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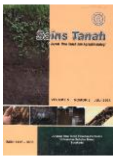

Changes in Rainfall Pattern in Bengawan Solo Sub-Watershed

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ABSTRACT

Rainfed farming is vulnerable to climate variability, which changes rainfall patterns. Rainfall variability disrupts rainfed rice cultivation because a change in rainfall will affect the rice crop calendar. An analysis of long-term trends over a specific area is required to understand rainfall variability. The aim of this study was to assess climate variability in terms of rainfall magnitude and frequency by analyzing spatial and temporal rainfall trends in Bengawan Solo Sub-Watershed as well as the rainfed rice production. Daily rainfall data from 10 rain gauge stations over the sub-watershed area from the years 1975 to 2020 were used. The data was managed and collected by the Bengawan Solo Watershed authority. Pearson, Mann-Kendall, and Sen's Slope tests were applied to assess the recorded data correlation, rainfall trends, and magnitude of trends into annual, monthly, and 10-day. The findings of the study indicated the spatial and temporal inhomogeneous rainfall pattern for all locations for 10-day, monthly and annual patterns. The mountainous regions at Tawang Mangu and Ngrambe stations tend to experience an upward trend (positive magnitude), while the coastal regions at Nglirip and Bojonegoro stations have a downward trend(negative magnitude). Those trends also confirmed that coastal regions would be drier than mountainous regions in the future. Understanding this rainfall trend can assist with rainfed farming strategic planning.

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1. INTRODUCTION

Climate change is a global challenge for the earth's living creatures in the 21st century. The earth's temperature has risen by around 0.8 degrees Celsius over the past century, according to the Intergovernmental Panel on Climate Change. By the end of 2100, global temperatures are expected to be 1.8 - 4 degrees Celsius higher than in 1980-1999. This temperature increase is equivalent to 2.5 – 4.7 degrees Celsius compared to the pre-industrial period (IPCC, 2015). Rainfall patterns may be affected by global climate change which of the parameters used to determine the water supply for agricultural, industrial, and household purposes. Water utilization in rainfed agriculture will be essential to meeting future food demands. Changes in rainfall patterns and hydrological regimes are putting pressure on rainfed food production (Amarasingha et al., 2015; Yang, 2012). Because Indonesia's agriculture sector is the primary source of economic growth and is subject to climate change, it is critical to examine climate change related to rainfall patterns.

Most of the watersheds on the island of Java are in critical condition. Bengawan Solo is one of the priority watersheds in a very critical watershed. Most of the river areas in Java experience chronic water scarcity, resulting in water stress with a water use index of 44% (Hatmoko et al., 2013). This situation is exacerbated by water scarcity in the agricultural sector with the characteristics of erratic rainfall, soil moisture deficits, high evapotranspiration, and lower groundwater levels (Stewart & Peterson, 2015). The dominant land use in the watershed is dry land agriculture and rainfed. The majority of rice is grown in Bengawan Solo Watershed in the rainfed area with minimal irrigation during the rainy season. These characteristics will be increasingly sensitive as a result of climate change, as rainfall will vary significantly in time and space, affecting rice production (Ansari et al., 2021). Several researchers state that rainfall patterns raise in the Bengawan Solo watershed. Rainfall trend in the upper Bengawan Solo watershed has raised during 1990-2016, causing the last longer rainy season, namely 7 months (October-April) in 1990-1998 and 1999-2007 (Auliyani & Wahyuningrum, 2020). Another study stated that the Bengawan Solo watershed was predicted to have rainfall decreasing by 1 mm in the period 2040-2069 (Sipayung et al., 2018). However, there is little evidence related to the type and direction of rainfall pattern impacts, particularly for rice cropping of the sub-watershed. Information on the relative impacts of rainfall variability on water availability would help to estimate the effectiveness of rainfed farming practices at the sub-watershed level.

Rainfall is an important element in determining rice production (Boonwichai et al., 2018; Tiamiyu et al., 2015). Rainfall has relatively high variability in space and time which determines the sustainability of rice production. Increased rainfall due to climate change will have positive things on rice cultivation. Food production activities become more secure with the water availability of rainfall. Meanwhile, the negative impact of climate change is that a decrease in the volume of rainfall will threaten the occurrence of drought, which will disrupt the sustainability of national food production (Budiastuti, 2010). In climate change studies for water resource planning and management, rainfall trend analysis is critical (Aldrian & Djamil, 2008; Bekele et al., 2016). Aldrian and Djamil (2008) found substantial long-term rainfall variations in the Brantas Watershed. As a result, assessing the amount of fresh water available to meet the water demand for agricultural purposes necessitates a thorough examination of rainfall variability. Several studies have confirmed past climatic variability tendencies in southeast Asia. The extreme rainfall trend in Southeast Asia (northern Vietnam, Myanmar, and Thailand) is on the decline, whereas southern Vietnam and Luzon, Philippines are on the rise (Endo et al., 2009). However, a study found that regional factors impacted a rise in annual rainfall in Ho Chi Minh City (Khoi & Trang, 2016). Other researchers studied the impacts of temperature and rainfall on harvest and yield variation which demonstrated that ongoing changes in temperature and rainfall patterns boost global warming, resulting in a future water scarcity crisis and lower crop production (Abbas & Mayo, 2021).

Water scarcity due to changing rainfall patterns can result in a 40% reduction in annual agricultural production in the south and southeast Asia (Khadka, 2016). In Indonesia, rice production decreased during the wet season due to soil moisture stress caused by high rainfall frequency and magnitude. During dry seasons, the rising temperatures cause rainfall frequency and magnitude which affect declining future rice production (Al-Ansari et al., 2021). Two researchers study the impact of rainfall change on rice production in a small region. An increasing temperature of 1 OC and rainfall change of 34% will have an impact on a decrease of rice production around 143.6 kg ha^{-1} during the dry season in Jakenan District (Estiningtyas & Syakir, 2018). The increased local rainfall, however, contributes to higher rice production. Rice production rise 0.4 % as a result of a 10% increase in rainfall (Levine & Yang, 2014). Those studies focus on a small region using global data or a few stations that did not yet represent the long conditions of the rainfall and hydrological cycles. Few studies examine the trend of rainfall as well as rice production in terms of the spatial and temporal in a rainfed area of the watershed. Furthermore, this study to assess climate variability in terms of rainfall magnitude and frequency through an analysis of spatial and temporal rainfall trends in the Bengawan Solo Sub-Watershed as well as the effect on rice production in rainfed areas using both useful commonly trend analysis used parametric approaches, which are limited to normal distribution also non-parametric approaches, which are unrestricted to normally distributed (Wang et al., 2012; Zarei & Eslamian, 2017).

2. MATERIALS AND METHODS

This study was conducted at Bengawan Solo sub-watershed area: 8°0'0" – 6°50'0" S, 110°45'5"- 112° 5' 50" E. The sub-watershed area is about 4,732 km^2 covering the southern part of Lawu Mountain to Bengawan Solo River mouth at the northern coast of Java in Figure 1. Daily rainfall data is used from 10 rain gauge stations over the sub-watershed. Those data are managed and collected by the Bengawan Solo Watershed authority. The availability of data and spatial distribution covering high to lower area are considered for data selection. The analyses are conducted about concerning rainfall data for 46 years from 1975 to 2020 (Table 1). Jiwan and Sembung stations missed data in 1975 because both stations were established in 1976 and 1989.

Table 1. Rainfall data availability over the Bengawan Solo Sub-Watershed

No.	Elevation (m)	Station Name	Data period
1	1030	Tawang Mangu (TW)	1975-2020
2	728	Ngrambe(NGB)	1975-2020
3	94	Jiwan(JWN)	1976-2020
4	60	Ngawi(NGW)	1975-2020
5	96	Doplang(DPG)	1975-2020
6	96	W. Notopuro(NPR)	1975-2020
7	43	Padangan(PDG)	1975-2020
8	91	Sembung(SBG)	1989-2020
9	154	Nglirip(NGP)	1975-2020
10	21	Bojonegoro(BJN)	1975-2020

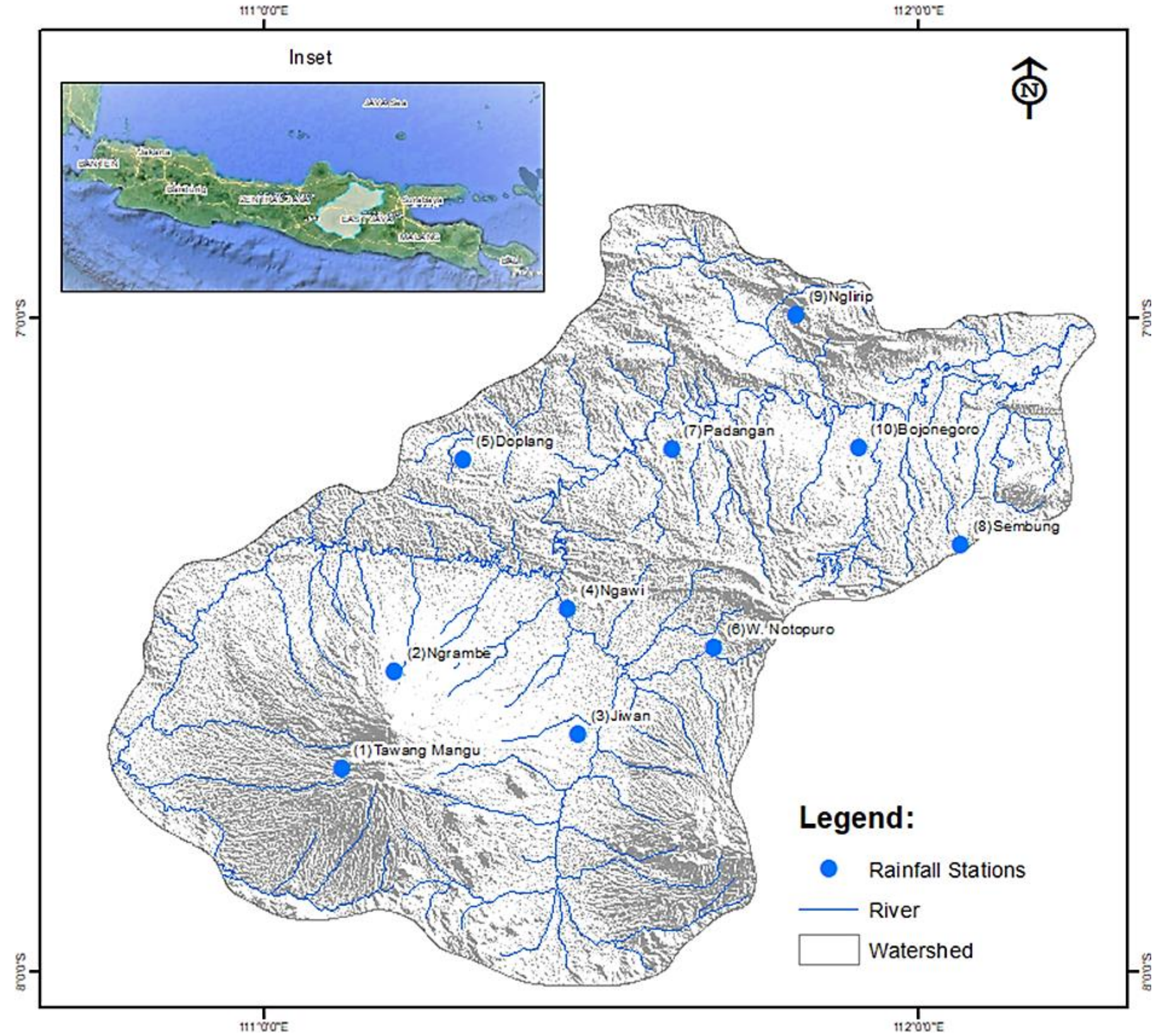

Figure 1. Rainfall station distribution in Bengawan Solo Sub Watershed

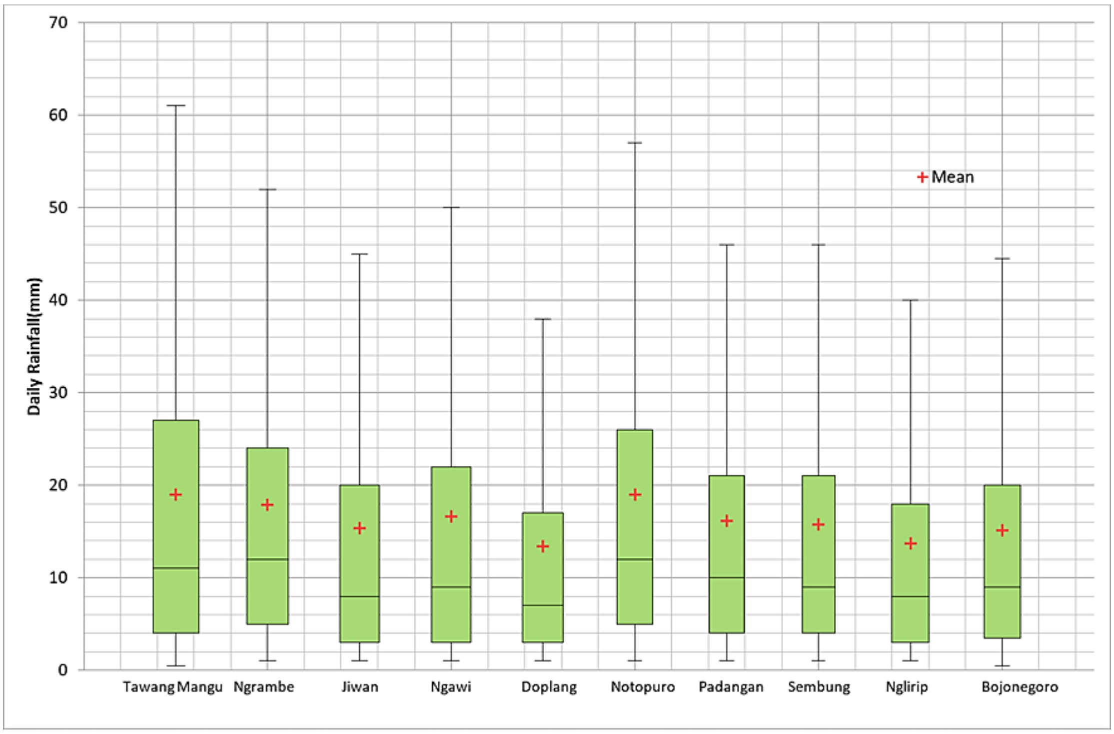

Figure 2. Boxplot diagram of rainfall characteristics for 10 stations

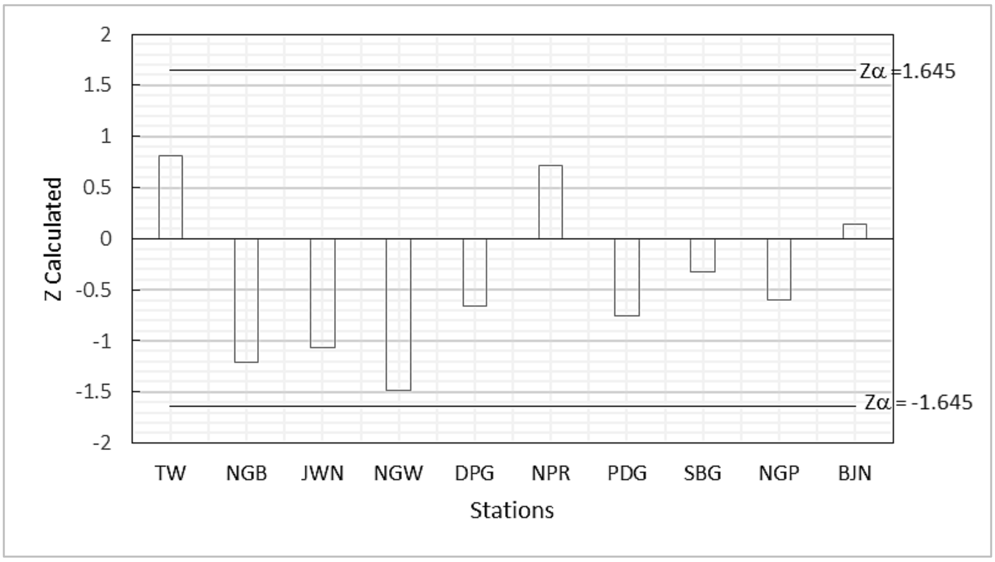

Figure 3. Trend evaluation of the heavy and extreme rainfall for all stations

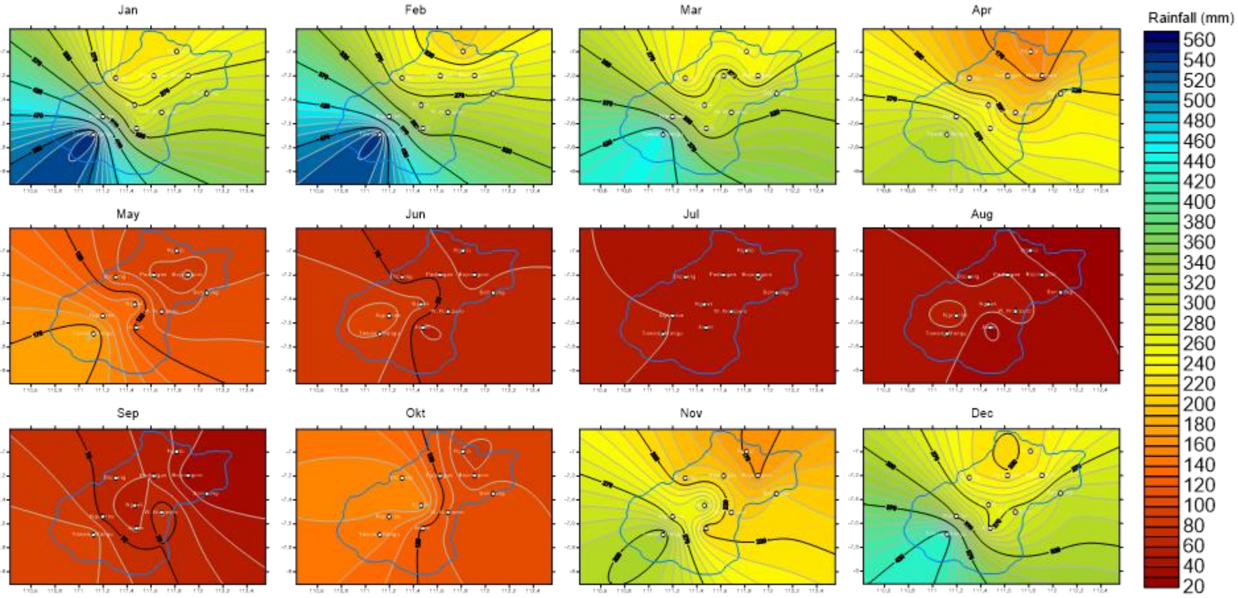

Figure 4. Spatial distribution of monthly rainfall over Begawan Solo sub-watershed

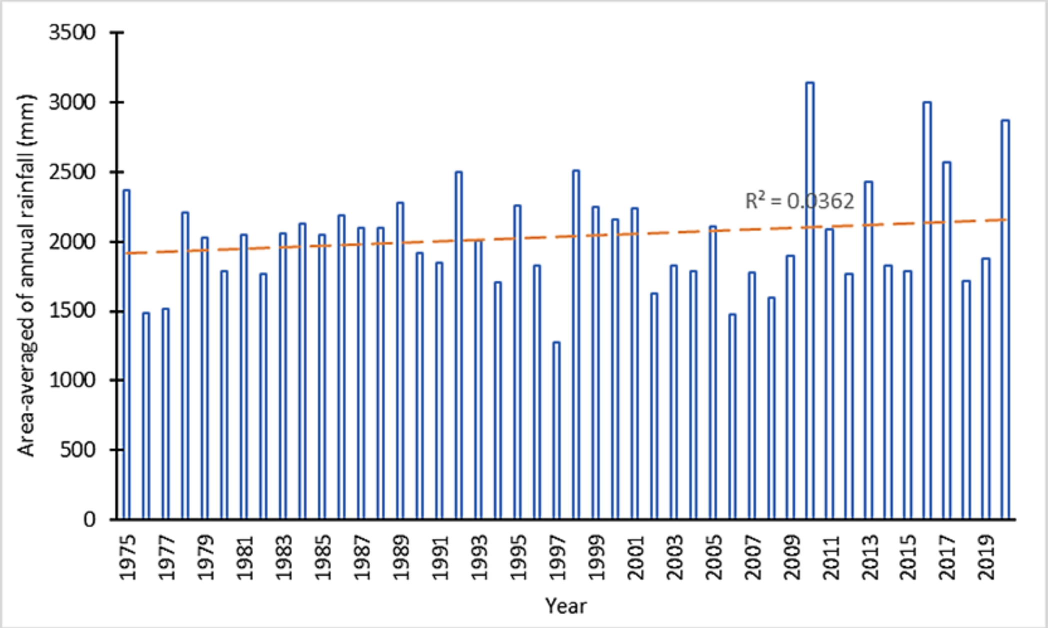

Figure 5. Average annual rainfall over Bengawan Solo Sub-Watershed

To evaluate rainfall patterns, descriptive analysis was employed for 10-day, monthly and annual rainfall. The study of intense rainfall has used analysis of rainfall statistical distributions to assess extreme rainfall periods (Fowler et al., 2003). A summary statistic of each station was calculated to describe the performance data record divided into mean, maximum, minimum, and quartile values. A descriptive statistic at each station indicates performance rainfall behavior.

2.1 Correlation Test

The correlation test correlates to the classical linear coefficient. This coefficient value ranges from -1 to 1, and it quantifies how closely two rainfall variables at two stations are linearly correlated. Correlation analysis is used to identify homogeneous rainfall zones through comparison between rainfall stations, which were based on seasonal/annual rainfall (Saikranthi et al., 2013). The Pearson correlation coefficient measures the proportion of a variable's variability that is explained by the other variable:

$$r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}} \qquad [1]$$

where x and y are series data, $\bar{x}$ and $\bar{y}$ are average at x and y.

2.2 Trend Mann-Kendall and Sen's Slope Analyses

The Mann-Kendall trend test (MK test) was used to determine the trend either in annual or seasonal rainfall (Hirsch & Slack, 1984; Weber, 1977; Zhang & Yan, 2014). This technique has been used in the majority of past trend analyses of hydrologic data (Camarasa-Belmonte & Soriano, 2014; Nkiaka et al., 2017; Pal et al., 2017). The World Meteorological Organization employs the MK test, which has been frequently used to study patterns in hydrological and meteorological data (Zeng et al., 2013). Sen's slope test was used to determine the magnitude of the change in the trend. For this test, the null hypothesis, H0, indicates that there is no series trend. Calculating Kendall's measure of association between two samples—which is based on the samples' ranks—is the foundation of the Mann-Kendall tests.

The trend test computations are made simpler by the first series, a rising time indicator whose ranks are evident. The test's S statistic and its variance are calculated as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) \qquad [2]$$

Where The function (Xj - Xi) has a value of +1 if sign > 0 and -1 if sign 0.

$$Z = \begin{cases} \frac{S-1}{\sqrt{V(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{V(S)}} & if\ S < 0 \end{cases} \qquad [3]$$

The p-value calculation would reveal a trend in the time series data. If the calculated value of P is less than the significance threshold alpha (use 1% and 5%), the change in the data is accepted, and the null hypothesis H0 can be rejected.

The trend slope's value is determined using Sen's slope evaluation. In other words, the slope's sign indicates whether the trend is increasing or decreasing. Sen's Slope formula is given by:

$$\beta i = xj - xi/j - i \qquad [4]$$

where n is the number of data points, xi and xj are the time series data values in i and j which j greater than i, respectively. The median of βi is then used to generate the Sen's slope estimator.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) \qquad [5]$$

3. RESULT

The data were statistically tested to describe the characteristics of the rainfall. The box plot for each station can be shown that there are huge variabilities in the daily rainfall data for all the stations (Figure 2). The mean rainfall is fairly uniform in all stations in the range of 13–18 mm. The maximum daily rainfall ranged from 140 to 270 mm occurring at Tawangmangu station which has the highest elevation. Heavy and extreme rain events were classified by the Agency for Meteorology Climatology and Geophysics as follows :

a. Heavy rain : 100 – 150 mm day^{-1}
b. Extreme rain : >150 mm day^{-1}

We applied the trend analysis to the frequency of heavy rain (P ≥ 100 mm/day) in Figure 3. Horizontal lines indicate the Z statistic value at a 95% confidence level. Data series with Z calculated less than 1.645 indicate no trend of heavy rainfall at most of the stations.

Meanwhile, the relationship between daily rainfall data is determined by using a correlation test for 10 stations. Table 2. The results of the correlation test reveal that the coefficient value for all stations is less than 0.2, indicating a weak relationship between stations. Furthermore, the daily rainfall data between stations are independent. It can be stated that recorded daily rainfall data between stations spatially represents different rainfall conditions over the watershed.

The contour of average monthly rainfall is spatially distributed at Bengawan Solo Sub-Watershed in Figure 4. It can be shown that monthly rainfall varies between 50 to 500 mm. Tawangmangu (TW) station receives the highest monthly average rainfall (550 mm) in January. Jiwan (JWN) station had the lowest annual rainfall of 25 mm in March. The highest peaks of rain occurred from December to January. The Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) uses rainfall of 150 mm month^{-1} as a boundary to mark areas that have seasons and non-season. All stations except Tawangmangu receive rainfall below 150 mm starting from May to October which is a dry season period. While the rainy season occurs when stations receive rainfall above 150 mm it generally occurs from November to April. There is a slight difference between the beginning dry season and the rainy season. Most stations experienced a dry season starting in May. However, Tawangmangu experienced delays at the beginning of the dry season which start from June.

The area-average annual rainfall, which is calculated using Thiessen Polygon in the Bengawan Solo Sub-Watershed is shown in Figure 5, the dashed line represents the linear trend. Average area annual rainfall trends in the Bengawan Solo Sub-

Table 2. Correlation of rainfall variable between 10 stations

	TW	NGB	JWN	NGW	DPG	NPR	PDG	SBG	NGP	BJN
TW	1,00									
NGB	0.15	1.00								
JWN	0.18	0.20	1.00							
NGW	0.12	0.16	0.13	1.00						
DPG	0.08	0.06	0.06	0.14	1.00					
NPR	0.11	0.19	0.19	0.18	0.04	1.00				
PDG	0.06	0.04	0.06	0.11	0.12	0.09	1.00			
SBG	0.10	0.06	0.12	0.12	0.14	0.15	0.10	1.00		
NGP	0.08	0.06	0.02	0.08	0.08	0.04	0.23	0.09	1.00	
BJN	0.05	0.01	0.03	0.08	0.09	0.05	0.18	0.13	0.14	1.00

Table 3. Mann-Kendall and Sen’s Slope trend for 10-day, monthly and annual rainfall in all stations

No	Station name	Sen's slope			Mann-Kendal test (p-value)		
		10 days	Monthly	Annual	10 day	Monthly	Annual
1	Tawang Mangu (TW)	0.005	0.047	0.794	0.181	0.302	0.932
2	Ngrambe(NGB)	0.007	0.037	-3.120	0.047**	0.351	0.636
3	Jiwan(JWN)	0.007	0.084	6.191	0.015**	0.021**	0.210
4	Ngawi(NGW)	0.004	0.047	1.593	0.103	0.177	0.769
5	Doplang(DPG)	-0.001	-0.011	-9.211	0.629	0.667	0.137
6	W. Notopuro(NPR)	0.011	0.098	15.000	0.000*	0.014**	0.006*
7	Padangan(PDG)	-0.001	0.005	0.423	0.629	0.852	0.940
8	Sembung(SBG)	-0.002	-0.018	-8.147	0.684	0.725	0.412
9	Nglirip(NGP)	-0.004	-0.027	-9.647	0.031**	0.311	0.167
10	Bojonegoro(BJN)	-0.004	-0.024	-7.850	0.035**	0.387	0.140

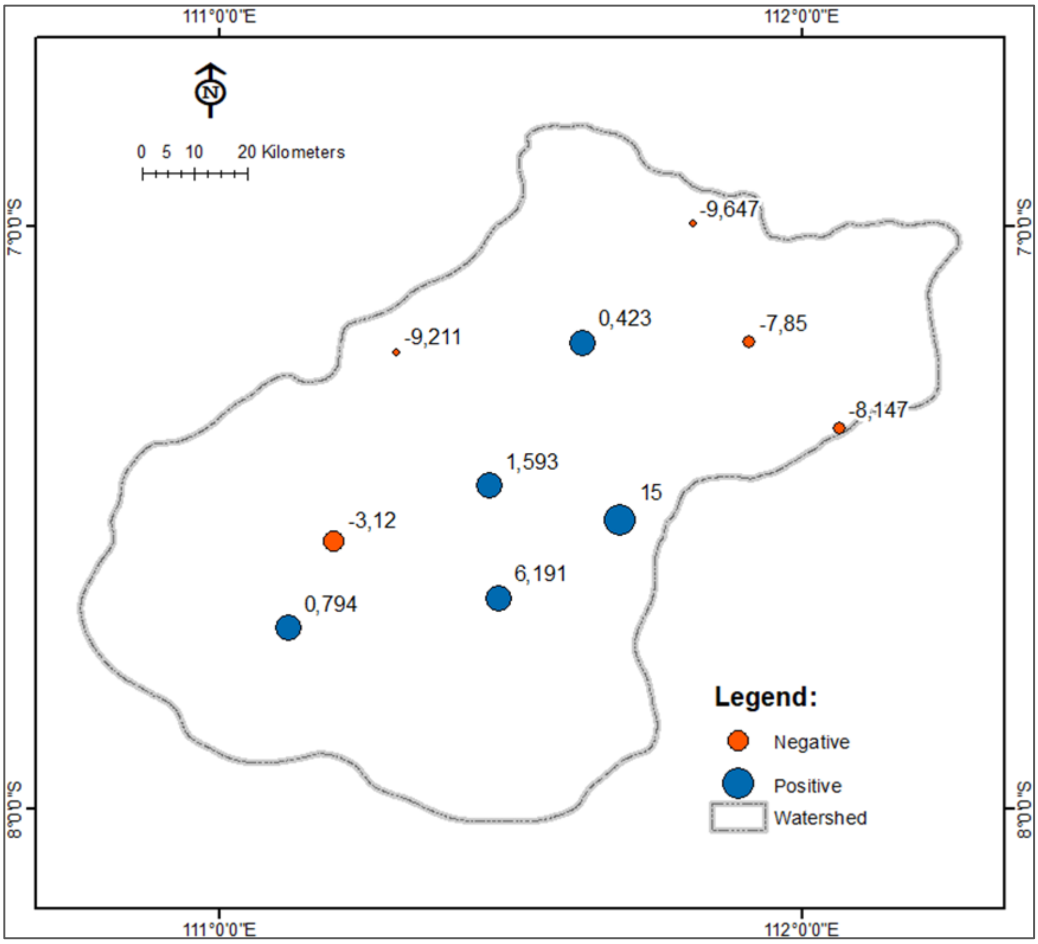

Figure 6. Distribution of annual rainfall trend test over the Bengawan Solo Sub-Watershed

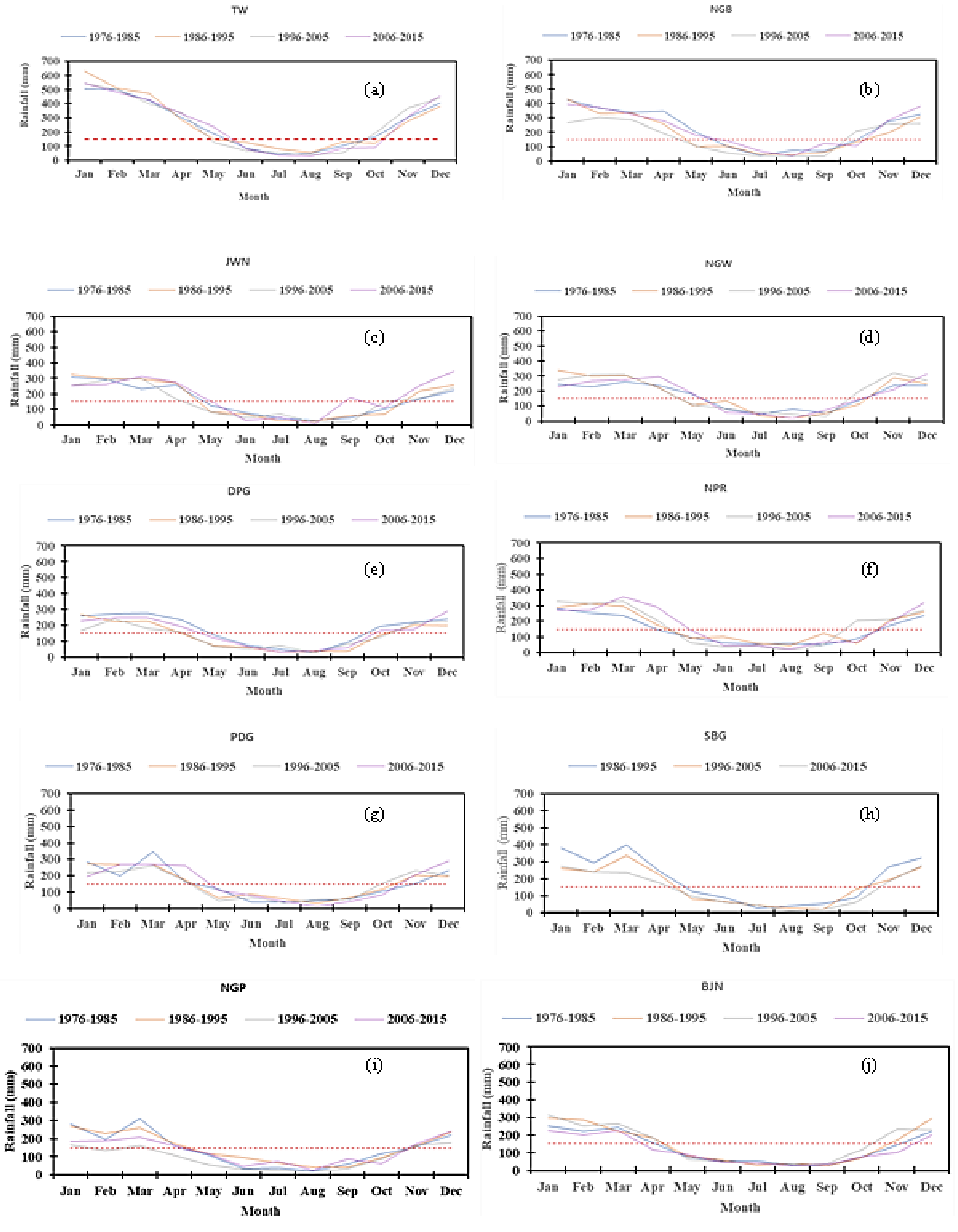

Figure 7. Rainfall changes in 4 decades compared to normal rainfall (red dotted lines) during 45 years in : (a). Tawangmangu Station, (b).Ngrambe Station, (c). Jiwan Station, (d).Ngawi Station, (e). Doplang Station, (f). W. Notopuro Station, (g). Padangan Station, (h). Sembung Station, (i). Nglirip Station, (j). Bojonegoro Station.

Watershed experienced an increase during 1975-2020. Area-average annual rainfall varies between 1,272.5 mm to 3,137 mm with an annual average of 2,037 mm. The result of the statistical analysis shows a positive increase in rainfall trend over the sub-watershed region.

3.1 Rainfall Trend Analysis

From 1975 to 2020, daily rainfall data has been collected from 10 rainfall stations in the Bengawan Solo Sub-Watershed. The data was divided into three series: 10-day, monthly and annual. The trend tests were performed on all data series using Mann-Kendall tests, Sen's slope estimator, and linear regression analysis. Trend analysis is employed for the total annual accumulated, monthly, and 10-day rainfall s shown in Table 3. The annual rainfall showed an insignificant trend because the null hypothesis of trend analysis was accepted which had a p-value greater than the significance value of 95 % for 9 stations. However, W. Notopuro station has a significant annual trend which has 15 of slope value.

The monthly rainfall showed only 2 significant trends at Jiwan and Notopuro stations with 5 % of the significance level. Additionally, the magnitude of rainfall changes for both stations slightly increases with a slope of less than 5%. The majority of stations have no significant trend indicated by the p-value of monthly rainfall is greater than the 0.1 of significance level, so the null hypothesis is accepted. While, the monthly rainfall sen's slope value is in the range of 0.1-0.05 so that the rainfall change is very small.

Meanwhile, 10-days of rainfall has a significant trend at 5 stations (NGB, JWN, NPR, NGP, BJN) with a small rainfall magnitude, indicated by Sen's slope value of less than 5 %. Whereas, other stations have no significant trend with a small magnitude of the slope. The significant 10-day trend slightly rise at Ngrambe, Jiwan, Notopuro station, while Nglirip and Bojonegoro stations smoothly decreased.

Annual rainfall changes at each station over the study area were spatially shown in Figure 6. In fact, the annual pattern is higher than monthly and 10-day rainfall. Obviously, the changes are distributed from the southern part to the middle-eastern part of the sub-watershed while the decreased changes are distributed from the southern part and northern part which indicated positive and negative signs, respectively. The most positive trend is 15 of slope at Notopuro station. The lowest negative trend is -9.647 of slope at Nglirip stations.

3.2 Rainfall Deviation

The change of rainfall pattern in 4 decades was investigated. One indication of climate change can be detected by the change of the average rainfall pattern in the study area. Normal rainfall is determined as the monthly rainfall averages for a 45-year period at the rainfall station. Changes in normal rainfall contain information on normal rainfall deviations for 45 years. The used data is monthly average rainfall data from the period 1975-1985, 1986-1995, 1996-2005, 2006-2015 as shown in Figure 7. The Figure shows changes in rainfall patterns compared to normal (red dotted lines) in the last 10 years. All stations have similar rainfall patterns during the decade periods. The graph also shows that there is a mild shift in the rainy or dry seasons between periods. The rainfall changes above normal, rainy season, starting from November to April. On the other hand, the rainfall changes below normal, dry season, starting from May to October. Additionally, the change of cumulative monthly rainfall fluctuated start from January to December for all stations; for examples, Tawangmangu station (TW) experienced the highest monthly rainfall start from January to March during 1986-1995 period, but experienced the lowest during April to June (Figure 7. (a)).

The average rainfall deviation in 4 decades is shown in Figure 8. There is a mild shift at the beginning of the rainy or dry seasons. The figure shows the maximum rainfall deviation during the rainy season in December which has a positive value of rainfall deviation of 92.3 mm at Sembung station while the minimum rainfall deviation during the rainy season, -34.6 mm, is at Nglirip. Otherwise, during the dry season the maximum rainfall deviation (43 mm) in September is at Jiwan Station and the minimum rainfall deviation (-25.3 mm) in October is at Tawangmangu Station. The positive value of rainfall deviation implies that the change in rainfall rise while the negative value of rainfall deviation implies that the change in rainfall decrease.

3.3 Rainfed Rice Yield Trend

Rainfed rice yield in Bengawan Solo Sub-watershed (Figure 9) showed an increasing trend from the year 1986-2016. The trend test of rice yield illustrated the computed p-value (0.0001) is lower than the significance level alpha of 0.05 which should reject the null hypothesis H0, and accept the alternative hypothesis Ha. Furthermore, there is a positive rice yield trend in the series. Related to the annual rainfall trend (Figure 5), it can be seen that rainfall and rice yield for a period of 30 years (1986–2016) have a relationship. The t-test was also carried out to determine whether the rainfall variable partially significantly affected rice yield with a confidence level of 95%. The result of the t-test shows a p-value of 0.0011 < 0.05 so the partial rainfall variable significantly affects rice yield with a 95% confidence level. Certainly, the rainfed rice yield can be influenced by other factors such as fertilizer, weeds pests and diseases, and water (Singh et al., 2016).

4. DISCUSSION

The two major findings were presented in this study. Firstly, climate variability over Bengawan Solo Sub-Watershed can be represented through rainfall pattern analysis. The pattern of rainfall magnitude and frequency over Bengawan Solo Sub-Watershed varies temporally and spatially. The orographic factor influences the area-average monthly rainfall as displayed by the distribution rainfall contour; high elevation areas have a larger amount of rainfall than lowland areas. The orographic factor regularly occurs over the mountains of the Bengawan Solo Sub-watershed region during the dry season, preserving the high rainfall. The mountain region (Tawang Mangu/TW) seems to have a higher rainfall amount in a year than the lowland region (Nglirip/NGP). The monthly rainfall magnitude is high with a rainfall amount exceeding 150 mm month^{-1} (Figure 4). In the rainy season, the mountainous region receives more rainfall than the lowland region. Consequently, the mountainous area in the southern is less vulnerable to climate change. The change in accumulated rainfall in recent decades indicates that the coastal areas at the northern are more affected by the decline of the monsoonal strength than the mountain areas.

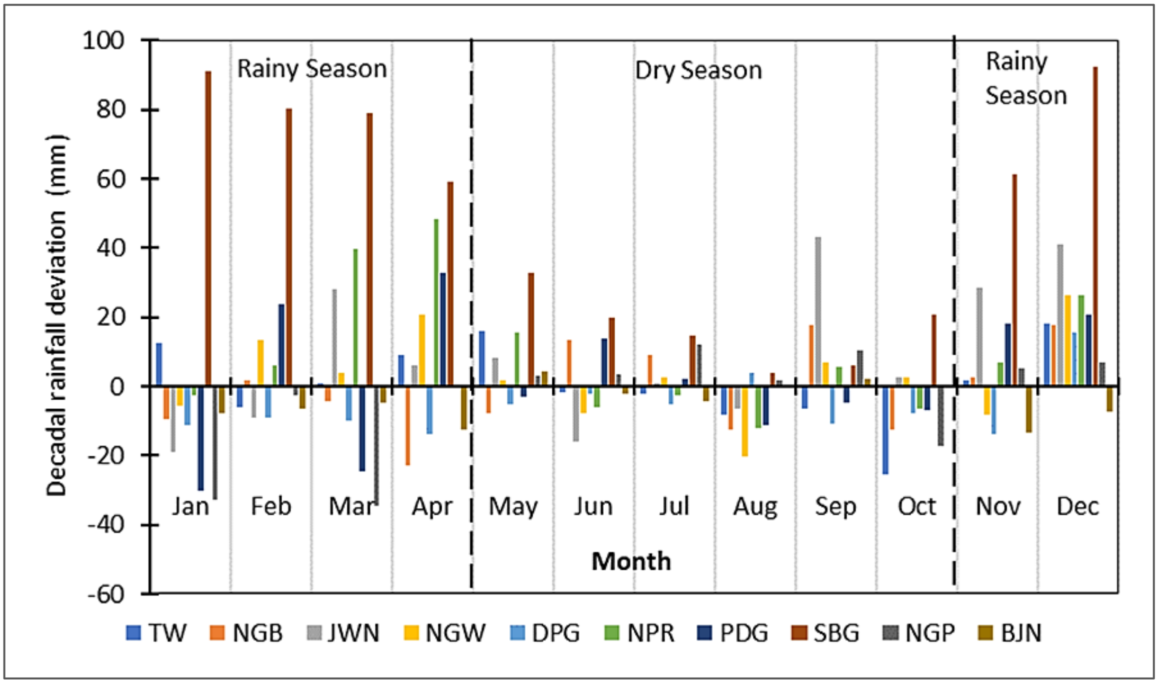

Figure 8. Average monthly deviation in decadal of rainfall over stations

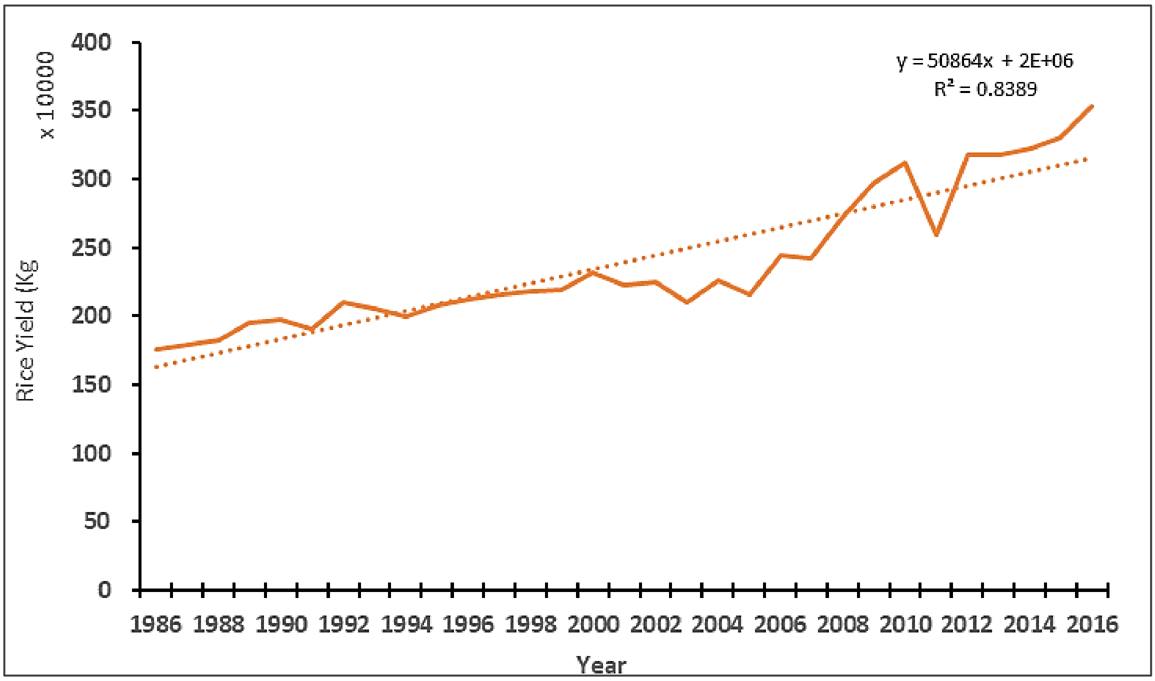

Figure 9. Rice yield trend on the rainfed area over the Bengawan Solo Sub-Watershed

The trend tests show positive and negative trends in the study area (Table 3). A decline in the monsoonal dominance tends to change the 10-day rainfall pattern. Compared to monthly and annual rainfall trends, the 10-day trend tends to move slowly but surely. The positive trend will benefit water availability in the cropping area with increasing accumulated rainfall magnitude. Whilst a negative trend tends to cause water shortages in rainfed areas. The 10-day rainfall trend needs to be considered for its impact on agriculture. The rainfall change is not significantly affected during the rainy season because of the abundant accumulated rainfall magnitude. However, the high possibility of water scarcity in rainfed areas will occur during the dry season because of decreasing accumulated rainfall. In addition, increasing rainfall magnitude and frequency lead to determining the onset of crop planting. The onset of crop planting follows the beginning of the rainy season in the rainfed area where rainfall is the main water supply.

Generally, the long-term annual rainfall trend of this study supports Johnston et al. (2012), who state that long-term trends in Southeast Asia are only significant in a few regions and annual patterns by employing the Mann-Kendall test. Studies on annual rainfall changes in Indonesia (Enung et al., 2020), who investigated rainfall trends in the Citarum watershed, revealed that most areas did not show significant annual trends. Other studies discovered no evidence of a substantial trend in annual rainfall in the monsoonal region (Ahmad et al., 2015; Sa'adi et al., 2017). This phenomenon of an annual rainfall trend is because of the interactions between annual variability and long-term monotonic tendencies.

The monthly rainfall pattern clearly confirms the monsoonal behavior in the Bengawan Solo Sub-watershed. This type of rain has a peak in the dry season or in the rainy season with a clear difference between the two seasons. The rainfall pattern of the Bengawan Solo Sub-watershed clearly implies the maximum value during the peak of the wet season from November to April. The amount of rainfall declines to its lowest during the peak of the dry season from June to September. This pattern is influenced by the Southeast Asian monsoonal wind pattern which passes and brings most of the air over the sub-watershed during the wet season (Avia, 2019). However, the wind brings dry air from the Australian continent during the dry season. The spatial and temporal climate pattern in the Bengawan Solo Sub-Watershed is dominated by the monsoonal pattern over a 1-year period. Hermawan (2011) states that the system of the Asian-Australian Monsoon influences rainfall in Indonesia, especially on Java Island, resulting in a single maximum rainfall peak in January, February, or December. The change of monsoon wind direction between summer and winter is because of the natural distinction between land and sea (Giarno et al., 2012). Because Indonesia is an equatorial country with many mountains, the influence of the monsoon has grown quite complicated. El Nino and La Nina events can potentially have an impact on monsoon wind patterns. The El Nino phenomenon pushed up the beginning of the wet season and the lengthening dry season while the La Nina phenomenon caused the and last longer early wet season (Suaydhi, 2016).

Secondly, the other finding is the influence of rainfall trends above Bengawan Solo Sub-Watershed on rainfed rice production. Landuse in the Bengawan Solo watershed is dominated by dry land agriculture and rainfed (43.78%), paddy fields (19.53%), forests (13.57%), settlements (10.84%), shrubs (9.24%), plantations (1.55%) and ponds (1.49%) (Sudinda, 2013). Rainfed area relies on rainfall for agricultural cultivation. Data on rice crop productivity was collected from the agriculture authority, the government of Central Java, during 1985–2016. The rainfed rice yield trend test demonstrates annual rainfall trend contributed on rainfed rice yield per year in Bengawan Solo Sub-Watershed This finding agreed with (Keblouti et al., 2012; Rahman et al., 2017), indicating that the rainfall variables accounted for 49, 45, and 41% of rice production variability in coastal, terrace, and rainfed area, respectively. Accordingly, rainfall has become a success key for rice cultivation in rainfed areas. Based on the rainfall trend, an increase in accumulated annual rainfall in rainfed areas provides an opportunity to promote increased rice production (Putra & Nurjani, 2021).

The other important thing of this study is the rainfall trend for future rainfall projections. The change in rainfall during the dry season would affect water availability over a sub-watershed. For example, Bojonegoro station has a minor rainfall change that tends to decrease in the period 1986-1995 to 2006-2015 (Figure 6). The negative rainfall deviation indicates the decreased frequency and magnitude of rainfall during the dry season which causes a reduction in water supply for rice crops in the rainfed areas as previous study (Klutse et al., 2021; Panda & Sahu, 2019; Susilokarti et al., 2015). The existence of a rainfall trend needs awareness in planning water availability and food security. Meanwhile, the decreasing rainfall trend has reduced water availability in the sub-watershed region. An increasing rainfall trend has the potential to store enough water to supply water demand. Furthermore, because of the misunderstanding of rainfall variability by farmers, they could experience crop failures.

5. CONCLUSION

The quantitative study used a statistical approach to clarify rainfall magnitude and frequency over the Bengawan Solo Sub-Watershed as well as the effect on rice production in the rainfed area. The results showed that rainfall variability puts the risk of rice production. Temporal changes observed in rainfall patterns, with a decreasing trend in the monsoon, could decline crop production in the middle and coastal watershed. To avoid any unfavorable circumstances for rice production, more concern and specific measures are required. To effectively cope with rainfall variability consequences, a collective effort is required to apply diverse adaptive and mitigation techniques, including research and appropriate development activities. A proper way is needed to anticipate water shortages in the dry season by rainwater harvesting. This is a critical concern not only for the current study area but also for the entire tropical region, because similar patterns may exist under similar climate systems. Future research is needed to clarify run-off trends, which have been influenced by land-use changes as the catchment area has grown rapidly.

Declaration of Competing Interest

The authors declare that no competing financial or personal interests that may appear and influence the work reported in this paper.

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