Lombok.

During the *Triple dip La Niña* period, rainfall in this season was observed to reach 100 mm. This value is quite high considering that during the JJA season the Lombok region received rainfall <80 mm [32]. This indicates that the Triple dip La Niña phenomenon modifies the normal pattern of the JJA season which is the dry season by having a strong influence on increasing rainfall. Changes in rainfall intensity can be seen from the rainfall anomaly map presented in Figure 3.b. The map shows that most of the Lombok region experienced increased rainfall with several areas in the western and central parts of Lombok showing positive anomalies reaching >100%. The magnitude of the change in rainfall during the JJA period was influenced and triggered by global-scale atmospheric-ocean phenomena such as ENSO. The peak of ENSO events occurred in August in the JJA season and September in the SON season [33][24][31]. Meanwhile, the eastern region of Lombok was observed to experience a weak positive anomaly. Similar things are also observed in rainfall anomalies in South Sulawesi during the La Niña year, which shows that during the dry season (JJA) there is a drastic increase in rainfall with positive anomalies of >70% [34]. However, the effects are not always the same in several areas due to seasonal differences topography and the emergence of other global phenomena that accompany the *La Niña* period.

d. *Rainfall in the SON Period*

Similar to the MAM period, the SON period (September-October-November) also includes a transitional season in Indonesia which is marked by the transition of the Asian-Australian monsoon winds. However, in the SON period, the movement of rain moving south occurs gradually due to the push of the monsoon winds and a clear pressure gradient between Asia and the Indian Ocean [27]. The variability of rainfall in this period is also influenced by the emergence of global phenomena such as ENSO. The influence of ENSO is seen to decrease in the western region and shift to the eastern region of Indonesia [28][25].

In the SON period, the monsoon transition is more towards the movement of the Asian monsoon which brings moist air. This is what causes the western and central areas of Lombok to have higher rainfall intensity as shown in Figure 4.a. Meanwhile, the spatial pattern observed in the eastern region, especially the northeastern region of Lombok, shows a rain shadow effect phenomenon where the area behind the mountain receives less rainfall because the air mass has lost most of its water vapor content after passing through the mountainous area. In the *La Niña* phase, large-scale vertical movements associated with the Walker circulation and local-scale wind cycles contribute to increased rainfall in the SON period [26].

Eastern regions such as Nusa Tenggara, Sulawesi, and Maluku experienced increased rainfall (wet anomalies) during the *La Niña* phase in the SON season [25]. This condition is in line with the findings of this study which are shown in Figure 4.b. In general, the SON period showed a dominant positive anomaly in the Lombok region. The Triple dip La Niña phenomenon that occurred in 2020-2023 also contributed to the variability of rainfall in Lombok which was reflected in the dominance of positive anomalies in the SON period although with a lower intensity than the JJA period. This indicates that the influence of prolonged *La Niña* still has a significant impact on increasing rainfall in this region. Although the map does not show a clear pattern of positive anomaly distribution. This illustrates the complexity of local influences in modifying the influence of *La Niña* on changes in rainfall. In November, a significant positive anomaly was observed in the central part of

Lombok and part of the east coast of Lombok experienced a decrease in rainfall [16].

3.2.2. Correlation of ONI Index and Rainfall

a. *Correlation of ONI Index and DJF Period Rainfall*

The DJF period is the peak of the rainy season including in Lombok. The findings in this study indicate a significant strong correlation between rainfall and the ONI index in one of the rain posts, namely Senaru. Although the influence of *La Niña* on rainfall tends to weaken after September and changes in rainfall in the following period are associated with the Asian monsoon [35]. However, the influence of *La Niña* does not completely disappear in all areas, such as in the Senaru area which still responds positively to increased rainfall in this period. This indicates the relationship between ENSO in modulating monsoon changes so that it affects rainfall variability. *La Niña* can strengthen the Asian monsoon depending on the *La Niña* phase and its location [36]. In East Asia, *La Niña* strengthens the East Asian cold monsoon through wind anomalies from the north. While the effect in Southeast Asia is an increase in rainfall due to the strengthening of water vapor flow.

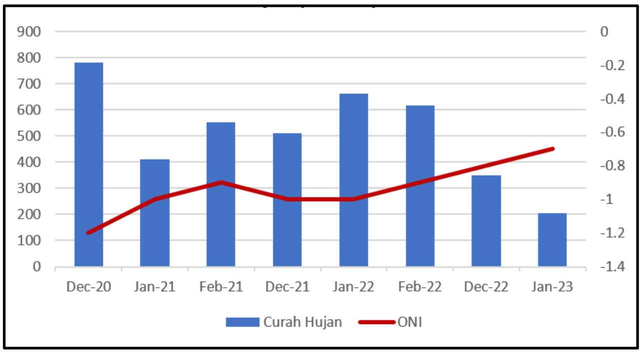

Figure 10. Rainfall pattern and ONI index in Senaru during the DJF period

The graph in Figure 4.10 containing rainfall distribution data for the Senaru area and the ONI index shows that when the ONI index value is at a more negative value, meaning that *La Niña* conditions are stronger, rainfall tends to be higher. Conversely, when the ONI index shows an increasing trend, meaning that *La Niña* conditions are weakening, rainfall actually decreases drastically.

The dominance of negative correlations observed in the DJF period shows that most of the Lombok region experienced increased rainfall. The greatest impact of ENSO on rainfall fluctuations in the DJF season occurred in the northern and southern parts of Indonesia, especially in parts of the Java Sea, parts of the Nusa Tenggara Islands, parts of northeast Sulawesi Island, parts of the Maluku Islands, and a small part of Papua [28].

b. *Correlation of ONI Index and Rainfall in MAM Period*

In the MAM period, there was no significant relationship between rainfall and the ONI index, although in some rain posts it showed a strong correlation. Similar things were also found in the Smarang area which showed a correlation between rainfall and the ENSO index in the MAM period which showed an insignificant correlation accompanied by a unidirectional relationship between rainfall variations and the ENSO index [37]. The absence of a significant pattern in this period indicates that the effect of La Niña on rainfall changes is not dominant due to the emergence of phenomena other than ENSO in influencing rainfall such as MJO and tropical cyclones.

The ENSO signal weakened during this transition period. The influence of ENSO on atmospheric dynamics during the MAM period weakened, especially in the western and southern parts of Indonesia. The decrease in the strength of the LLW (Low-Level Wind) was the main cause of the reduced supply of water vapor and also had an impact on the MF (Mass Flux) which also weakened and increased OLR (Outgoing Longwave Radiation) [38]. The 2020-2023 *Triple Dip La Niña* period also did not show any strengthening of zonal winds and there was a decrease in rainfall in the Bali-Nusa Tenggara region during the MAM season, which is contrary to the characteristics of *La Niña* which is associated with increased rainfall [9]. This strengthens the findings of the study and supports the previous theory which states that there is no clear or significant relationship between rainfall and ENSO during the MAM season.

c. *Correlation of ONI Index and Rainfall in JJA Period*

In general, negative correlations are observed to dominate almost all areas of Lombok in each period. The strength of this relationship is associated with the intensity of ENSO. In the *La Niña* phase with a moderate category, it tends to produce a negative correlation with very low to moderate intensity [39]. This is in line with the findings of this study considering that the *Triple Dip La Niña* conditions of 2020-2023 which are in the moderate category also produce a negative relationship with correlation levels ranging from very weak to moderate, even very strong correlations are observed. In addition to intensity, the influence of ENSO also depends on the period of ENSO [40].

The JJA period is known as the peak of ENSO events in Indonesia. The strongest *La Niña* impact occurs in the JJA and SON seasons with effects that move dynamically from southern Indonesia, then towards and ending in eastern Indonesia [41]. Based on Table 3, it can be seen that the Bayan and Janapria regions have a significant relationship between rainfall and the ONI index. When viewed geographically, the Bayan region is located north of Lombok Island. This indicates that the northern coastal area of Lombok Island tends to be responsive to changes in rainfall due to the ENSO phenomenon compared to other regions. A similar thing is also seen in the northern region of

Java which tends to be responsive to the ENSO phenomenon as indicated by a strong and significant correlation during the JJA and SON seasons [42]. The topographic factor of the northern coastal area of Java with relatively flat topography causes minimal orographic influence that can modify weather patterns [26]. On Java Island, the mountainous area is mostly located on the southern coast of Java so that the northern region of Java tends to be more open to the influence of the monsoon and ENSO. This is similar to the geographical conditions on Lombok Island with the topography in the northern region being lowlands. This makes the northern region of Lombok Island more dependent on seasonal patterns and the emergence of ENSO phenomena has an effect on modulating convective activity. Meanwhile, the significance of the relationship between rainfall and ENSO observed in the Janapria region is likely the result of synergy between local influences and ENSO in modulating changes that lead to increased rainfall in the region. During the *Triple Dip La Niña* period of 2020-2023, there was an increase in relative humidity in the JJA season. Temporally, in JJA 2020, the Lombok region was seen to experience a decrease in relative humidity. Then gradually there was an increase and the peak was seen in JJA 2023 where the Lombok region experienced an increase in relative humidity of around 1-10%. This indicates that ENSO influences the formation of rainfall through the mechanism of increasing relative humidity [9].

The changes in rainfall that occurred in the two regions depended on changes in the ONI value as shown in the graph in Figure 11. Rainfall decreased when the ONI value was greater and vice versa. A drastic increase in rainfall was observed in August 2022 coinciding with the strengthening of La Niña which was marked by an ONI index value of -0.9. Compared to the August 2020-2021 period, rainfall in Bayan and Janapria increased by >100%. Meanwhile, other regions were observed to have a moderate-strong correlation and did not have a significant relationship to rainfall variability.

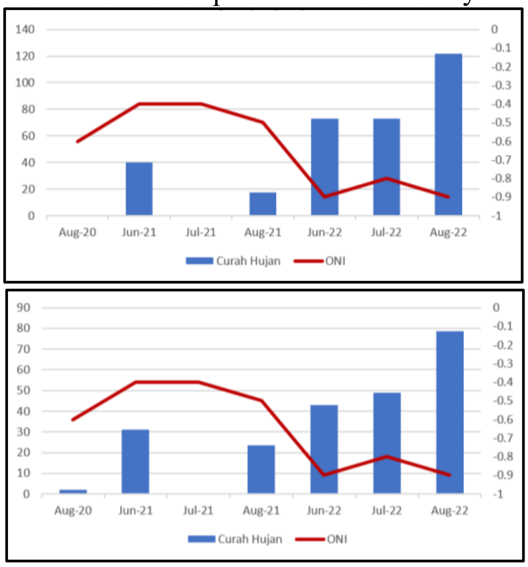

Figure 11. Rainfall patterns and ONI index in Bayan and Janapria during the JJA period.

d. *Correlation of ONI Index and SON Period Rainfall*

During the SON period, most parts of Indonesia experience a transition season from the dry season to the rainy season with rainfall variability that has a fairly strong correlation with ENSO, including in Lombok [43]. The correlation between rainfall and the ONI index is observed to have a significant relationship in the Pringgabaya area (seen in Table 4). This makes the Pringgabaya area the only responsive area with rainfall that follows the ONI index variation pattern. The ONI index pattern and rainfall graph in Figure 12 shows that in general rainfall fluctuations in the range of 0 - 131 mm tend to increase and decrease along with changes in the ONI index. The highest rainfall was observed in October-November 2020 coinciding with the strengthening of La Niña conditions (the ONI index is increasingly negative). This shows that the intensity of the *La Niña* event has an effect on changes in rainfall. This means that the smaller the ONI index, the more rainfall will increase.

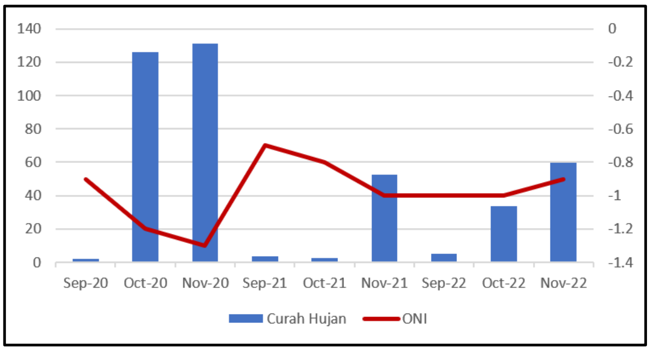

Figure 12. Rainfall patterns and ONI index in Priggabaya during the SON period

Based on Figure 9, the location of the Priggabaya area is in the northeast of Lombok Island. This shows a shift in the *La Niña* effect in Lombok which shifted eastward in the SON season. In the previous season, the *La Niña* effect was strongest in the north and center of Lombok. This shift is in accordance with the theory that shows that the ENSO effect in the SON period shifts eastward and weakens in the west. This is influenced by changes in wind circulation, shifts in rainfall patterns and changes in SST [38][25][24]. Along with the shift in the impact of ENSO, the influence of IOD in this season has also entered the eastern part of Indonesia which includes part of the Nusa Tenggara Islands, thus affecting rainfall fluctuations [44].

4. Conclusion

The Triple Dip La Niña phenomenon of 2020-2023 affects the distribution of rainfall in Lombok which varies each season. The DJF period shows high rainfall in the northern part of Lombok with a dominance of positive anomalies reaching 40%. The impact of the *Triple Dip La Niña* phenomenon is not significant in this period and only the Senaru area is observed to have a very strong correlation (r = -0.839). In MAM, rainfall decreases with the highest concentration of rainfall in northwest Lombok and a negative anomaly of 20-50%. There is no clear signal of the influence of the *Triple Dip La Niña* this season. The JJA period shows low rainfall with the eastern part of Lombok being drier. However, there is a strong positive anomaly with a significant increase in rainfall reaching >100% which is observed in the western and central areas of Lombok. Bayan and Janapria are strongly correlated with ENSO in this season (r = -0.816 and r = -0.759). The SON period shows an increase in rainfall in western and central Lombok compared to the previous season. Strong positive anomalies due to the influence of *Triple Dip La Niña* are still observed, although they are unevenly distributed and limited in scope. Pringgabaya shows a significant correlation (r = -0.861) indicating a shift in the impact of ENSO to the east.

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