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An analysis of extreme rainfall trends from 1960 to 2015 in urban areas of Surabaya

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Abstract. Extreme rainfall event considered as the primary cause of many hydro-meteorological disasters around the world. Extreme rainfall event propagated more prolonged disaster when occurring in urbanised areas. This research presents an analysis of trend and rainfall variability in the most urbanised areas of East Java. The study is conducted at Surabaya City and its sub-urban areas (Mojokerto, Sidoarjo). Daily rainfall data from 1960 to 2015 obtained from existing measurement sites are used as input for this study. Firstly, a frequency distribution of extreme rainfalls (1-day maximum) is presented. Then, analysis of trend detection conducted using Mann-Kendall, Rank-Sum and Median Crossing test. Finally, spatial variability of extreme rainfall was presented by interpolating point measurement to produce thematics maps. The interpolation was conducted using IDW methods. The results show the trend and variability (temporal and spatial) of extreme rainfalls on the regions of Surabaya.

1. Introduction

The extreme climate change is one of the major issues in this century because the sustainability of economic and living conditions depend on the human ability to manage some risks which are related to extreme phenomena[1]. The intense rainfall in a region can provoke some disasters, such as floods and landslides. The extreme rainfall occurs when the intensity is very heavy, or it reaches until ≥ 20mm /day[2]. Extreme rainfall probably caused both from the magnitude of intensity and the duration of rainfall events [3]. The climate propagation greatly influences the water resources system.

The trend detection in climate elements such as extreme rainfall is essential to project the trend of climate variable in the upcoming period. Several studies in various countries have been done to show the trends and changes in extreme rainfall, such as in India [4][5][6], in British Columbia [7], in Australia[7], in Canada[8], Piera region[9], in the Italian region [10], and in China[11][12].

In Indonesia, Subarna[13] has analysed the trend of four climatic parameters (i.e. rainfall, temperature, evaporation and number of rainfall-days during the period 1998-2007 using the Mann Kendall test at Bandung climatological station. Furthermore, Muharsyah[14] detected trends and change of temperature at several regions in Papua using regression and Mann Kendall tests. He obtained relatively similar results. However, the Mann-Kendall test have shown more accurate result (at 99% confidence level). The use of parametric tests such as linear regression has a weakness. The use of a linear regression method to detect trends is difficult when data is random and only short observation period is available [15].

Some methods to analyse change and trend of hydrological and climate variables have been developed. The publications of textbooks and reports from Zbigniew[4], Helsel and Hirsch[5], Härdle et al.,[6] summarise the principles of statistical methods that can be used to detect trend and change. Many statistical tools have also been developed. One of the examples is TREND Detection[16]. TREND detection can be functioned to analyse the change in time series related to the climatic or hydrological variables. The changes can be in the form of trends, jumps, shifts and seasonal patterns. TREND software can detect trends, changes and randomness of the hydrological data by using 12 statistical tests[16]. The analysis of trends in extreme rainfall is urgently required to provide water resources planning and adaptation to the disasters risks in the future. The extreme rainfall is assumed to be one of the flood causes. When the soil layer becomes wet due to the previous rainfall events, and then it is followed by an extreme rainfall duration in high intensity, this will trigger hydro-meteorological related disasters, such as flash floods and landslide.

This research evaluates the trends of extreme daily rainfall. The maximum daily rainfall or 24-hours rainfall data is obtained from the daily rainfall data series. Therefore, each year represented by one maximum daily rainfall (24-hour) data. There is a possibility of increase and decrease trends due to the number of extreme rainfall events from the 1960 to 2015. The results of trends analysis and the spatial variability of extreme rainfall are then visualised as thematic GIS Layer.

2. Methodology

2.1 Study site, input data and tools

This research was conducted at the UPT PSDA (*Unit Pelaksana Teknis – Pengelolaan Sumberdaya Air*) in Surabaya (Figure 1). On the context of water resources management, the East Java region is divided into nine (9) areas of water resources management units (UPT-PSDA). The UPT is part of Local Province Government, coordinated by Dinas PU Pengairan. One office of the UPT PSDA is located in Surabaya. Figure (1a) shows the working area (or administrative boundary) of UPT. The working area of the UPT covers Surabaya city, Mojokerto city, Mojokerto Regency and Sidoarjo Regency. The study was conducted from April to August 2018. The data processing and analysis are done at the Laboratory of Environmental Control and Conservation (*Laboratorium Teknik Pegendalian dan Konservasi Lingkungan*) - Faculty of Agricultural Technology – The University of Jember. The data are obtained from the UPT PSDA office through several collaboration schemes (student internships and research, Post-Graduate Team Grants).

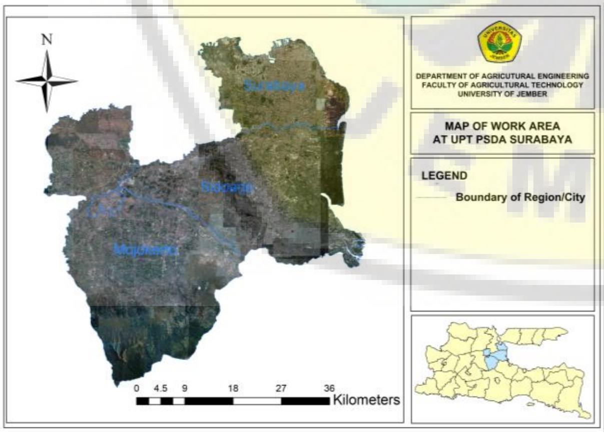

Figure 1a. Working area Boundary of UPT PSDA

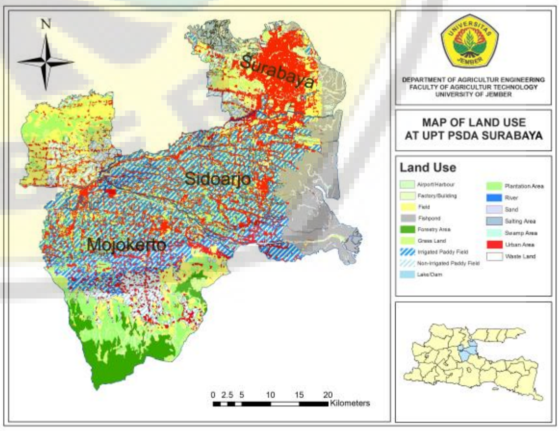

Figure 1b. Land use map

The study area is one of the most urbanised areas in East Java. Major land use occupations (% of total area) are: irrigated paddy (26%), Urban area (19%), plantation (12%), fish pond (11%), non-irrigated paddy field (7,5%), and forest (5%). Other land use occupation (~ < 10%) are composed of areas for urban factory or building (1,5%), bare soil and grass-land (5%), salt production area (1%), river, waterbody and airport (1%). The data is interpreted from RBI maps (http://tanahair.indonesia.go.id).

The input data for this study is daily rainfall data series obtained from 62 rainfall stations distributed around the study area. This study use the stations, having a long period of rainfall data record and continuously (at least 40 years). Furthermore, only 24 rainfall stations were selected for this analysis. The recording period is started from 1960 to 2015. The analysis is prepared using TREND (Trend Detection Software)[16]. GIS software is used to visualise the spatial distribution of trend, spatial variability of extreme rainfall and other thematic maps.

2.2 Procedure

2.2.1 Preliminary Analysis

The preliminary analysis is used to describe the distribution of 24-hours extreme rainfall at each sub-region. The 24-hour extreme rainfall is defined as the maximum daily rainfall. Furthermore, the maximum 24-hour rainfall data is selected for each station per year. Afterwards, each station is analyzed throughout the recording period. Furthermore, 24-hour rainfall distribution is presented in the form of graphics and histograms. Then, the selected 24-hour extreme rainfall data series modified into the (*.csv) format. Finaly, the data is analysed in the TREND software.

2.2.2 Statistical Analysis

The statistical test uses three non-parameteric tests, i.e (1) Mann-Kendall, (2) Rank-Sum and (3) Median Crossing. The Mann-Kendall Test is one of non-parametric tests recommended by WMO to test the trend in meteorological data. Rank-Sum test is used to determine changes in data that occur between periods based on their relative ranking [17]. Median Crossing Test is used to evaluate the characteristics of data series (If the data come from random or not-random processes based on the median value) [16]. The use of non-parametric methods is based on the assumption that generally rainfall are not normally distributed. According to Helsel and Hirsch [5], the use of non-parametric methods in the analysis of hydrological data is more general than the use of parametric method. The non-parametric method is relatively unaffected by the distribution of data [17]. Furthermore, Chiew and Siriwardena stated that most data on the hydrological time-series are not normally distributed, hence the non-parametric method is well-suited to apply [16].

2.2.3 Interpretation

The results of analysis are displayed in the form of graphs and tables. Afterwards, based on the statistical test we can get a conclusion whether there is a trend for maximum rainfall to be occured sequentially or not.

3. Result and Discussion

3.1 Pre-liminary Analysis Result

Figure (2) displays the annual distribution of 1-day extreme rainfall at the 8 stations. The amount of 1-days extreme rainfall during 1960 to 2015 is between 80-130 mm. Figure (2) also shows a ratio of annual value of 1-day extreme rainfall and its standard deviation.

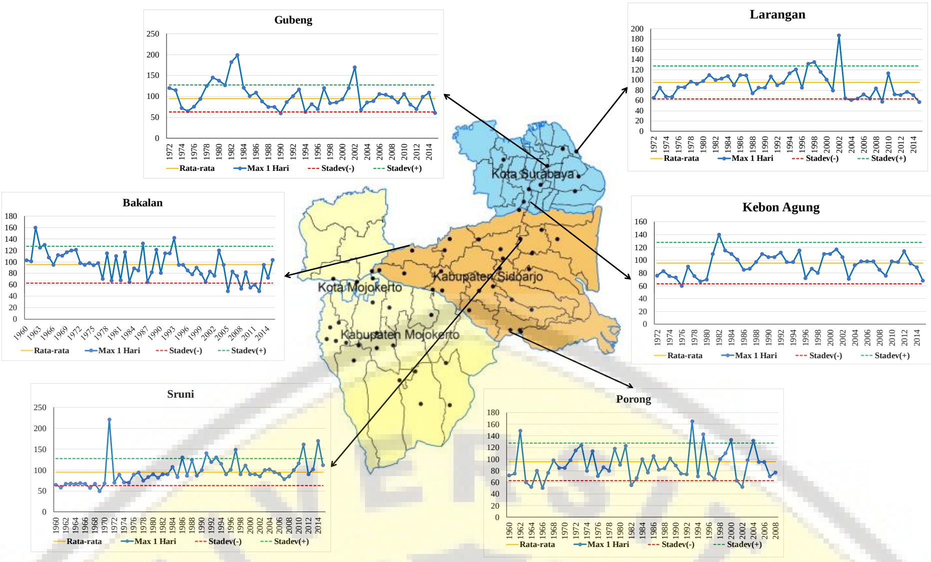

Figure 2. The annual distribution of 1-day extreme rainfall at 8 stations.

The higher deviation between the value and the standard deviation, shows the magnitute of extreme rainfall event.

Figure 3 show the frequency distribution of annual maximum of 24-hour rainfall during the period of analysis. The 1-day extreme rainfall occured mostly between 100-150 mm/day. The frequency distribution to the 6 stations is also not in the form of normal distribution.

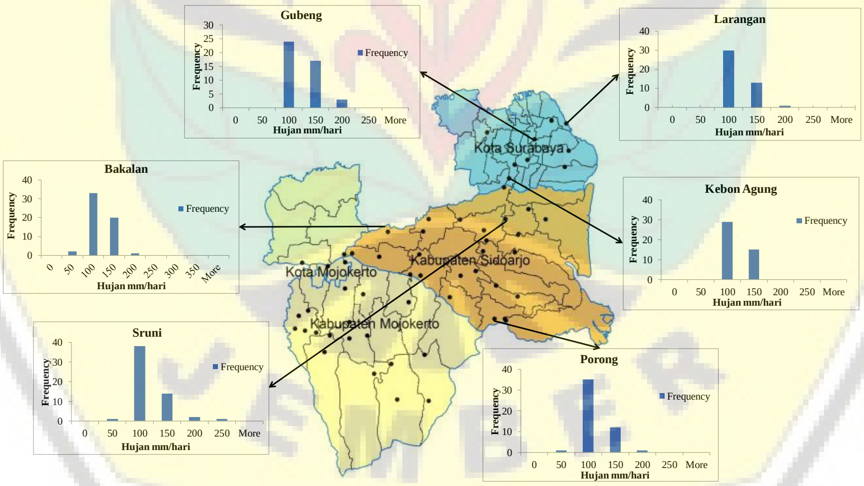

Figure 3. The frequency distribution of annual maximum of 24-hour extreme rainfall.

3.2 Statistical Test Results

3.2.1 Mann-Kendall Test

The test illustrates that there is an extreme rainfall trend when the Z > critical value ($\alpha = 0.05$) and vice versa [18]. Table (1) shows the test results from 24 rain-gauges. A positive value of Z indicates an upward trend, while a negative value of Z indicates a downward trend. Bono, Cepiples, Durung Bedug, Kedung Cangkring, Klangen, Kludan, Sidoarjo and Sruni stations experienced some significant increases in extreme rainfall trends (Table 1). The results of the research at 24 Rain gauge showed that 8 location (33.33%) experienced a significant upward trend and 1 location (4.17%) experienced a downward trend. The other location showed no extreme rainfall trends. There were 11 points (45.83%) shows unsignificantly trend and 4 stations (16.67%) show decreased trend unsignificantly.

Table 1. Mann-Kandall test result

No.	Stasion Name	Critical Value	Extreme Rainfall	
			Value |Z|	Result
1	Bono	1,96	2.537	significant increases
2	Bakalan	1,96	-4.255	significant decreases
3	Botokan	1,96	0.784	not significant
4	Budung Bulus	1,96	0.658	not significant
5	Cepiples	1,96	2.458	significant increases
6	Durung Bedug	1,96	2.551	significant increases
7	Gedangrowo	1,96	1.343	not significant
8	Kedung Cangkring	1,96	2.982	significant increases
9	Kedung Ploso	1,96	-0.028	not significant
10	Kemlaten	1,96	1.315	not significant
11	Ketawang	1,96	-0.954	not significant
12	Ketintang	1,96	0.926	not significant
13	Klangen	1,96	3.315	significant increases
14	Kludan	1,96	2.824	significant increases
15	Krian	1,96	0.071	not significant
16	Ponokawan	1,96	0.346	not significant
17	Porong	1,96	0.621	not significant
18	Prambon	1,96	0.855	not significant
19	Sidoarjo	1,96	2.543	significant increases
20	Sruni	1,96	5.414	significant increases
21	Gubeng	1,96	-1.436	not significant
22	Kandangan Sememi	1,96	0.678	not significant
23	Kebon Agung	1,96	0.799	not significant
24	Larangan	1,96	-1.123	not significant

3.2.2 *Rank-Sum Test*

Table (2) display the positive value of Z in the Rank-Sum test. It is shows that the median at the beginning of the previous period is greater than the median of the final period, or it has a downward trend and vice versa.

Table 2. Rank-Sum test result

No.	Station Name	Critical Value	Extreme Rainfall	
			Value |Z|	Result
1	Bono	1,96	-2.466	different
2	Bakalan	1,96	2.581	different
3	Botokan	1,96	-0.090	not different
4	Budung Bulus	1,96	-0.794	not different
5	Cepiples	1,96	-2.181	different
6	Durung Bedug	1,96	-1.991	different
7	Gedangrowo	1,96	-1.726	not different
8	Kedung Cangkring	1,96	-3.269	different
9	Kedung Ploso	1,96	0.828	not different
10	Kemlaten	1,96	-0.254	not different
11	Ketawang	1,96	0.893	not different
12	Ketintang	1,96	-1.549	not different
13	Klangen	1,96	-3.499	different
14	Kludan	1,96	-3.692	different
15	Krian	1,96	-0.057	not different
16	Ponokawan	1,96	-0.254	not different
17	Porong	1,96	-0.670	not different
18	Prambon	1,96	-1.434	not different

19	Sidoarjo	1,96	-2.542	different
20	Sruni	1,96	-4.728	different
21	Gubeng	1,96	1.608	not different
22	Kandangan Sememi	1,96	-1.491	not different
23	Kebon Agung	1,96	-0.599	not different
24	Larangan	1,96	0.927	not different

There are 10 locations experiencing significant changes between periods. It is shown by the "different" in table (2). The results also show that 9 sites (37.5%) subject to have positive change in extreme rainfall significantly. Station Bakalan have decreased change significantly between periods. Whereas the unsignificant changes were found at 14 locations (58.33%).

3.2.3 The Median Crossing Test

The test is used to see the characteristics of the data by comparing each data by their median value. The value of Z > the critical value (α 0.05) indicates that extreme rainfall data are not derrived from some random processes. Table 3 displays the result of the median crossing test.

Table 3. Median Crossing test result

No.	Stasion Name	Critical Value	Extreme Rainfall	
			Value |Z|	Result
1	Bono	1,96	3.910	Non-random data
2	Bakalan	1,96	2.023	Non-random data
3	Botokan	1,96	0.944	Random data
4	Budung Bulus	1,96	0.438	Random data
5	Cepiples	1,96	0.590	Random data
6	Durung Bedug	1,96	0.405	Random data
7	Gedangrowo	1,96	1.089	Random data
8	Kedung Cangkring	1,96	1.753	Random data
9	Kedung Ploso	1,96	0.944	Random data
10	Kemlaten	1,96	2.292	Non-random data
11	Ketawang	1,96	0.405	Random data
12	Ketintang	1,96	0.405	Random data
13	Klangen	1,96	2.292	Non-random data
14	Kludan	1,96	1.769	Random data
15	Krian	1,96	2.562	Non-random data
16	Ponokawan	1,96	0.944	Random data
17	Porong	1,96	0.000	Random data
18	Prambon	1,96	0.674	Random data
19	Sidoarjo	1,96	0.429	Random data
20	Sruni	1,96	2.832	Non-random data
21	Gubeng	1,96	1.982	Non-random data
22	Kandangan Sememi	1,96	3.507	Non-random data
23	Kebon Agung	1,96	0.799	Random data
24	Larangan	1,96	3.507	Non-random data

The results show that extreme rainfall data of Bono, Bakalan, Kemlaten, Klangen, Krian, Sruni, Gubeng, Kandangan Sememi, Larangan are derrived from some non-random processes (37.5%) and additionally (62.5%) from random processes. The overall results from of the 24 rainfall are obtained from some random processes. The hydrological data such as rainfall record generally come from some random processes because the data are related to condition of natural dynamics.

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3.3 Spatial Distribution of Extreme Rainfall Trends

Figure (4) present the spatial distribution of 1-day extreme rainfall from the Mann-Kendall test results. Most of the this site have no experience the extreme rainfall trend. It was shown that only 8 stations experienced a 1-day increase in extreme rainfall and 1 station was experienced a significant downward trend.

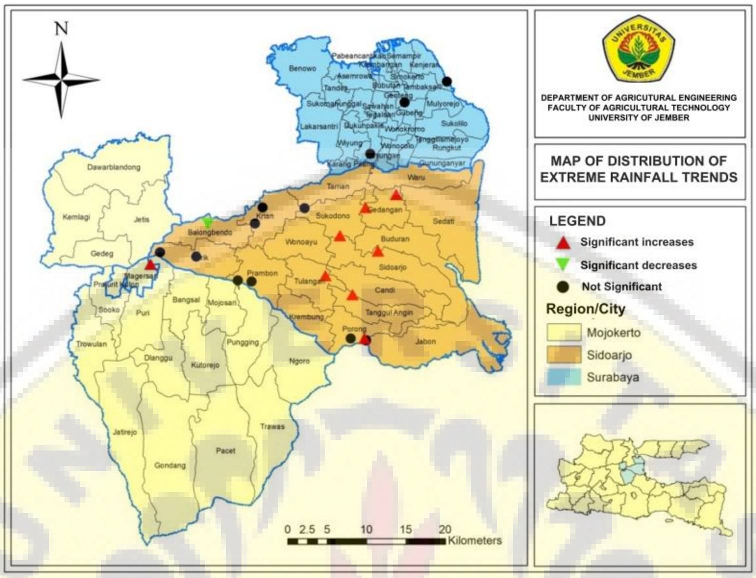

Figure 4. The distribution of extreme rainfall trends

The increase of rainfall trend is indicated by a red-triangle symbol. The decrease of rainfall trend is indicated by a green-inverted triangle symbol. The rainfall station that does not experience the rainfall trend is indicated by a black-circle symbol.

Figure 5 shows a plot of extreme rainfall trends. The plots in Figure 5, shows some discrete trends and changes in extreme rainfall. The trends are classified into 3 parts, i.e. the stations having a significant upward / downward rainfall trend (| Z | ≥ | 1.96 |), the station subject to unsignificant trend (-1.96 <Z <0 or 0 <Z <1.96), and the station having no trend (Z = 0).

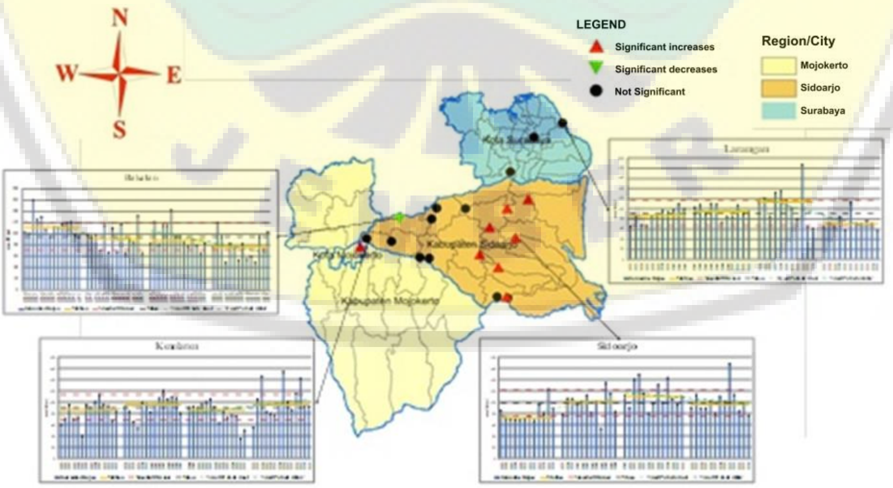

Figure 5. The graphical presentation of 1-day extreme rainfall trends.

The plots describe the trends or changes in each rainfall station. The significant upward trend is found at Sidoarjo. The unsignificant downward trend is found in Larangan. The unsignificant upward trend show in Kemlaten. The significantly downward trend is shown in Bakalan.

Rainfall stations that experience trends and changes in extreme rainfall are showed by the difference in median (the orange line) that significantly increases. The trend and change in period

1960 to 1987 is less than in period 1988 to 2015. The areas subject to upward trend in extreme rainfall phenomenon need to be adapted. The extreme rainfall event can trigger some related disasters.

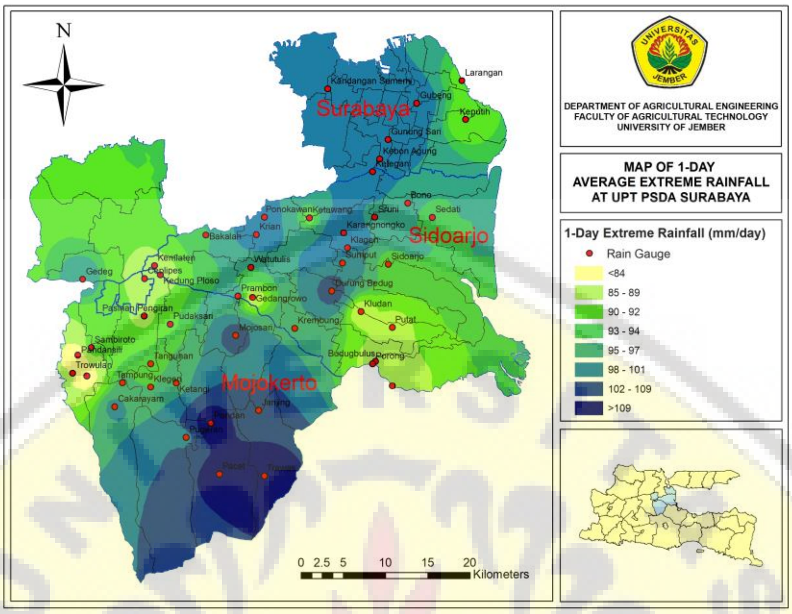

Figure 6. Spatial distribution of 1-day extreme rainfall

Figure 6 present the spatial distribution of 1-day extremes rainfall events in the regions. The map interpolated from point values using IDW interpolation method. The maps show the present of high extrem rainfall value on the southern mountain region of Mojokerto (the blue areas) cover the District of Pacet, Trawas and Pandaan. The blue areas range form Southern to Northern part (Surabaya City), from high altitude to low altitude.

4. Conclusion

Based on the the Mann-Kendall Test results, it can be concluded that most of the location have no experience in extreme rainfall trends (62.5%) from 1960 to 2015. The districts that experience the increase in extreme rainfall trends are Gedangan, Puri, Tulangan, Porong, Sukodono and Tanggul Angin. The Rank-Sum test show that most of the stations have no changes in extreme rainfall events. The Median Crossing test showed that data series from more than 62.5% of stations are come from random processes.

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