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TREND AND CHANGE OF ANNUAL RAINFALL IN EAST JAVA

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ABSTRACT

The climate change propagates the magnitude and variability of rainfall received at local areas. Statistical analysis of rainfall measurements is used to observe the influence of this global phenomena on specifics location. This research aims to analyze the annual rainfall trend in East Java. The daily rainfall data from 237 locations used as the input for this study. The spatial and temporal variability of annual and monthly rainfall performed by Histogram visualization of rainfall data amongst sub-region. Three statistical methods (i.e., Median-Crossing, Mann-Kendall, and Rank-Sum Test) are used forthe analysis. Annual rainfall data ranging from 1980 to 2015 was evaluated using those three statistical tests. The spatial variability of annual rainfall trends in specific regions visualised using the histogram. The result shows that a few locations have a positive trend of annual rainfall over the two decades. While other sites indicate no significant trend, this study also produces thematic maps showing the value of trends in each location.

Keywords: spatial, temporal, variability, trend, rainfall.

INTRODUCTION

Climate change causes the increase in surface temperatures on the earth and the occurrence of unusual rainfall events. According to IPCC (2007), climate change is an alteration of average or variability of climate factor for such an extended period, generally. It is valid for decades or even more.

In Indonesia, climate change causes an increase in sea surface temperatures and a variation of the intensity of rainfall. This condition will increase the probability of flood risk in the rainy season and drought risk in the dry season (National Development Planning Agency, 2014).

Statistical analysis of rainfall time series uses to identifier the trend or change in climate variables. The study shows if a pattern or a change occurs at a specified period. Furthermore, the result will guide the planning and management of water resources.According to Salas (1980), time-series analysis used to create mathematical models to synthesize hydrological data and to detect a change. Three types of changes exist in rainfall time series analysis, i.e. (a) trends, (b) jump *(shift)*, and (c) a seasonal cycle change *(annual change)*.

The three types of analysis may be applied for a series of rainfall data that occur in a particular region. Many statistical methods and tools used to analyze the trends and changes in a hydrological or climatic variable (Robson *et al.* 2000). Both parametric and non-parametric methods commonly used for the analysis (Chiew and Siriwardena 2005), (Robson *et al*. 2000). Furthermore, Hessel *et al*., (2002) have presented in their textbook many statistical methods available to detect climatic trends and changes.

Previous studies have elaborate non-parametric methods to detect the rainfall trends, for example, the study conducted by Kampata *et al.*, (2008), Miller and Piechota (2008), Caloiero *et al*., (2011), Armstrong *et al*., (2012), and Wickramagamage (2016). According to Hirsch (2002), the use of the non-parametric method in the analysis of hydrological data is stronger than the use of a parametric method because the non-parametric test not depends on the data distribution. Furthermore, according to Chiew and Siriwardena (2005), most of the hydrological time-series data is un-normally distributed, therefore the non-parametric method is more suitable.

TREND is one of the statistical tools that can be applied to evaluate the trend and change in hydrological time-series data (Chiew and Siriwardena 2005). In general, the TREND provides 12 statistical tools functioned to test the trends, changes, and jump in a series of hydrological data. TREND used to detect surface flow trends in the South western part of Western Australia (Durrant and Byleveld 2009). The analysis of rainfall trends and changes in several areas of East Java have also studied. Indarto *et al*., (2011) studied the trends of annual rainfall changes at nine rain gauges in East Java by using the Mann-Kendall and Rank Sum Test.

This study aims to analyze the annual rainfall trend in East Java and to visualize the distribution of trend on the thematic GIS map. The thematic maps utilised for planning, monitoring, and evaluating the water resources in the region.

RESEARCH METHOD

The study was conducted in East Java Province. The 237 rain-gauges (recording periods from 1980 to 2015) are selected for the analysis (Figure-1). The trend analysis carried out at each location. The preliminary analysis uses to visualize the distribution of monthly and annual rainfall globally on the region.

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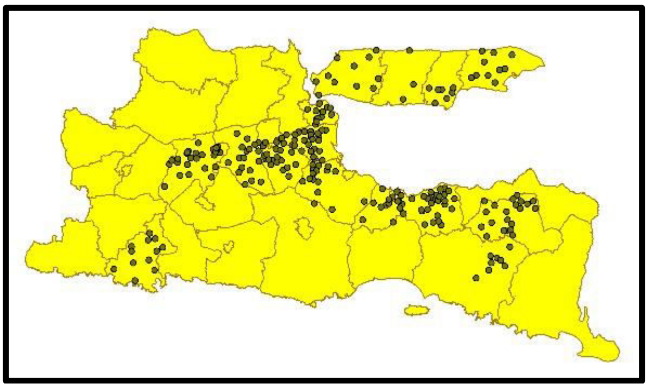

Figure-1. The map of the rain gauge in East Java.

The monthly rainfall data was determined as the cumulative of daily rainfall for one month period. Annual rainfall data calculated as the accumulated amount of daily rainfall data for one year. The monthly rainfall presented in the form of a histogram. Then the histogram of selected rain-gauge presented to describe the spatial variability of rainfall among each sub-region. Furthermore, the histogram of the frequency distribution is calculated for selected rain-gauge to visualize annual rainfall spatial variability among sub-regions.

Three non-parametric tests, i.e., Median Crossing (MC), Mann-Kendall (MK) and Rank-Sum (RS) are used for the analysis (using a level of significance $\alpha = 0.05$). The hydrological time-series data un-normally distributed; therefore, the non-parametric method is well-suited for this analysis (Chiew and Siriwardena 2005).

The MC is a non-parametric statistical test to determine the characteristics of the data related to random processes. The Z was value of the MCdetermined by equation (1).

$$Z = \frac{|m-\mu|}{\sigma^{0.5}} \quad (1)$$

Where:

n = the (n) years of rainfall data

m = the (m) values of 0, which is followed by 1 and vice versa

$$\mu = mean = \frac{(n-1)}{2} \quad (2)$$

$$\sigma = varian = \frac{(n-1)}{4} \quad (3)$$

The zero hypothesis [H_0] rejected if Z is more than Z (1-α/2). Therefore the data does not come from a random process.

The MK is a statistical test recommended by WMO to detect trends in hydrological and meteorological data series (World Meteorological Organization 1988). The Z value of MK calculated by equation (4) (Hessel *et al.* 2002).

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var\ (S)}} & S > 0 \\ 0 & S < 0 \\ \dfrac{S+1}{\sqrt{Var\ (S)}} & S = 0 \end{cases} \quad (4)$$

Where:

S = Statistic Value = P-M

P = Total value of Rj>Ri

M = Total value of Rj<Ri

Ri = Relative annual rainfall score in year - i

Rj = Relative annual rainfall score in year - j (i + 1 to n)

Var (S) = Variant of statistical values = n(n - 1)(2n+5)/18 (5)

The Z value follows the normal distribution. The positive Z value represents apositive trend and vice versa. The zero hypothesis (H_0) rejected if | Z | more than $Z_{(1-\alpha/2)}$, and there is a trend in the data series.

Rank Sum (S) is a statistical test to see if there is a change in data series. The data series divides into two periods (initial and final). The RS test result does not show the actual value, but it shows the relative ranking(Hessel *et al.* 2002). The Z value of RS was calculated by equation (6).

$$Z = \begin{cases} \dfrac{W - 0.5 - \mu}{\sigma} & If\ W > 0 \\ 0 & If\ W = 0 \\ \dfrac{W + 0.5 - \mu}{\sigma} & If\ W < 0 \end{cases} \quad (6)$$

Where:

W = Number of ranks in small data/groups

W = n

μ = mean= $\frac{n(N+1)}{2}$ (7)

σ = varian = $\sqrt{\frac{nm(N+1)}{12}}$ (8)

The Z value follows the normal distribution. The positive Z value indicates that the median of the previous (initial) period is higher than the median of the final periods and vice versa. The zero hypothesis (H_0) rejected if | Z | is more than Z (1-α / 2), then there is a change or difference in annual rainfall between the initial and final periods. Finally, the results displayed in the form of graphs and tables. A simple thematic map created to visualize the distribution of trend and change around the regions.

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RESULTS AND DISCUSSIONS

Preliminary analysis

Figure-2 shows the monthly rainfall distribution of the nine rain gauges. Figure-2 also shows the difference of the precipitation received between rainy (wet) seasons and the dry seasons. The selected rain gauge visualized to show the relative spatial distribution of monthly rainfall in this region.

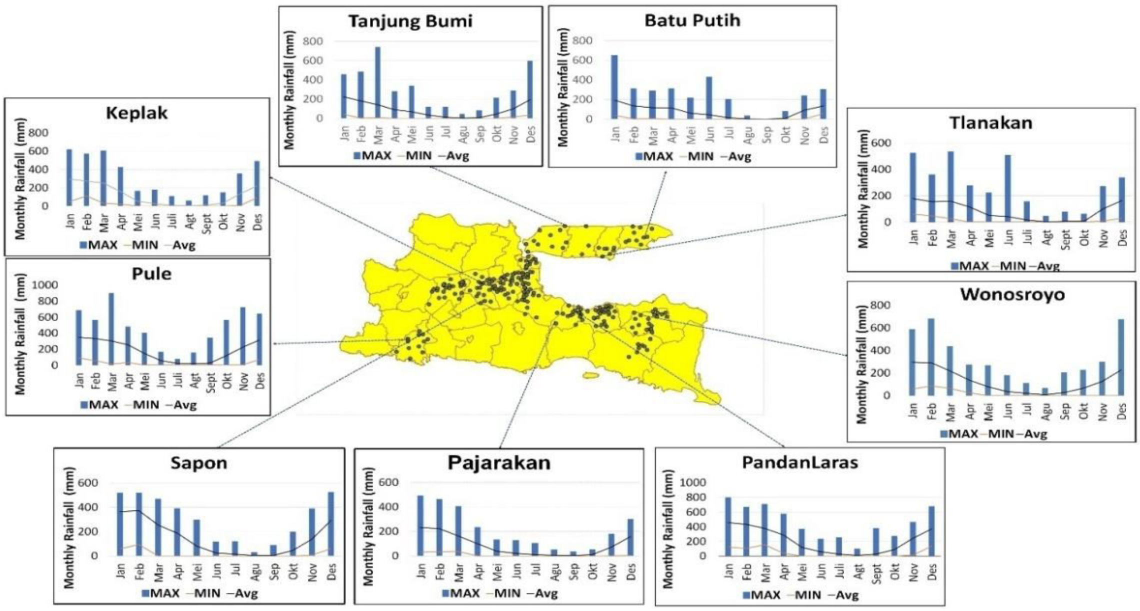

Figure-2. Monthly rainfall distribution of nine (9) rain-gauges.

The rainy season starts from October or November to April or May. However, the season starts differently among the sub-regions. The frequency distribution of annual rainfall from the nine selected rain gauges is presented in Figure-3.

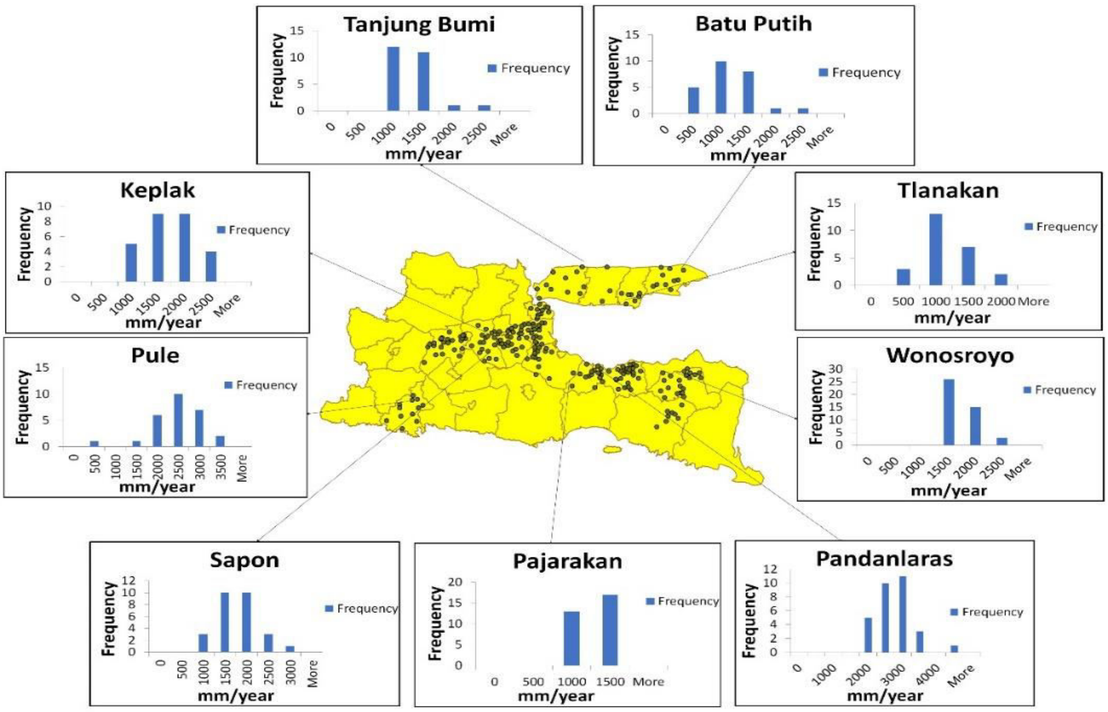

Figure-3. The frequency distribution of annual rainfall at 9 rain-gauges.

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The annual rainfall ranges from 1000 mm/year to 3500 mm/year. The most frequency of annual rainfall ranges from 1000-2500 mm/year. The highest annual rainfall during the period has occurred at PandanLaras (± 4500 mm/year). Contrary, the lowest annual rainfall has occurred at the Tlanakan, BatuPutih and Pule (± 500 mm/year).

The statistical test results

Table-1 shows the result of Median Crossing (MC) test at the five selected rain gauges. These five (5) rain gauges used as a sample for the discussion.

Table-1. The result of the MC test.

Stations' name	Critical value	|Z| value	Results
Asem Jajar	1,96	3,157	Significant
Batur	1,96	0,557	Insignificant
Keplak	1,96	1,964	Significant
Tlanakan	1,96	0,447	Insignificant
Wonosroyo	1,96	0,234	Insignificant

As shown in Table-1, the Asem Jajar and Keplak have a positive value of Z. It is mean that the data from the two locations come from non-random process. Furthermore, the MC test results from 237 rain gauges showed that 22 rain gauges (9,3%) indicate the data series acquired from non-random processes. However, the majority of rain gauges (i.e. 215 units or 90, 7% locations) indicate that the data series results from the random processes.

According to Mann-Kendall test results, the annual rainfall data show a trend if the value of Z exceeds its critical value ($\alpha_{0.05}$ = 1.96) and vice versa. A positive Z value pointed out a rising of annual rainfall trend, while a negative Z value indicates a negative trend of rainfall. The results of the Mann Kendall test at the fiverain gauges presented in Table-2.

Table-2. The results of the Mann Kendall.

Stations' name	Critical value	|Z| value	Results
Asem Jajar	1,96	0,607	Insignificant
Batur	1,96	-0,678	Insignificant
Kaplan	1,96	-2,030	Significant
Tlanakan	1,96	2,919	Significant
Wonosroyo	1,96	-0,569	Insignificant

Based on Table-2, the negative trend of annual rainfall shownat Kaplan.A positive Z value indicates thepositive trend as occurs at Tlanakan. The Mann Kendall test result from the 237 rain gaugesshowed that the 20 stations (8.44%) have a positive trend significantly. Ten (10) locations or 4.22% show a negative trend significantly. However, most of the locations (86.5%) have no significant trend of annual rainfall.

The trend of annual rainfall is probably caused by several factors, such as the influence of a warm and humid climate. A warm climate can increase the frequency of convection in the atmosphere, causing the frequency to increase and accelerate the hydrological cycle (Cheng *et al.,* 2011). In this condition, the role of La Nina and El Nino events can also influence the tendency of rainfall to rise or fall. The La Nina event triggers the trend of rising rainfall, while El Nino events influence the decrease of rainfall.

The significantpositive trend occurs at some locationsprobably lead to hydro-meteorological related disasters, such as erosion, sedimentation, floods and probably landslide.The disaster will decrease agricultural productivity. Therefore, mitigation and adaptation efforts are needed. Besides that, we also have to prepare water resource allocation plansto fulfil the currentwater needs.

The results of the Rank Sum (RS) test show some significant results, in other words, there are changes in annual rainfall if the value of Z exceeds its critical value (α 0.05 = 1.96) and vice versa. A positive Z value indicates that the change in annual rainfall or the median value of theinitial period is more than the final period and vice versa. The results of the RS test at five rain gauges presented in Table-3.

Table-3. The results of the Mann-Kendall.

Stations' name	Critical value	|Z| value	Results
Asem Jajar	1,96	0,705	Insignificant
Batur	1,96	1,618	Insignificant
Kaplan	1,96	1,445	Insignificant
Tlanakan	1,96	-2,366	Significant
Wonosroyo	1,96	0,801	Insignificant

Based on Table-3, Tlanakan Station points out significant changes in rainfall. This indicated by a negative Z value exceeding the critical value. From the 237 rain gauges conducted by the RS test,indicate that: 43 stations (18.14%) have experienced a significant change, where 18 stations (7.59%) have an adverse change in annual rainfall and 25 stations (10.55%) have positive change. The annual rainfall significantly decreased at ten stations (4.22%).

However, the majority of rain-gauges (81.01%) have no change in annual rainfall series. About 82 stations (53.59%) experienced insignificant changes in rainfall, while 109 stations (45.99%) have an insignificant positive change in rainfall.

The changes in the annual rainfall were probably accelerated by human activities such as land degradation, deforestation, and urbanization (Robson *et al.*, 2000). The overall Rank Sum test results represent the rainfall conditions of regions in East Java which do not undergo the annual rainfall changes with a percentage of more than 80% of the rain gauge.

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The thematic map of rainfall trend

Based on the Mann-Kendall test using the significance level of α 0.05, the map of annual rainfall trends describes the trend of rainfall in the regions of East Java. A red triangle symbol indicates the rising rainfall trend; the decreasing rainfall signified by a green inverted triangle symbol while a black circle symbol denotes the rain gauge that does not experience the rainfall trend.

Figure-4 shows the distribution of annual rainfall trends in East Java. Based on the map, the positive trend of annual rainfall showed at 20 rain-gauges, and the negative trend occurs at ten (10) rain-gauges. Based on the administrative area, the increase or decrease trend in rainfall occurs in the Regency/City of Surabaya, *Sidoarjo, Mojokerto, Bangkalan, Sumenep, Probolinggo, Pasuruan, Jombang, Nganjuk and Trenggalek*.

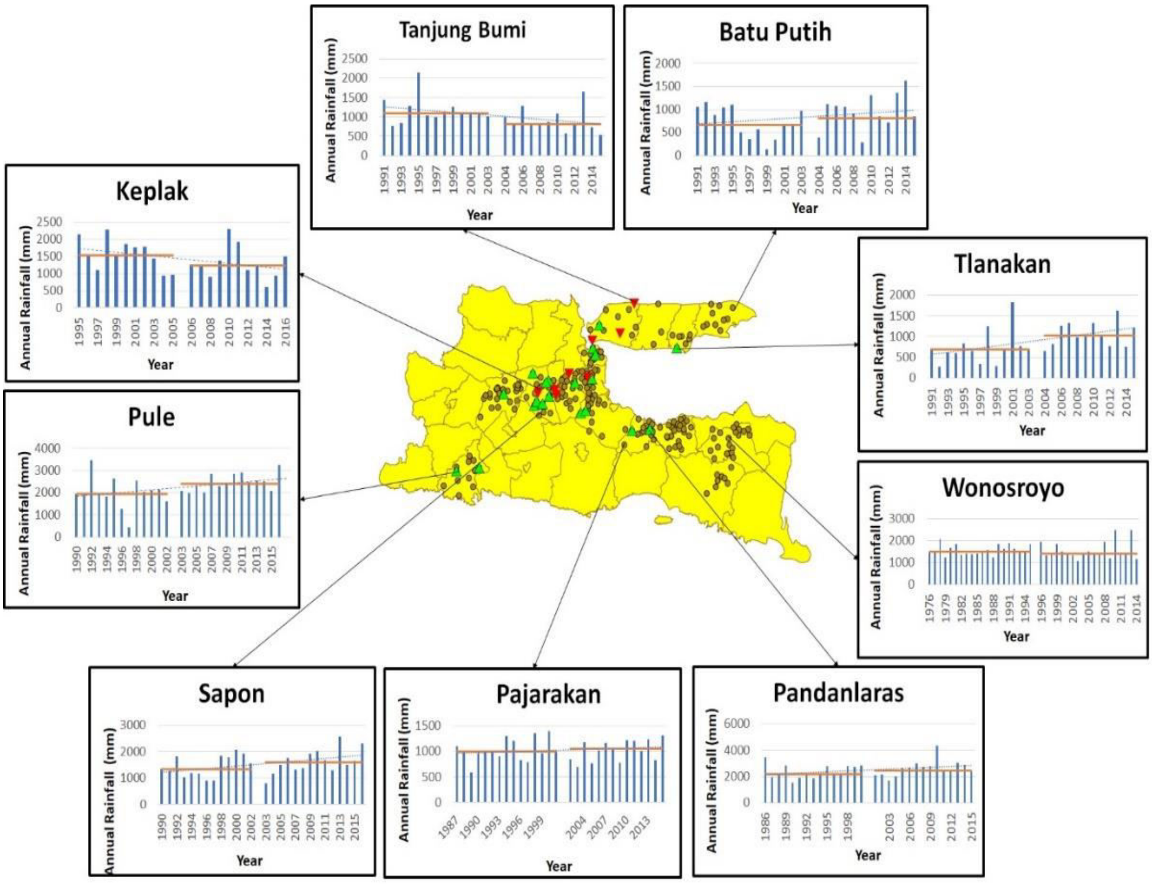

Figure-4. The map of annual rainfall trends in East Java.

Figure-4 also shows the annual rainfall changes in the initial and final periods. The line-graph cross-over the histogram shows the existing Change of the annual rainfall. The slope of line-graph (the orange lines) shown the change between the initial and the final period.If the median value of the initial period is lower than the final period, the positive change exists between the two periods.

CONCLUSIONS

According to Mann-Kendall test, no significant change of annual rainfall exists for most parts of the East Java regions (86.50%). The annual rainfall trends occur locally on the mountain areas. The Rank Sum test results also show that most of the region (81.01%) in East Java has no shift in annual rainfall. The increase of annual rainfall can propagate the risk of a hydro-meteorological related disaster such as flood, erosion, sedimentation, and land-slides. Therefore, in the area where the annual rainfall tends to increase, it is necessary to adapt and to mitigate possible floods and landslides.

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