EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2024, 25(3), 211–219
https://doi.org/10.12912/27197050/181175
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Received: 2023.12.27
Accepted: 2024.01.18
Published: 2024.02.25

The Effect of ENSO on Seasonal Rainfall Using the Monte-Carlo Bootstrap Method in the Southern Part of Java, Indonesia

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ABSTRACT

ENSO is a global climate phenomenon that has been able to affect weather and climate conditions in Indonesia, especially in the southern part of Java Island, which is represented by Yogyakarta province. Subseasonal to seasonal (S2S) is a seasonal period that tries to bridge the gap between a relatively short period and a climate that has a relatively long period. The author has conducted a study that aims to determine the effect of the global ENSO phenomenon on the increase and decrease in rainfall in the southern part of the Java island region during the S2S season. In this study, the data obtained from the Nino 3.4 data and seasonal rainfall data in The southern part of Java, which is represented by Yogyakarta province in the years 2001–2022 were used. The method used is the Monte-Carlo Bootstrap permutation resampling method. The results show that in general the southern part of the Java Island region is affected by El Nino and La Nina phenomena both in the peak period of the rainy season and the peak of the dry season of JFM, JJA, ASO, and OND although the responses from several sample areas have different effects.

Keywords: ENSO, subseasonal to seasonal, rainfall, Monte-Carlo Bootstrap, Java Island.

INTRODUCTION

Subseasonal to seasonal (S2S) is a weather/climate forecast period that aims to end the gap between daily weather forecasts and seasonal climate forecasts (Arriyadi, 2017). Rapid technological progress is directly proportional to the reliability of forecasting weather and climate. However, there are no forecasts for the period between daily and seasonal development a lot, so it produces a low predictability gap or 'desert of predictability' (Vitart et al. 2016). This period is then referred to as the subseasonal to seasonal period. There are no standard provisions regarding the length of the S2S period. Vitart et al. (2016) stated that the S2S period is from the 14^{th} to the 60^{th} day. The development of the S2S model is a solution to the challenge of continuing to produce accurate predictions (Robertson et al. 2015). Forecast formation in the S2S period can be used for various sectors, such as agriculture, health, energy, water resource management, and anticipating extreme events and natural disasters (White et al. 2017). The ENSO phenomenon which includes La Nina and El Nino is one of the main factors that greatly influences climate variability in Indonesia, especially in the Southern Part of Java, which is most affected by El Nino (Irawan, 2006) and has a monsoon rainfall pattern. The occurrence of El Nino and La Nina events causes a decrease and increase in rainfall in Indonesia. Concrete evidence has occurred, namely the super El Nino phenomenon that occurred in 2015 which caused more than 50% of areas in Indonesia to experience drought (BMKG, 2016). Apart from El Nino, the super La Nina phenomenon occurred in the following year, 2016, causing a wet drought where the dry season was short and the rainy season lasted longer, thus causing flood disasters in several areas in Indonesia. The occurrence of ENSO is characterized by SOI (Southern oscillation index) values which are in the range -35 to 35 with negative to strong negative values indicating the presence of El Nino, while positive to strong positive values indicate the occurrence of La Nina (Sitompul and Nurjani, 2013). The decrease in rainfall caused by El Nino will of course affect rainfall and long dry seasons have a direct impact on the agricultural sector such as crop failure and weakening of food security (Safitri 2015).

During La Nina conditions, the sea surface temperature in the waters of the Eastern Equatorial Pacific is lower than normal conditions, while the sea surface temperature in Indonesia becomes warmer (Radini, 2015). This increase in sea surface temperature then causes a lot of convection to occur and causes air masses to gather in Indonesian territory, including air masses from the Eastern Equatorial Pacific which supports the formation of clouds and rain. This event, rainfall far above normal which can cause floods and landslides and is often accompanied by strong winds (Sitompul and Nurjani, 2013). Based on the previous problem, the aim of this research is to determine the influence of the global ENSO phenomenon on the fluctuation of rainfall in the southern part of Java Island in 2001–2022.

MATERIALS AND METHODS

Materials

Study area

The study area of this research is the southern part of Java, which is represented by Yogyakarta province (Figure 1). Yogyakarta province is located in the Southern Part of Java Island which is a direct border with the Hindia Ocean. Yogyakarta province consists of five regencies; Gunung Kidul, Bantul, Kulon Progo, Sleman and Jogja Regencies, with area is ±3,185.80 km^2 and number of total populations is 3,457.491. Annual rainfall shows during 10 years around 1400–3200 mm/year.

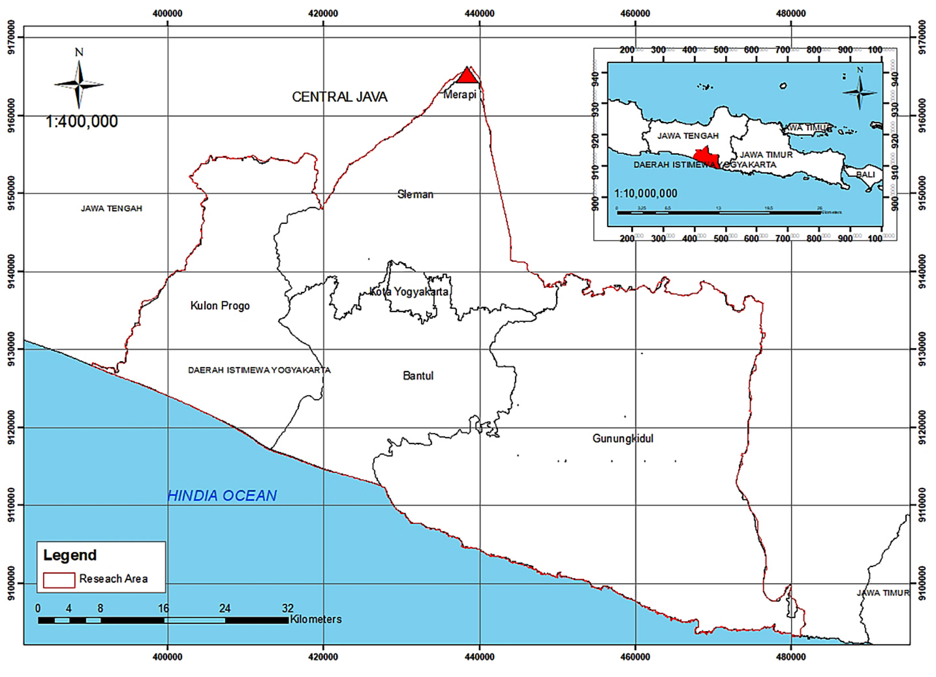

Figure 1. Location of study area

Table 1. ENSO event years during the period 2001–2022 based on ONI data

Event	Season	Years
El Nino	JFM	2002, 2004, 2006, 2009, 2014, 2015,2019
	JJA	2002, 2004, 2006, 2009, 2014, 2015,2019
	ASO	2002, 2004, 2006, 2009, 2014, 2015,2019
	OND	2002, 2004, 2006, 2009, 2014, 2015,2019
La Nina	JFM	2007, 2010, 2011, 2012, 2016, 2018, 2021, 2022
	JJA	2007, 2010, 2011, 2012, 2016, 2018, 2021, 2022
	ASO	2007, 2010, 2011, 2012, 2016, 2018, 2021, 2022
	OND	2007, 2010, 2011, 2012, 2016, 2018, 2021, 2022

Note: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml.

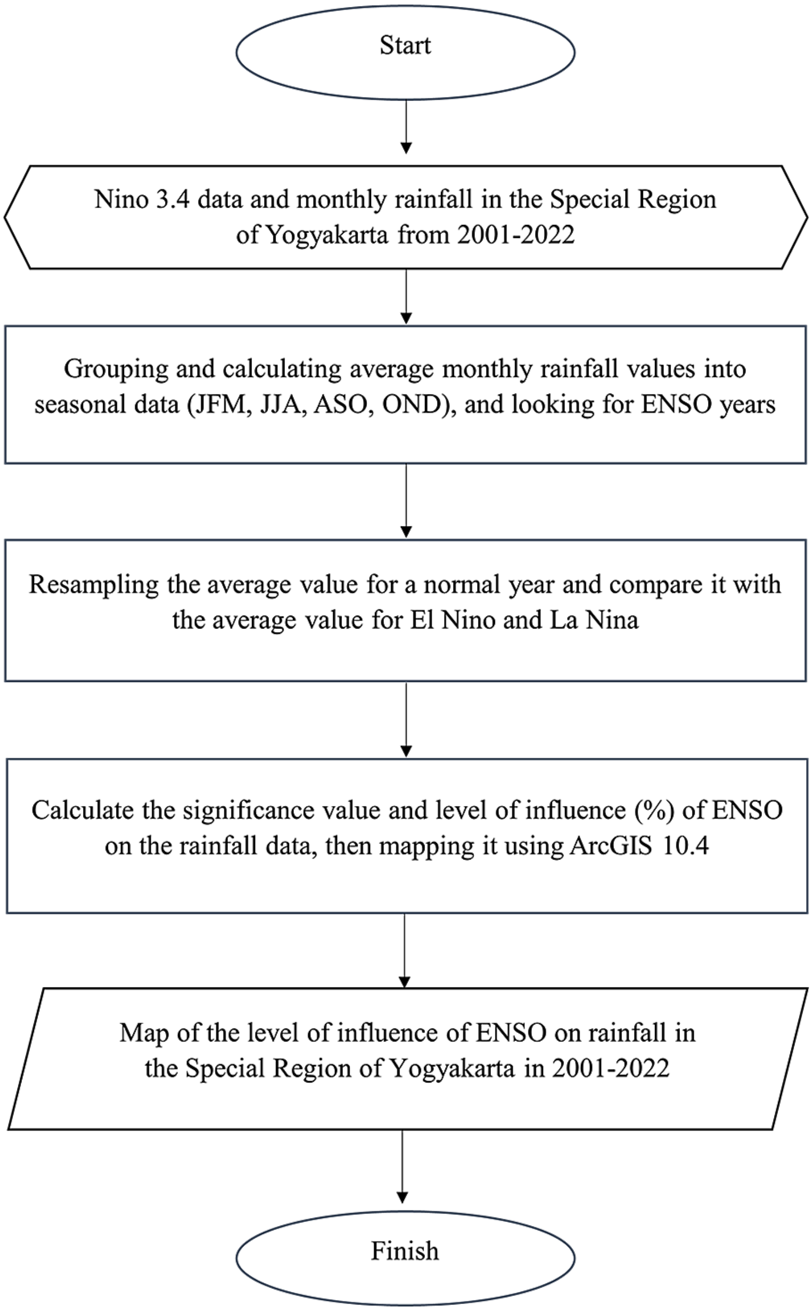

Figure 2. Flow chart of analysis of the influence of ENSO in the Special Region of Yogyakarta using the Monte-Carlo Bootstrapping method on seasonal rainfall in 2001–2022

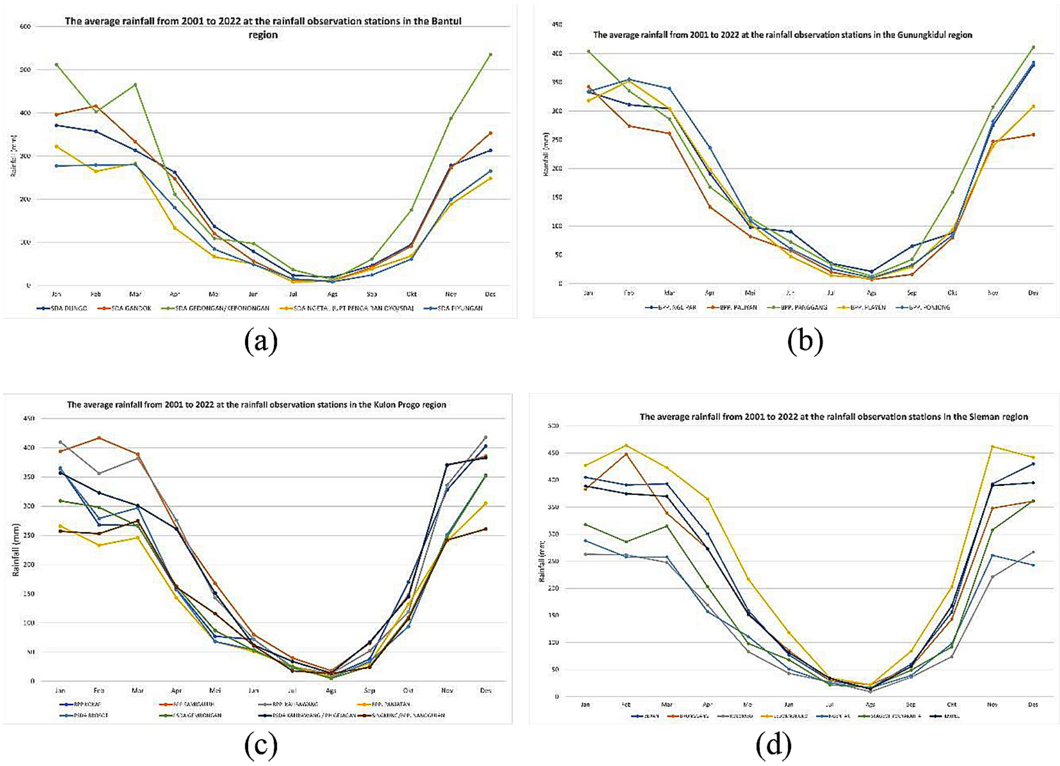

Figure 3. Monthly rainfall average data in a study area in the special region of Yogyakarta in 2001–2022 (a) Bantul Region; (b) Gunungkidul Region; (c) Kulon Progo Region and (d) Sleman Region

Data

This research used the Oceanic Niño Index (ONI) and monthly rainfall data for 2001–2022. The list of ENSO years as indicated in Table 1 was derived based on the ONI, developed by the Climate Prediction Center (CPC) of NCEP NOAA (available at http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml). The ONI index is calculated using a three-month running average of the anomaly of the Extended Reconstructed Sea Surface Temperature Version 5 (ERSST.v5; Huang et al. 2017) in the Niño 3.4 region (5N-5S, 120-170W). El Niño (La Niña) is defined to occur when ONI reaches at least +0.5 °C (−0.5 °C). As observed in Table 1, ENSO years may vary for each season, depending on the ONI value. Periods not identified as El Niño or La Niña years are considered neutral years.

The data monthly rainfall data used are 25 samples of rain observation posts (stations) belonging to the Meteorology, Climatology, and Geophysics Agency (BMKG) spread across the Southern Part of Java. The sample area with the longest rainfall data series was selected. Pandak, Piyungan, Sewon, Nglipar, Paliyan, Panggang, Playen, Ponjong, Gejagan, Gembongan, Kalibawang, Kokap, Panjatan, Samigaluh, Singkung, Beran, Cangkringan, Gamping, Colombo, Ngentak, Tempel and Turi, the data used is seasonal data every year on this data**.** A depiction of the monthly average values for rainfall observation at the 25 meteorological stations used in this study can be observed in Figure 3. This research uses the Monte-Carlo Bootstrapping permutation resampling method, namely a resampling method that assumes the sample data represents the population of the data. This method can be used to measure uncertainty by calculating standard errors and confidence intervals and understanding the concept of statistical inference (performing significance tests). The advantage is that it is easy to apply to various statistics, has better accuracy than other methods, and has fewer assumptions because there is no requirement for normality or large sample sizes.

METHODS

The first step is to group monthly rainfall data in the southern part of Java in 2001–2022 into seasonal data in the form of JFM, JJA, ASO, and OND. Then determine the ENSO year which consists of El Nino (marked red), La Nina (marked blue), and normal (not marked) years based on the page http://www.cpc.ncep.noaa.gov/products/

analysis_monitoring/ensostuff/ensoyears.shtml. The data is grouped based on ENSO years, both El Nino years, La Nina years, and normal years. Re-sampling is carried out only on seasonal data in normal years, then looks for the average seasonal rainfall values (JFM, JJA, ASO, OND) after the data has been *resampled*. The results of the average seasonal rainfall values for normal years are then subjected to a Monte Carlo Bootstrap resampling process with 1000 samples, employing the following mathematical formula: Given the initial sample data X with a size of n, can generate a bootstrap sample, denoted as X^*, by resampling with the replacement for n times ($n = 1000$).

$$X^* = (X^*_1, X^*_2, X^*_3, \ldots, X^*_n) \quad (1)$$

where: X – represents the initial sample data to be analyzed, which can be neutral year rainfall data; n – the amount of data to be resampled (1000).

Then the calculation of statistics for each Bootstrap sample. Considering a statistical function T applied to the bootstrap sample, denoted as T^*.

$$T^* = T\,(X^*) \quad (2)$$

where: T – represents the statistical function applied to the sample data. This function yields a single value or a vector of values reflecting certain characteristics of the data, such as mean, median, variance, or other statistical functions.

Sampling distribution estimation is done by repeatedly resampling to generate many bootstrap samples and calculating the statistic T^* for each sample. The distribution of T^* provides an estimation of the sampling distribution of T. From the resulting distribution values, the 5th percentile is then employed for establishing the lower limit of El Niño influence, and the 95th percentile is used to gauge the impact of La Niña events.

Meanwhile, seasonal data for El Nino years and La Nina years only looks for average rainfall values (JFM, JJA, ASO, OND). The results of the average seasonal rainfall value for a normal year, then the lower percentile and upper percentile values are calculated using the Excel formula and using an alpha value of 5%. Then make a hypothesis, namely that H0 is accepted if the average value is in the range between the lower percentile value and the upper percentile value, then this means that the value is not significant or the area is not affected by El Nino/La Nina in that year, while H1 is accepted if the average value if the average is outside the range between the lower percentile value and the upper percentile value, it means that the average value is significant or the area was affected by El Nino/La Nina in that year (H0 is rejected). The conclusion with the MC Bootstrap method is used to determine the effect of ENSO on the area, if the conclusion is obtained to accept H0, namely there is a similarity in the value of rainfall in the ENSO year with the average value of rainfall in the neutral year, then the area is not significant to the influence of ENSO modulation events. If the conclusion is obtained to accept H1 and reject H0, then calculate the level of ENSO influence on several regions in the Southern Part of Java with the calculation of the rainfall anomaly value. The anomaly value of the modulation of ENSO influence is obtained with the Equation 3:

$$\%\,Anomaly = \frac{Xevent - Xneutral}{Xneutral} \times 100\% \quad (3)$$

where: X_{event} – average rainfall ENSO year; $X_{neutral}$ – average rainfall neutral year (Supari et al., 2017).

After getting the value of anomaly influence of ENSO then classify group them into 4, namely; not affected (black dot symbol), <20% (green triangle symbol), 20–50% (orange triangle symbol), and >50% (red triangle symbol). The results of the level of influence were mapped using ArcGIS 10.4 software, to obtain a map of the level of influence of El Nino/La Nina in the DIY area in 2001–2022.

RESULT AND DISCUSSION

Based on data on the origin.cpc.ncep.noaa.gov page, Indonesia experienced neutral years where ENSO did not occur in 2001, 2003, 2005, 2008, 2013, 2017, and 2020. In neutral years or under normal conditions, the east-west circulation corresponds to the alternation of the Asian Monsoon and the Australian Monsoon. The difference in east-west heating, especially that which occurs between land and sea, is the main cause of the large east-west circulation due to air rising at one longitude and air falling at another longitude. This condition leads to surface warming in the central and eastern tropical Pacific Ocean, causing cooling, and vice versa, affecting

Indonesia's climate in connection with El Niño and La Niña phenomena (Hendon, 2003). The Walker circulation weakens (strengthens), influencing sea surface temperature and impacting the overall climate in Indonesia. Monitoring the Walker circulation during ENSO events can be done using the southern oscillation index (SOI), a numerical value derived from the difference in sea-level air pressure observations between Tahiti and Darwin. The east-west circulation also results in seasonal variations, where in many parts of Indonesia, east winds prevail during the Australian rainy season, while west winds dominate during the Asian rainy season (Mulyana, 2002). The occurrence of El Nino in 2002, 2004, 2006, 2009, 2014, 2015, and 2019 resulted in several changes in weather behavior in the areas it passes through, such as a decrease in rainfall, while La Niña which occurs in other years will have an effect on increasing rainfall. normally. In tropical areas, these two ENSO climate anomalies usually cause shifts in rainfall patterns, changes in the amount of rainfall, and changes in air temperature. Further consequences are the occurrence of increasingly long dry seasons, droughts that stimulate forest fires in sensitive areas, floods, and increased pest and plant disease disorders (Irawan, 2006)

From Figure 4, it can be analyzed that during the rainy season in the JFM period in El Niño years, statistically significant negative anomalies in seasonal rainfall are observed with a reduction of more than 50% at 8 rainfall observation stations scattered across 5 districts/cities. Meanwhile, 17 other rainfall stations do not show statistically significant impacts due to El Niño. The prominent impact of the El Niño event statistically is the reduction in rainfall during the rainy season (Fig. 4a). During the dry season, spatially anomalous dry conditions occur across the entire Southern Part of Java, with 60% of the total stations indicating statistically significant negative anomalies marked by varying reductions in rainfall from less than 20% to over 50%. Most stations record anomalies with magnitudes greater than 50% relative to their neutral years (Fig. 4b). Throughout the ASO period, the dry conditions persist across the entire southern part of Java, with the distribution pattern of affected rainfall stations and the severity of rainfall reduction remaining

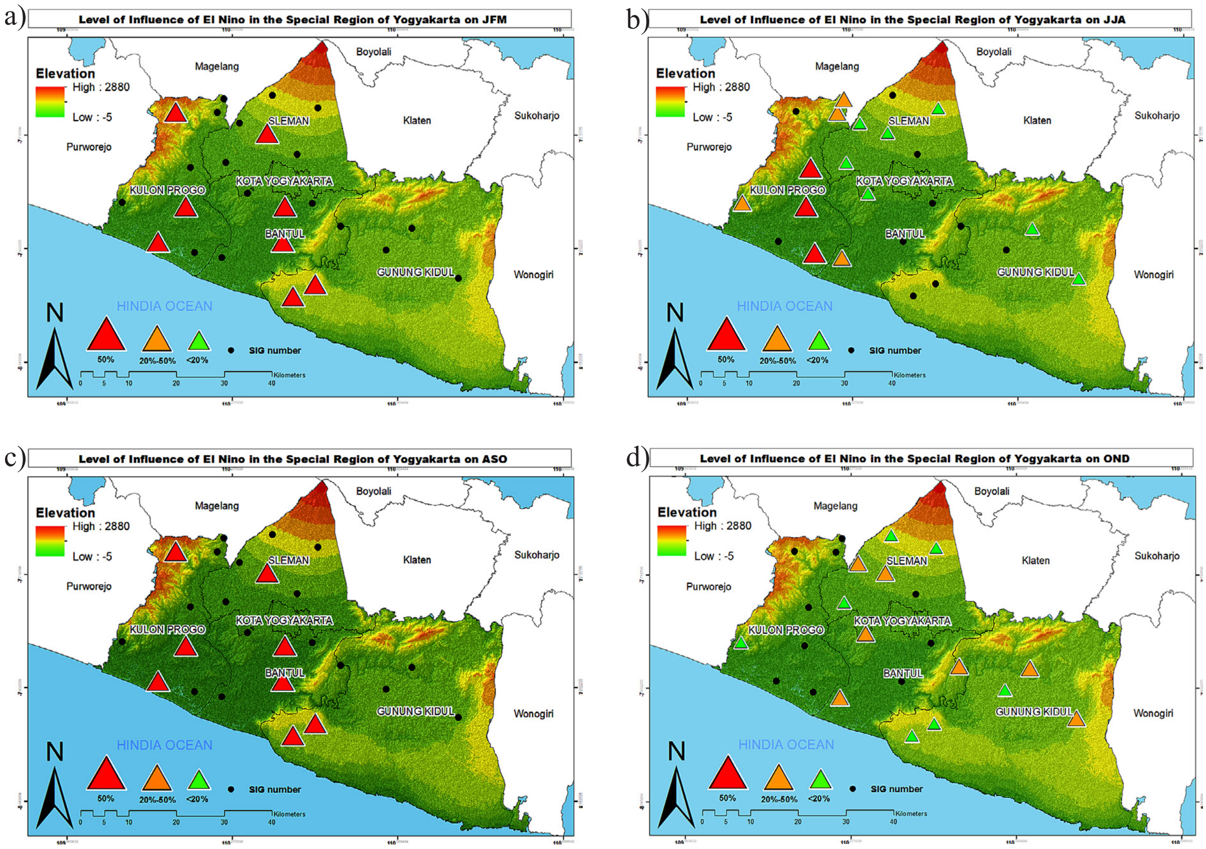

Figure 4. Level of influence of El Nino in the special region of Yogyakarta in 2001–2022 (a) JFM, (b) JJA, (c) ASO and (d) OND

consistent and closely resembling that observed in JJA. However, the reduction in rainfall is only <20% (Fig. 4c). Nevertheless, the number of stations indicating statistically significant negative anomalies in rainfall reduction is higher than in JJA, amounting to 80%.

Entering the early rainy season, the modulation effect of El Niño during the OND season varies in significance, ranging from unaffected by El Niño to significantly affected by El Niño, with a reduction in rainfall ranging from <20% to >50%. The distribution pattern of rainfall observation stations with relatively dry rainfall is dominated by the Eastern region, while the western region shows no significant reduction in rainfall (Fig. 4d). The occurrence of El Nino is caused by warming sea surface temperatures in the Pacific Ocean region and simultaneously changes in air pressure which have different impacts in each region. During El Nino, there is a strengthening of easterly winds in the southern tip of the islands of Sumatra, Java, Bali, Lombok, and Nusa Tenggara. Meanwhile, the easterly winds that blow in Central Kalimantan and Central Sulawesi are relatively the same in El Nino and La Nina years. Topography also influences rainfall values in the southern part of the Java area, thus El Nino will also have an impact (Mulyana 2002).

Based on the http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml page 2002, 2004, 2006, 2009, 2014, 2015, and 2019 can be classified as El Nino years. The occurrence of El Nino certainly influences rainfall fluctuations that occur in regions in Indonesia, one of which is the southern part of Java region. In the JFM period (see Figure 4a) there were 8 areas that had strong significance (more than 50%) marked with red triangle symbols, while the black dot symbols depicted areas that had no influence on El Nino, totaling 17 areas in the southern part of Java. El Nino during this period caused a decrease in rainfall which occurred evenly in all areas of The southern part of Java, but only in a few spots, and this area could be classified as experiencing a strong El Nino. This is supported by research (Hamada, 1995) which states that the start of the rainy season in the Java region occurs later when El Nino occurs compared to the average.

Most of the southern part of Java area in the JJA period was influenced by El Nino with varying significance values with a total of 14 regions with details; 3 areas with a strong influence value (greater than 50%) are marked with a red triangle symbol, 4 areas with a medium influence value (between 20–50%) are marked with an orange triangle symbol and 7 areas with a small influence value (less than 20%) is marked with a green triangle symbol (Figure 4b). Meanwhile, there are 9 regions that are not affected by El Nino. In general, this period is the dry season where little rainfall is produced due to the influx of dry southeast winds from Australia towards Indonesia (Mulyana 2002), which is why many areas were affected by El Nino in the JJA period. The area most affected by El Nino in the JJA period was Kulonprogo.

In Figure 4c, during the ASO period, there was a dry season in Indonesia, and at the same time El Nino occurred, causing a mild dry season in most of The Southern Part of Java. There were 19 regions with low influence values (less than 20%) and 6 regions without influence El Nino. Most of Indonesia's territory during the ASO period is a transition period from the dry season to the rainy season in the areas of Lampung, Java, Nusa Tenggara, and Sulawesi (Mulyana 2002). Gunung Kidul and Sleman are the areas most affected by El Nino. In Figure 4d, there are 15 areas affected by El Nino in the OND period with details; 7 regions with moderate influence values (between 20–50%) and 8 regions with low influence values (less than 20%) as well as 10 regions that have no influence on El Nino. In this period there was an increase in rainfall compared to the previous period. El Nino mostly occurred in the Gunung Kidul and Sleman areas during this period, so these areas experienced a decrease in rainfall levels.

La Nina is an ENSO phenomenon that causes Indonesian sea conditions to become warmer, in contrast to El Nino which causes Indonesian sea conditions to become cooler (Aldrian, 2008). The process of La Nina begins with the weakening of El Nino, resulting in the movement of seawater with hot temperatures towards the west which will eventually reach Indonesian territory. The hot temperatures cause the Indonesian region to turn into a low-pressure area (minimum) so that all the winds around the South Pacific and Indian Ocean will move towards Indonesia. This wind carries a lot of water vapor, so in Indonesia there will often be heavy rain (Safitri, 2015). The level of influence of La Nina shows a strong level with an influence of >50% in almost all JFM, JJA, ASO, and OND seasons as shown by the red triangle

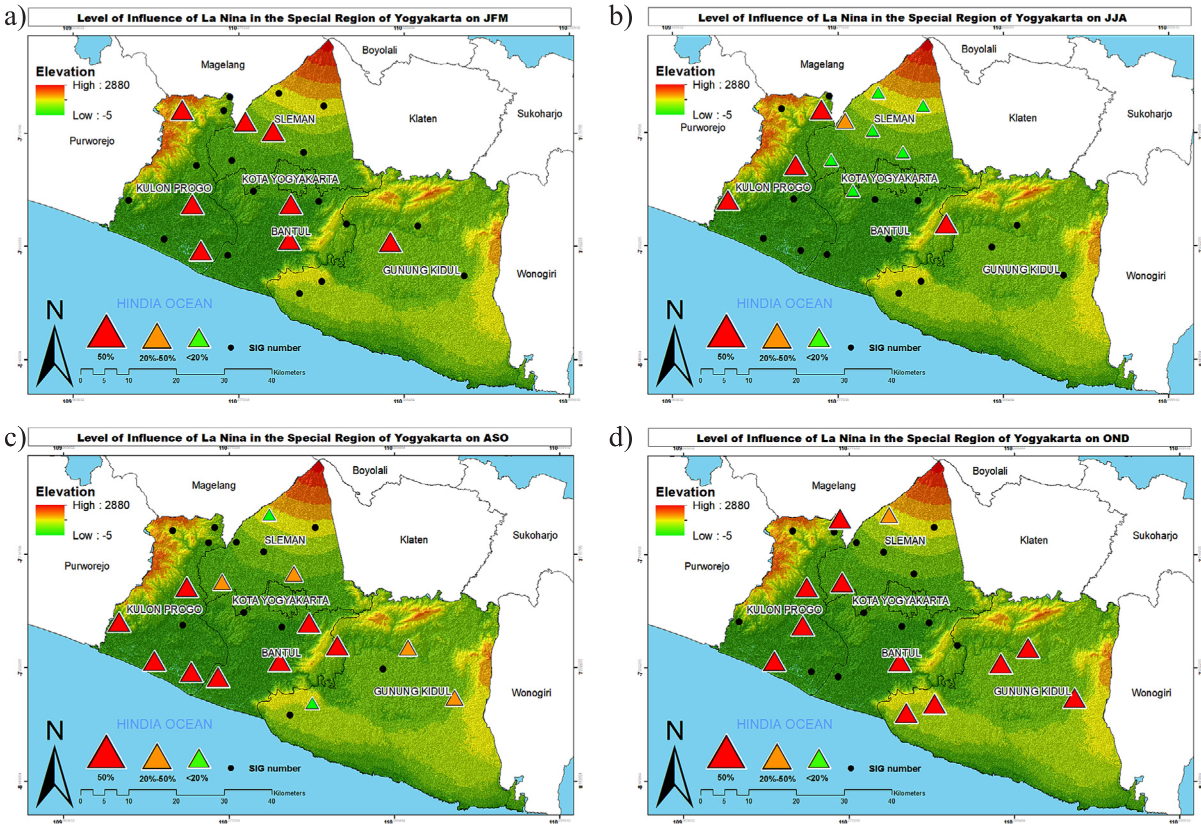

Figure 5. Level of influence of La Nina in the special region of Yogyakarta in 2001–2022 (a) JFM, (b) JJA, (c) ASO, and (d) OND

symbol. The green and orange triangle symbols in several other areas indicate that the influence of La Nina has a low level of influence with a value category of <20% and moderate with a value category of 20–50%. Areas that are not affected by La Nina are shown by black circle symbols.

The influence of ENSO including La Nina and El Nino varies between regions depending on the location and topographic conditions at that location. Regions with monsoon climates in Indonesia such as Java, Sumatra, Bali, and Nusa Tenggara are the areas most affected by ENSO because they are related to wind circulation in the Northern Hemisphere (Asia) and winds from the Southern Hemisphere (Australia). Java Island is the area with the greatest ENSO influence among the Indonesian islands because Java Island is the center of the Asia-Australia monsoonal region (Qian et al. 2010). The sothern part of Java is particularly influenced by ENSO, which is quite strong because it is an area with a monsoon climate.

Figures 5a and 5d illustrate the level of influence of La Nina on the entire southern part of the Java area during the rainy season in the months of JFM (January-February-March) and OND (October-November-December) showing quite a strong influence with the value categories >50% more than some areas and others show that La Nina has an effect on rainfall in the value category of 20% –50% with an orange triangle symbol to no effect (No. Sig) which is marked with a black dot symbol. The dry season period in JJA (June-July-August) and ASO (August-September-October) shows the influence of La Niña, which is quite strong too, but more varied as seen from the presence of red, orange, and yellow triangle symbols and black dots.

CONCLUSIONS

Based on the description of the results and discussion above, it can be concluded that areas that are strongly affected by El Nino in the dry season with decreased rainfall during the JJA-ASO period are shown by most of Kulon Progo and Sleman Regencies, while during the rainy season, the JFM-OND period has a strong influence in most of Gunung Kidul and Sleman

Regencies. La Nina has a strong influence in the rainy season during the JFM-OND period in most of Gunung Kidul Regency, while in the JJA-ASO period, La Nina has a strong influence in most of the Bantul and Sleman Regencies. Strong levels of El Nino influence occur during the rainy season (JFM) while varying levels of El Nino influence occur in the OND period. Strong levels of La Nina influence occur during the dry season (JJA and ASO) with varying results. In general, El Nino and La Nina influence rainfall in the JFM, JJA, ASO, and OND periods in the southern part of Java.

Acknowledgment

We would like to express our gratitude to the Meteorology, Climatology, and Geophysical Agency for their generous financial support, which was instrumental in the completion of this research. Their funding provided the necessary resources, enabling the execution of experiments, data collection, and analysis integral to this study. This work was made possible through their investment in scientific endeavors, and we appreciate their commitment to advancing research in this field.

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