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SPATIOTEMPORAL CHARACTERISTICS OF EXTREME RAINFALL EVENTS OVER JAVA ISLAND, INDONESIA

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ABSTRACT

The patterns and trends of extreme daily rainfall within period of 1981 – 2010 have been analyzed for Java Island, Indonesia particularly East Java Province. A set of extreme indices recommended by WMO were calculated using high quality data from 84 rain stations to express the frequency and intensity of those events. The spatial patterns was identified by mapping climatological mean of indices while temporal trends was assessed using the non-parametric Mann-Kendal test. The study found that the spatial pattern of extreme rainfall events over East Java Province is generally characterized by low frequency and intensity in the coastal area, and high frequency and intensity in the mountainous area. The dominant finding from trend assessment is not-significant trend. However, the consistently significant trend was observed in some districts. Rain stations in District of Ponorogo, Ngawi, Bojonegoro, Gresik and Sumenep showed significant negative trend for almost all indices whereas significant positive trend was found in District of Surabaya and Pasuruan.

Key words: spatio-temporal characteristics, extreme rainfall events, Java Island

ABSTRAK

Penelitian ini menganalisis pola keruangan dan kecenderungan perubahan terhadap waktu dari kejadian hujan harian ekstrim di Pulau Jawa, khususnya wilayah Propinsi Jawa Timur, dalam periode antara tahun 1981-2010. Sebagaimana direkomendasikan WMO, frekuensi dan intensitas hujan ekstrim dinyatakan dalam indeks hujan yang dihitung menggunakan data dari 84 stasiun hujan yang telah diuji kualitas datanya. Pola keruangan dianalisis dengan cara memetakan rata-rata klimatologis dari indeks sedangkan pola kecenderungan diuji dengan menggunakan uji non-parametric Mann-Kendal. Hasil penelitian menemukan bahwa kejadian hujan ekstrim dengan frekuensi dan intensitas yang rendah secara umum terjadi didaerah pantai, sedangkan kejadian dengan frekuensi dan intensitas yang tinggi *terjadi didaerah pegunungan. Uji kecenderungan umumnya menunjukkan tidak terjadi perubahan yang signifikan. Namun pada beberapa kabupaten, ditemukan data kejadian hujan ekstrim yang berubah secara signifikan dan konsisten untuk beberapa indeks. Di Kabupaten Ponorogo, Ngawi, Bojonegoro, Gresik dan Sumenep, kejadian hujan eksrim cenderung berkurang secara signifikan dan konsisten. Sementara di Surabaya dan Pasuruan, kejadian hujan ekstrim justru ditemukan meningkat secara signifikan dan konsisten.*

Kata kunci : pola keruangan, kejadian hujan ekstrim, bencana hidro - meteorologi, nilai ambang, Pulau Jawa

INTRODUCTION

Extreme rainfall events are among the most devastating weather phenomena since they are frequently followed by flash floods and sometimes accompanied by severe weather such as lightning, hail, strong surface winds, and intense vertical wind shear [*Jones et al.* 2004]. Consequently, they generate large economic, social and environmental impact [*Manton et al.* 2001; *Carvalho et al.* 2002; *Jones et al.* 2004]. In rural area, the extreme rainfall events can damage crops and livestock. While in urban area, these events often cause flood problem due to inadequate drainage system to accommodate a sudden large amount of rainfall [*Carvalho et al.* 2002]. In global perspective, these events are also supposed being responsible for rapidly rising costs of losses since the 1970s [*Rosenzweig et al.* 2007]. Changing of probability of extreme rainfall events implies seriously to many sectors such as engineering, regional planning and other activities which traditionally assumed that climate is stationary [*Suppiah and Hennessy,* 1998].

Observational studies over some regions suggested evidence of change in climate extremes. Using daily rainfall data from 1931 – 1996, *Kunkel et al.* [1999], examined the trend of extreme rainfall events over the Conterminous United States and Canada and found an indication of increasing trend in the number of 7-day, 1-yr events. Even, some climate divisions have experienced increases of 50% – 100%. *Zang et al*. [2001], found an upward trends in the number of extreme rainfall events for the spring over eastern Canada when they examined the characteristic of extreme rainfall events using site specific threshold over whole country. Study on this event in the Alpine Region by *Frei* and *Schar* [2001], also confirmed an increasing trend for autumn and winter season.

However, some other studies in tropical region revealed inconsistent result. For example in Peninsular Malaysia, *Suhaila et al.* [2010] found that almost all stations in the eastern region show a decreasing trend of frequency of extreme rainfall events during southwest monsoon period. Nevertheless, the western region even shows the contrast result, an increasing trend. *Manton et al.* [2001] found different trend when assessing extreme rainfall events over Asia Pacific Region. An increasing trend was observed in Fiji and French Polynesia. However, Solomon Island, Philippines, New Zealand, Malaysia and Japan showed decreasing trend. The others country even show no significant trend. Over Indonesia, they concluded that the trend of extreme rainfall events is not significant. Unfortunately, they only used six rainfall stations e.g. Pangkalpinang, Jakarta, Balikpapan, Manado, Ambon and Palu which are inadequate certainly to display climatic condition of the whole country. The study at regional scale using more rainfall stations is therefore needed to figure out the actual trend.

There were high frequency of severe disaster events over Java Island related to extreme weather event such as flood and landslide event. National Agency for Disaster Management, *BNPB* recorded that more than 1,000 occurrences of floods and landslides strike the Island with various intensity within 2002 - 2008. The recent example of those disasters is flood which occurred in the end of 2007. Expanding from Central to East Java, it caused hundreds of casualties and damaged thousands houses. The flood was triggered by heavy rainfall event with intensity more than 100 mm/day taking place simultaneously and intensively in December 25, 2007 [*Hidayat et al*. 2008]. The record from Wonogiri Dam, Upper Solo Basin and Madiun Basin showed that the return period of rainfall ranging from 40 up to more than 100 year. The similar disaster reoccurred at the beginning of 2009 [*BNPB*, 2011].

The study of extreme rainfall events is especially relevant for Java Island because it is the most populous Island in Indonesia, with more than 120 million people living there. For national perspective, Java is the centre of economic activity, national government system and agricultural product. This paper reports the pattern of extreme rainfall events both spatially and temporally in the context of hazard study which was found from the study. In the following section, data and analysis techniques are described, followed by some results, a discussion and finally conclusion in the last section.

Situated between 105º 2’ – 114º 6’ E and 5º 8’ – 8º 8’ S, Java is one of the big islands in Indonesia whose area is 126,700 km². Its topography is characterized by low land whose elevation is less than 30 meter in the coastal area and mountainous area whose elevation could reach up to more than 3,500 meter. The Statistics Indonesia (*BPS*) reported that the population of Java Island in 2005 was 128.5 million inhabitants, distributed in six provinces i.e. Banten, Jakarta, West Java, Central Java, Yogyakarta and East Java Province.

The climate of Java is mainly controlled by monsoon system. There are two monsoon systems influencing this area. The northwest (*NW*) monsoon is active from November to March (*NDJFM*) and the southeast (*SE*) monsoon is working from May to September (*MJJAS*) [*Aldrian* and *Susanto*, 2003]. The characteristic of those two monsoons is significantly different. The northwest monsoon is wet and implies much rainfall while the southeast monsoon is dry and is responsible for less rainfall period over Java.

East Java Province where the analysis was focused comprises of two main islands i.e. the eastern part of Java Island and Madura Island. In the middle-south part of Province, there is mountainous area stretching out in the east-west direction while in the north part, the area is dominated by low land which is also known as lower part of Bengawan Solo watershed, the largest watershed over Java Island.

The daily rainfall data within period of 1981 – 2010 collected from regional office of *BMKG*, National Agency for Meteorology, Climatology and Geophysics were used for the study. The catalogue lists 931 rain stations over East Java province. However, the available raw data for this study are only 461 series.

Not all of these raw series were used for the recent study. First, the series were checked for gross error including the existing of data with not-standard format and duplicated data. Second, the spatial consistency was checked by comparing the tested daily data to its neighbors in the radius of 25 km using inter-quartile method [*Gonzalez-Rouco et. al.* 2001], see Figure 1. The detected outliers were trespassed by threshold. The distance of 25 km was defined based on spatial correlation function of daily data taken from 90% complete series. Third, following study by *Kunkel et al*. [2003] and *Ngongondo et al.* [2011], series with more than 10 % missing observation were excluded from the analyses. This procedure removed 67 % of tested series confirming that data completeness is major problem. The missing values were not filled to avoid bias on assessing the trend. The last, the homogeneity of the rainfall series was checked by using hybrid method proposed by *Wijngaard et al.* [2003]: the standard normal homogeneity test (*SNHT*), the Buishand range test, the Pettitt test, and the Von Neumann ratio test. Series were excluded when at least one of those four tests detected a shift. The procedure on running homogeneity test is detailed in *Wijngaard et al*. [2003]. Finally, a total of 84 daily rainfall series from raw dataset survived all selection procedures. Only these series were used for analysis of extreme indices (Figure 2).

Day	Tested	Neighbor-1	....	Neighbor-n	Threshold
					$Q_3 + (3*IQR)$
1	Value-1	Value-2	....	Value-n	Threshold-1
2	Value-1	Value-2	....	Value-n	Threshold-2
3	Value-1	Value-2	....	Value-n	Threshold-3
.	.	.	....	.	.
.	.	.	....	.	.
n	Value-1	Value-2	....	Value-n	Threshold-n

Figure 1. A schema to calculate outliers threshold. IQR = Q3 – Q1

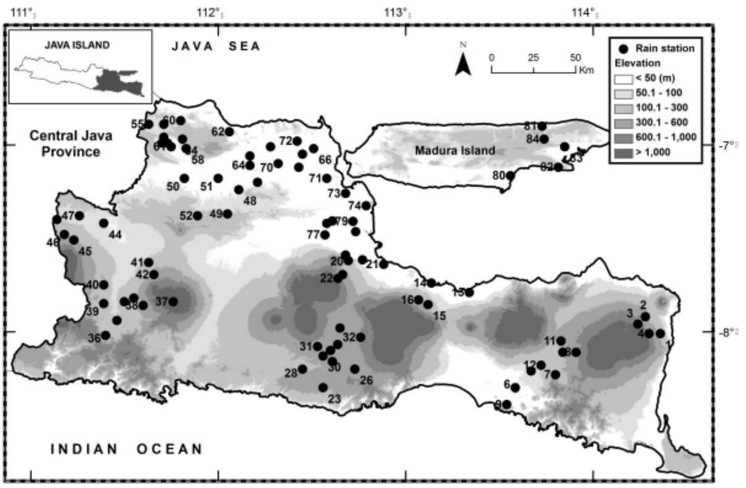


Figure 2. Topographic map of study area and spatial distribution of high quality data

THE METHODS

Extreme Indices

Adopting research by *Hernandez et al.* [2009] and *WMO guidelines* [2009], the analysis of extreme rainfall events was expressed by some indices which are widely used for describing extreme weather events. The indices were calculated as annual value for each station. A limit of 1 mm was operated to define a rainy day [*WMO*, 2009; *Bodini* and *Cossu*, 2010].

A fix threshold of 100 mm daily rainfall amount was chosen considering the criteria developed by *BMKG* [*BMKG*, 2010]. Instead of designing new threshold, the study was directed of evaluating the *BMKG's* fix threshold. The operability of fix threshold was assessed by finding a link of threshold to disasters which were generated by extreme rainfall events. For this goal, data of floods and landslides disaster over East Java Province in the last ten years were collected from *BNPB* data base system. The considered disasters are only those affecting large area and cause casualty/s. The fix threshold is said operable when the observed rainfall in the day of disasters falls mostly larger than the fix threshold. The method on defining site specific threshold closely adopts that of *Kunkel et al*, [1999, 2003] and *Fu et al,* [2010]. One day duration events were examined and were screened using three precipitation thresholds which are expressed by recurrence interval of 1, 5 and 25 year. Using 30 years daily rainfall record (1981 – 2010), threshold for 1 year recurrence interval was defined by sorting daily rainfall from largest to smallest observation. The largest 30 daily rainfall within period 1981 – 2010 were extracted and the smallest of these 30 observations were selected as threshold.

For 5 and 25 year return period, the threshold value was calculated using the generalized extreme value distribution, *GEV*. The distribution of *GEV* follows [*Coles*, 2001],

$$f(x) = \begin{cases} \frac{1}{\sigma}\exp\left(-(1+kz)^{-1/k}\right)(1+kz)^{-1-1/k} & k \neq 0 \\ \frac{1}{\sigma}\exp(-z - exp(-z)) & k = 0 \end{cases}$$

where z = (x - μ) / σ, and k, σ, μ are the shape, scale, and location parameters respectively. The scale must be positive (σ > 0), the shape and location can take on any real value. The range of definition of the GEV distribution depends on k:

$$1 + k\frac{(x-\mu)}{\sigma} > 0 \qquad for\ k \neq 0$$

$$-\infty < x < +\infty \qquad for\ k = 0$$

Various values for the shape parameter (*k*) correspond to the Gumbel, Frechet and Weibull distribution as shown in Table 1.

Table 1. Correspondence between GEV and three basic extreme value distribution

GEV shape parameter	Type based on Fisher-Tippett Theorem	Domain
k>0	Frechet	x>m-s/k
k <0	Weibull	x>m-s/k
K = 0	Gumbel	-∞<x<∞

Source: [*Orjubin*, 2008].

The threshold for certain return period (or also popularly known as “return level” in extreme value terminology) is determined using formula as follows [*Coles*, 2001]:

$$X_T = \mu - \frac{\sigma}{k}\left[1 - \left\{-\log\left(1 - \left(\frac{1}{T}\right)\right)\right\}^{-k}\right]$$

$$T = return\ period$$

Some extreme indices suggested by *WMO* were also calculated i.e. R20mm, R50mm, *R90p, CWD, RX1d, RX5d, SDII, RTOT*. The final detail extreme indices applied in the study are presented in Table 2. Each index was calculated for each station and was expressed as annual series.

Table 2. Detail extreme rainfall indices which are used in the study

NOTATION		DESCRIPTION
Frequency Indicator [*adapted from Hernandez et al.* 2009; *WMO*, 2009; *BMKG*, 2010]		
1	R20mm	The number of rain day with rainfall larger than or equal to 20 mm (moderate rain days)
2	R50mm	The number of rain day with rainfall larger than or equal to 50 mm (heavy rain days)
3	R90p	The number of rain day with rainfall larger than or equal to 90th percentile of 1981 – 2010 series
4	CWD	Consecutive wet day; maximum length of wet spell
Intensity Indicator [*Adapted from WMO*, 2009]		
5	RX1d	Maximum daily rainfall
6	RX5d	Maximum cumulative rainfall of 5 consecutive rain days
7	RTOT	Total annual rainfall
8	SDII	Simple daily intensity index; total annual divided by number rain day
9	RI90p	Daily rainfall value at 90th percentile of 1981 – 2010 series
10	R1yr	Daily rainfall value for 1-year return period
11	R5yr	Daily rainfall value for 5-year return period
12	R25yr	Daily rainfall value for 25-year return period

Spatial Pattern and Trend Estimation

Since rain gauges with high quality data are not proportionally distributed, spatial point pattern analysis was selected as method to explore spatial characteristic of extreme rainfall events. This method is commonly used to analyze pattern of distributed point whether the variable are distributed at random or represent a clustered or regular pattern [*Pfeiffer*, 1996].

The application of point pattern analysis in studying extreme rainfall events could be found in *Kunkel et al.* [1999], *Tank and Konnen* [2003], *Deni et al.* [2010] and *Fu et al.* [2010].

The temporal trend was identified by using Mann-Kendal test. It is a familiarly used technique of detecting trend for environmental series data which is often not distributed normally [*Hipel*, 1994]. *WMO* also recommends this method for trend assessment in climatological data [*WMO*, 1988]. Many studies used this method to detect rainfall trend both for mean rainfall such as *Aldrian and Djamil* [2007] in Indonesia, or for extreme rainfall events such as *Zang et al.* [2001] in Canada, *Fu et al*. [2010] in Australia and *Ngongondo et al.* [2011] in Malawi.

Here, the procedure to operate Mann-Kendal analysis was quoted from Yue and *Wang* [2004] and *HydroGeoLogic, Inc* [2005]. The data values are evaluated as an ordered time series. Each data value is compared afterward to all subsequent data values. The detail procedures are:

a. Calculate the Mann-Kendall statistic.

The initial value of the Mann-Kendall statistic (S) is assumed to be 0 (e.g. no trend). If a data value from a later time period is higher than a data value from an earlier time period, S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S.

The formula to calculate S is given by :

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k)$$

Where:

$$sign(x_j - x_k) = \begin{cases} 1, \text{if } x_j - x_k > 0 \\ 0, \text{if } x_j - x_k = 0 \\ -1, \text{if } x_j - x_k < 0 \end{cases}$$

b. Compute a normalized test statistic Z as follows :

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & , if\ S > 0 \\ 0 & , if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & , if\ S < 0 \end{cases}$$

c. Compute the probability associated with this normalized test statistic expressed in p-value. The probability density function for a normal distribution with a mean of 0 and a standard deviation of 1 is given by the following equation:

$$f(z) = \frac{1}{\sqrt{2\pi}} \quad e^{-\frac{z^2}{2}}$$

p-value = 1 – f(z)

d. Decide level of significance (α = 10 %).

Conclude the trend using this criteria; the trend is said to be decreasing if Z is negative and is said to be increasing if the Z is positive. The trend is statistically significant if p-value is less than α otherwise it is not significant or no trend.

Slope of the trend was estimated using Theil-Sen slope estimator. The Theil-Sen estimator (*TSE*) was proposed by *Theil* [1950] and was extended by *Sen* [1968]. It is a robust estimate of the magnitude of a trend with a high breakdown point up to 28.9 % outliers in the data, has a bounded influence function, and possesses a high asymptotic efficiency [*Dang et al*. 2008]. As a robust method, it is not affected by single errors or outliers. The slope of trend was calculated as the median of pair-wise slopes, given by following formula:

$$b = median\left(\frac{x_j - x_i}{j - i}\right) \ for\ i = 1, \dots \dots \dots, n\ and\ i < j$$

where *b* is the estimate of the slope of the trend and x_i x_j and is the j^{th} and jth observation. It has been commonly used in identifying the slope of the trend in the hydrological data series [*Yeu et al*, 2002 cited in *Deni et al*, 2010].

Method for Severity Analysis

As a final result of study, the severity analysis of extreme rainfall events based on regional index at district level was run. Representing characteristic for regional level, the analysis was done using Thiessen polygon weighted method as studied by *Fu et al.* [2010] when assessing national trend for Australia. For the current study, the frequency of extreme rainfall events per districts was calculated based on index R50mm as representative of fix threshold and index R90p as representative of site specific threshold.

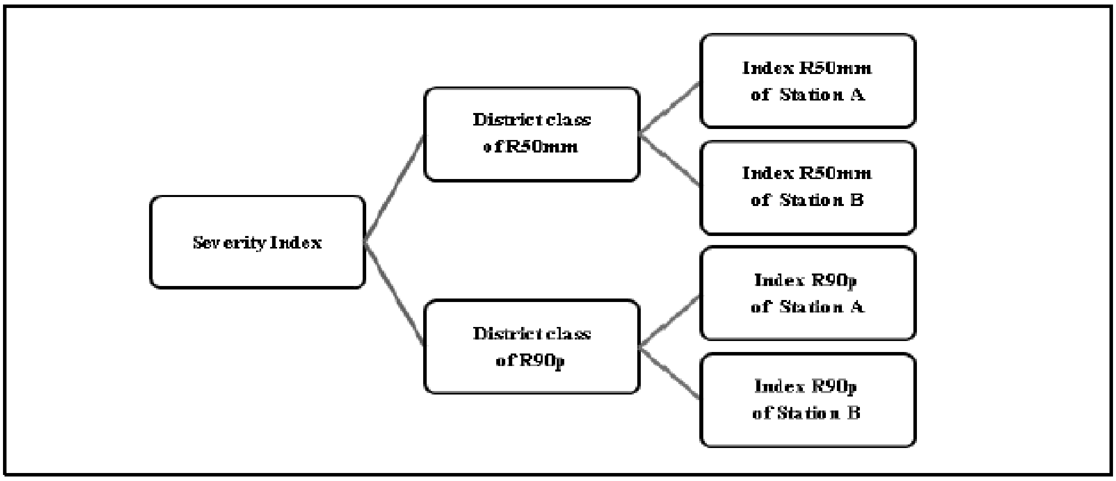


Figure 3. The procedure to generate severity index

First, stations value for index R50mm and R90p was weighted to generate districts index. The districts index of R50mm and R90p was divided then in to three classes. The class of index R50mm was overlaid with class of index R90p to produce severity index. The procedure to produce severity index is described in Figure 3.

RESULT AND DISCUSION

Spatial Characteristic of Extreme Rainfall Events

There were at least 22 hydro-meteorological disaster events causing casualties occurred in the last ten years. The maximum daily rainfall observed per district related to those disaster ranges from 66 up to 350 mm as displayed in Figure 4. In general, concluding from box plot displayed in the Figure 4, the daily rainfall depth mainly fall in the range of 150 – 250 mm with 200 mm as a mean.

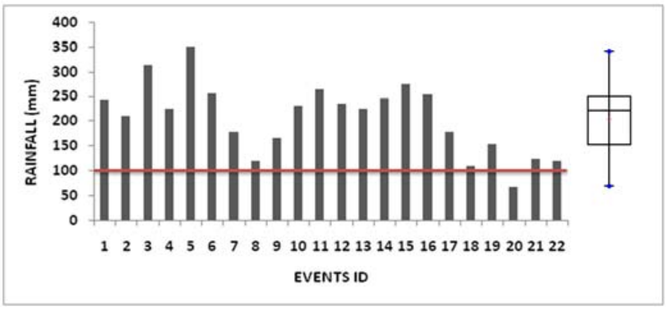


Figure 4. Histogram and box plot of rainfall correspond to disaster. Events ID refer to Appendix. Horizontal line indicates fix threshold

It was seen that daily rainfall being more than 100 mm is potential to generate serious problem to environment. Thus, a fix threshold of 100 mm as designed by *BMKG* is operable because it links well to hydro-meteorological hazard. It does not mean that every rainfall event exceeding those thresholds will always trigger disaster. However, in context of disaster preparation, 100 mm could be designed as fix threshold for occurring hydro-meteorological hazard.

Threshold for 1-year return period (R1yr) at each station was calculated by sorting daily rainfall depth from the largest to the smallest. The value of threshold was taken from rank of 30th of the sorted series. Meanwhile threshold value for 5-year return period (R5yr) and 25-year return period (R25yr) were calculated using statistic toolbox under Matlab based on generalized extreme value distribution. Annual maxima series of each station was set first and was tested using *GEV* function to generate the parameter of shape (k), scale (σ), and location (μ) of series. Those three parameters were used then to calculate return level, a value of rainfall for given return period.

A box plot for all site specific thresholds is shown in Figure 5. Each box encloses the middle of 50 % of data in which the median and mean value is displayed as a line and red plus symbol "+" within each box, respectively. The upper and lower ends of the box are upper and lower quartile (Q3 and Q1). The lines extending from the top and bottom of each box denote the minimum and maximum values based on quartile criteria (1.5 times the inter- quartile distance, Q3 – Q1). Blue dots are the minimum and maximum values based on threshold distribution.

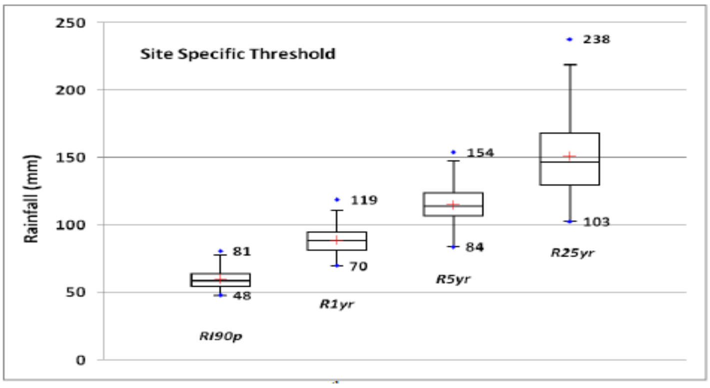


Figure 5. Box plot of threshold based on 90th percentile, 1-yr, 5-yr and 25-yr return period

The calculation revealed that threshold values based on 90th percentile (RI90p) varies from 48 mm up to 81 mm. The minimum value was observed at Station Lamongan (ID: 68) and Bluto (ID: 82) while the maximum value of threshold was found at Station Pasewaran (ID: 3). Threshold values for 1-year return period vary from 70 – 119 mm. Station Galis (ID:80) recorded rainfall amount of 70 mm as minimum value. Meanwhile Station Pasewaran (ID: 3) observed rainfall amount of 119 mm as maximum value for 1-year return period. Threshold values for 5-year recurrence interval range from 84 mm recorded at Station Bluto (ID: 82) up to 154 mm observed at Station Pasewaran (ID: 3). For 25-year recurrence interval, threshold values diverge from 103 mm which was found at Station Lojejer (ID: 9) up to 238 mm which was identified at Station Gondanglegi (ID: 27). Station Bluto recorded the highest value for almost all site specific thresholds. The tested stations counted an average of 59, 89, 115 and 151 mm for rainfall amount at 90th percentile, 1-year, 5-year and 25-year return period correspondingly.

Figure 6 depicts spatial distribution of threshold for 1-year return period (R1yr). The values less than 80 mm were identified in small part of northern coast, in the southwestern part of study area and the southern coast of Madura Island. Nevertheless, the cluster is not really clear. In the northeastern coast and in the southern part which is mountainous areas, thresholds are dominated by values more than 80 mm. The spatial pattern of thresholds based on 90th percentile, threshold for 5-year return period and 25-year return period (not shown) are relatively similar with that of 1-year return period.

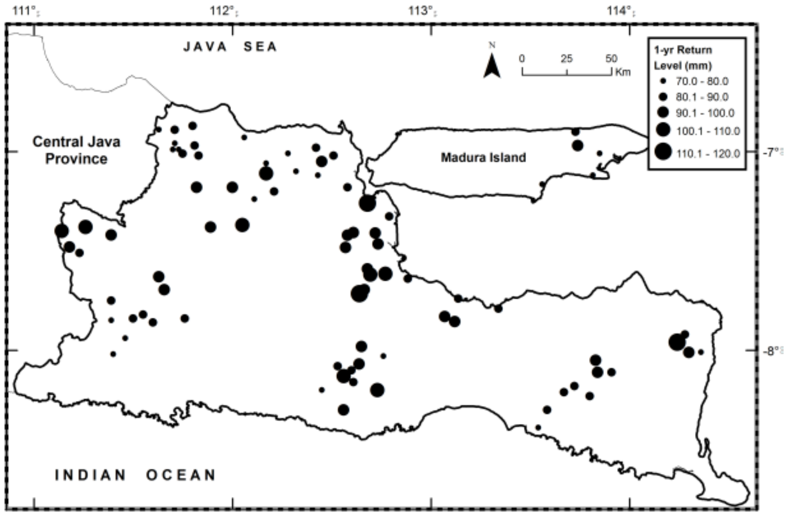


Figure 6. Spatial pattern of threshold for 1-year return period

For those site specific thresholds which are representative of daily intensities, the general spatial pattern can be recognized. In the northern coast, the daily intensity for given recurrence interval are commonly low. The mainland of Madura and the valley of Mount Lawu and Wilis located in the southwestern part also recorded the low intensity. Meanwhile, the northeastern coast which is close to Straits of Madura and the mountainous areas recorded relatively high daily intensity. Surprisingly, the highest threshold was not always seen in the high land.

Different with site specific threshold, the annual index was calculated based on annual block meaning that there is one value per year. Within the study period, there are 30 values per station for each index in case of station with complete data. In the certain year where the data is not complete, the value of index was not calculated. The indices was calculated using *RCLIMDEX* software, the R language *GUI* recommended by *WMO* for extreme climate. To characterize spatial pattern of extreme indices, each annual index was averaged to obtain climatological mean of each index per station. Both frequency and intensity indicators were assessed and mapped. Fig 7 shows spatial distribution of annual frequency of daily rainfall exceeding 50 mm (R50mm). An average of 8 days was observed over the study area, with the lowest frequency identified in coastal area and a valley between Mount Lawu and Mount Wilis. This pattern is spatially coherent with that of daily rainfall exceeding 20 mm (not shown). However, the highest frequency was only seen in the northeastern slope of Mount Arjuno and Mount Ijen. The spatial distribution of daily rainfall exceeding 90th percentile (R90p) is similar with that of two indices explained before (not shown). For those three frequency indicators, the high frequency has never been found in low land. The topography and geographical effects noticeably influence the distribution of frequency of extreme events.

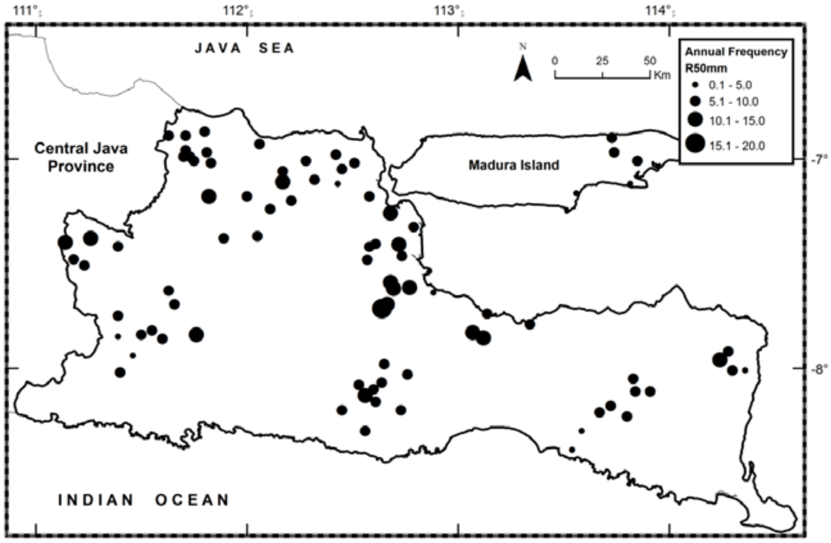


Figure 7. Annual frequency of daily rainfall event exceeding 50 mm (R50mm)

The spatial variation of annual total (*RTOT*) calculated using last 30 years data diverge from less than 1000 mm per year (Station Alas Buluh, ID: 1) up to more than 3000 mm per year (Station Prigen, ID: 22). Fig 8 presents map of annual rainfall over study area. The wettest areas with annual rainfall more than 2500 mm were observed in the mountainous area, near to the summit. Whereas the driest areas in which rainfall total is not more than1500 mm per year were identified mainly in the low land, near to coast. The valley between Mount Lawu and Mount Wilis was also recognized as dry area.

Overall, the pattern of climatological mean of indices can be drawn. All extreme indices, both frequency and intensity indicators behave similarly and form a specific pattern in respect of topographic and geographic feature. The lowest values of indices were predominantly found in coastal area while the largest values were identified mostly in the mountainous area. Thus, we can say that the rainfall events over East Java Province are mostly categorized as orographic rainfall.

The effect of topography on the extreme indices was also explored by plotting them in the X-Y graph. Drawing the fitted equation in a scatter plot of value of climatological mean versus elevation of station allows us to assess the level of relation. The elevation of stations ranges from 2 up to 1788 meters. Using this original value, the scatter plot will looks like concentrated points since the elevation of stations is mostly less than 500 meters. To obtain clear pattern, the elevation has been converted using logarithmic transformation. Thus the elevation value will seem in short range rather than that of the original value.

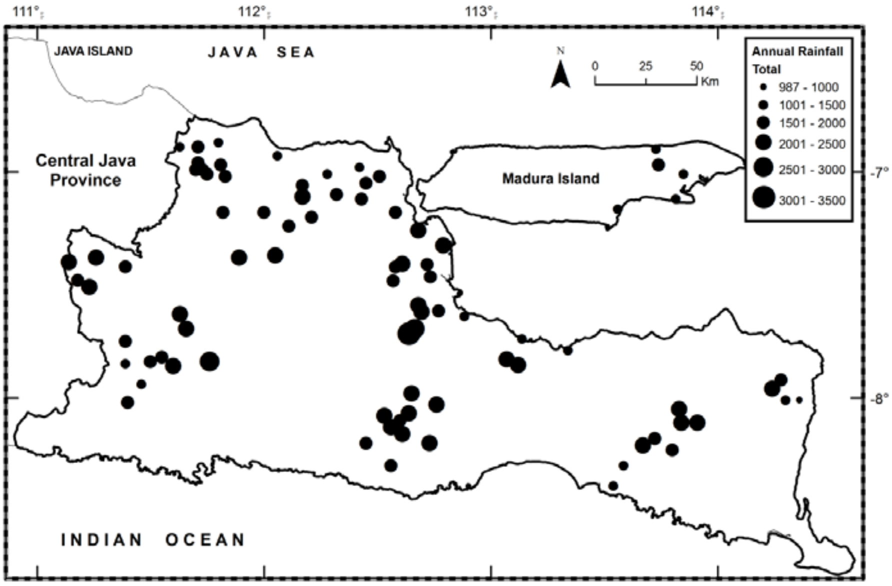


Figure 8. Annual rainfall total over study area

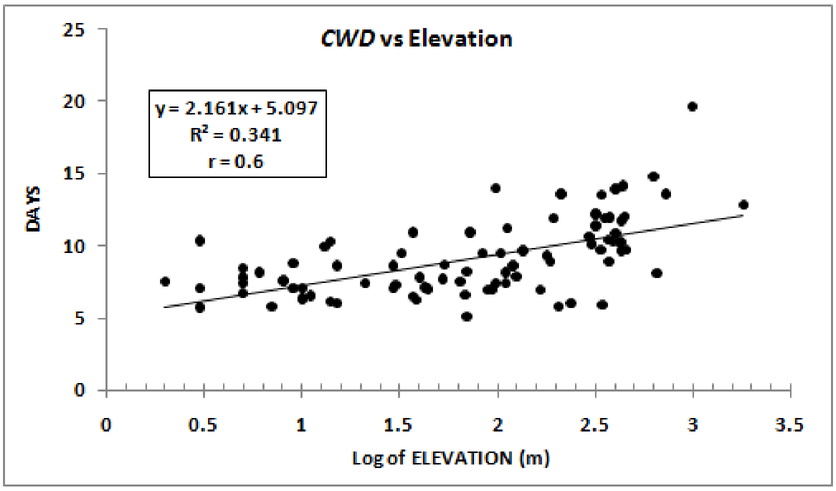


Figure 9. The scatter plot of index *CWD* versus log of elevation

Figure 9 shows a scatter plot of index *CWD* which represents maximum wet spell given for any elevation value. The control of elevation on wet spell was identified relatively strong. The correlation between those two variables produced correlation coefficient of 0.6. The linier equation can fit well enough to the scatter point by capturing about 34 % of index variation.

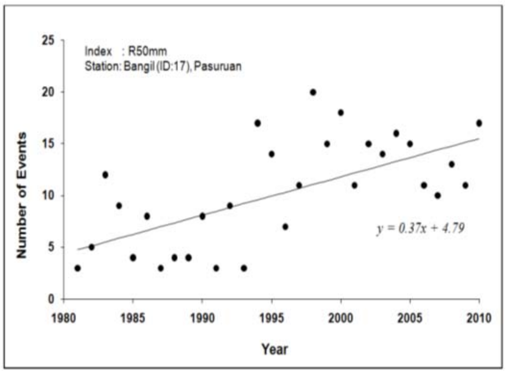
Overall, elevation was found influencing relatively significant to the index R20mm, *CWD* and *RTOT*. The correlation coefficient for those three indices is at least 0.5. For the other indices, the control of elevation is relatively weak (not shown) . The most significant relation was identified for maximum wet spell, *CWD*, and the lesser significant was seen for daily rainfall intensity, *SDII*.

Temporal Trend of Extreme Rainfall Events

Temporal trend of indices was assessed using *MAKESEN* version 1.0, an Excel template developed by Finnish Meteorological Institute. The software provides Mann-Kendal test to check the monotonic trend of tested series and

Theil-Sen slope estimator to estimate magnitude of trend slope. The significance level (α) was selected at 0.1, 1, 5 and 10 %.

The result of trend assessment to the number of daily rainfall event exceeding 50 mm (heavy rainfall event) revealed that 46 of tested gauges show negative trend where 11 are statistically significant. 37 stations show positive trend where 7 of them are statistically significant. 1 rain stations only were identified as series without trend. Overall the dominant identified temporal change is not-significant decreasing trend, similar with index R20mm. Figure 10 shows the example of detected trend at station Bangil, Pasuruan (left panel) and at Karangkedawuh, Jember (right panel). The magnitude of trend is presented in a robust linier equation. Even though the scatter dots are not fitting well to the linier line, the obvious trend can still be recognized from the graphs. The summary of trend assessment for all frequency indicators is presented in Table 3.



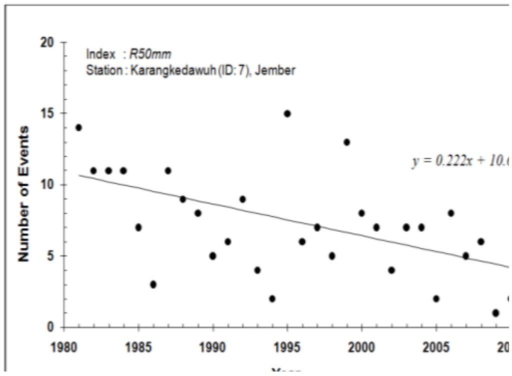


Figure 10. Scatter plot of index R50mm at Station Bangil-left and Karangkedawuh-right

Trend assessment for annual rainfall total showed that 12 (5) stations are decreasing (increasing) significantly. 3 stations were found as no-trend series. Total decreasing series both significant and not significant is 54 stations while total increasing series is 27 stations. The example of detected trend on annual rainfall is shown in Figure 11. The significant updraft trend was detected at Station Simo, Surabaya while significant downdraft trend was found at Station Babat, Lamongan. The gradient of linier line represents the magnitude of temporal change.

Table 3. Summary of trend assessment for all frequency indicators presented as number of station. Sig. = significant

INDEX	DECREASE			INCREASE			NO TREND
	Not Sig.	Sig.	Total (%)	Not Sig.	Sig.	Total (%)	
R20mm	45	8	63	23	6	35	2
R50mm	35	11	55	30	7	44	1
R90p	33	12	54	27	9	43	3
CWD	35	14	58	24	8	38	3

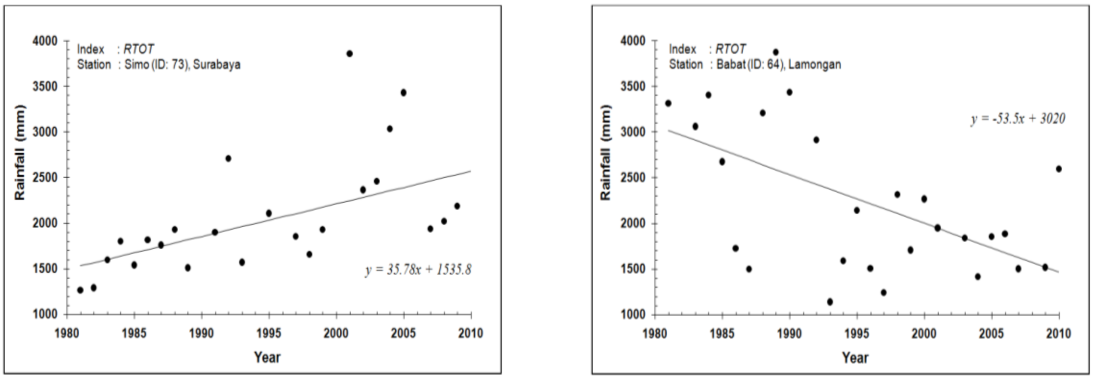


Figure 11. Temporal change of annual rainfall at Station Simo, left and Babat, right (Source: data processing)

The summary of assessment for all intensity indicators, RX1d, RX5d, RTOT and SDII is displayed in Table 4. Similar with frequency indicator, the not-significant trend is dominant finding for all indices of intensity indicator.

Table 4. Summary of trend assessment for all intensity indicators given in the number of station. Sig. = significant

INDEX	DECREASE			INCREASE			NO TREND
	Not Sig.	Sig.	Total (%)	Not Sig.	Sig.	Total (%)	
RX1d	34	8	50	30	10	48	2
RX5d	37	7	52	32	6	45	2
RTOT	42	12	64	22	6	32	3
SDII	22	15	44	31	15	55	1

Spatial Pattern of Detected Trend

The aim of spatial pattern analysis of detected trend is to identify the region where the coherent trend is. The spatial pattern of detected trend for index R20mm is shown in Figure 12. A cluster of decreasing trend (square legend) was seen in the north-west part of study area particularly in the north coast up to the low land located approximately 70 km from the coast. This area is known as the lower part of bengawan solo watershed. In the southwestern study area, a cluster of decreasing trend was also identified, located in the slope of Mount Lawu and Wilis which is including into madiun sub-watershed. In those two areas, 7 rain stations were even detected decreasing significantly (bold square) distributed in District of Ponorogo, Ngawi, Bojonegoro, Tuban and Gresik. The few small and isolated areas with not-significant decreasing trend were also found in all other districts.

In contrast, the small areas showing positive trend was mainly seen in the District of Surabaya, Sidoarjo, Pasuruan, Malang and Jember. There is at least one station with significant positive trend in those districts. Generally, the west part of East Java Province is dominated by decreasing trend while in the east part the decreasing and increasing trend take balanced proportion.

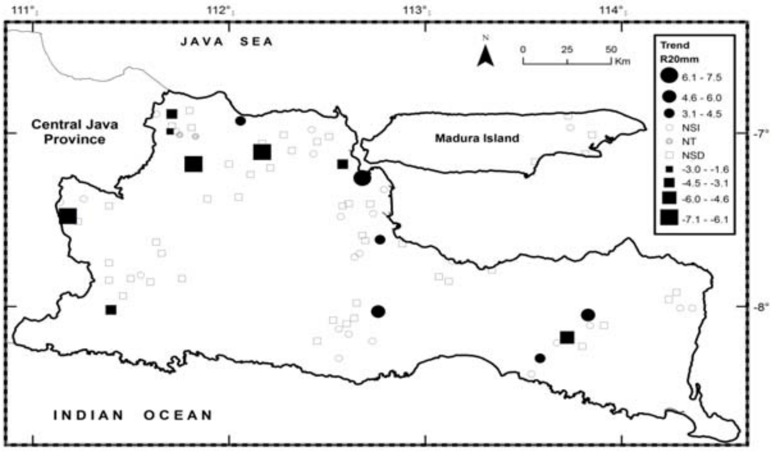


Figure 12. Trend of daily rainfall events exceeding 20 mm. Circle refers to positive trend, square to negative trend. Bold legend corresponds to significant trend. Magnitude is given in "events/decade". *NSI* = Not Significant Increasing, *NT* = No Trend and *NSD* = Not Significant Decreasing

The analysis of index R50mm, R90p and *CWD* showed that the negative and positive trends of frequency indicators are generally distributed randomly. Some cluster cases were found but not clear for other places.

The annual rainfall was observed decreasing in most of western part of East Java Province (see Figure 13). However, the number of stations showing not-significant trend is much larger than that of significant trend. Almost in all districts in this region, significant decreasing trend was observed including District of Ponorogo, Ngawi, Bojonegoro, Tuban and Lamongan. In contrast, there was no significant increasing trend seen in this region. In the eastern part of East Java Province, increasing and decreasing trend was distributed randomly. Even, in Pasuruan District, the significant increasing and decreasing trend was observed being close to each other. Comparing to other intensity indices, District of Bojonegoro, Lamongan and Sumenep were observed showing consistent decreasing trend for all intensity indicators.

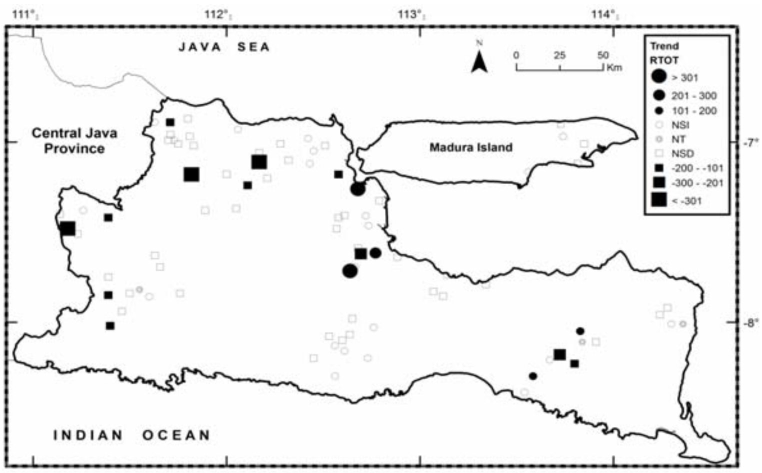


Figure 13**.** Similar with Fig 12 but for annual rainfall total. Magnitude is given in "mm/decade"

Severity Analysis

The climatological mean of index R50mm and index R90p was used to represent the frequency of extreme rainfall events from which the severity index was generated. The trend of extreme events was not considered on severity analysis since the detected trend for a district is generally not consistent. The index of selected stations was weighted using thiessen polygon to calculate district index. The stations involved for calculating district index were not only those located in related district but also stations located in radius of 25 kilometers from the boundary. Using this technique, the minimum selected stations for a district are 3 stations (for District of Pamekasan) and the maximum are 15 stations (for District of Tuban). The districts without rain station were not analyzed (see Figure 14).

District index was classified into three classes using equal interval technique. Class 1 refers to low frequency, class 2 to moderate frequency and class 3 corresponds to high frequency. Class of index R50mm and class of index R90p was overlaid to generate severity index following severity matrix as shown in Table 5.

The analysis produced severity map for extreme rainfall events given for district level (see Figure 15). The districts where rainfall events categorized being less severe includes Pamekasan and Sumenep, both are located in Madura Island. The districts in which rainfall events classified being more severe are Ponorogo, Madiun, Ngawi (located in the slope of Mount Lawu and Wilis), Bojonegoro (located in the low land), Malang, Pasuruan (located in the slope of Mount Semeru and Arjuno), Surabaya, Sidoarjo (located in the coastal area) and Jember which is located in the slope of Mount Argopuro. In the Districts of Magetan, Tuban, Lamongan, Gresik, Probolinggo, and Banyuwangi, extreme rainfall events were classified as moderate class. 13 districts could not be assessed since there is no sufficient rainfall data

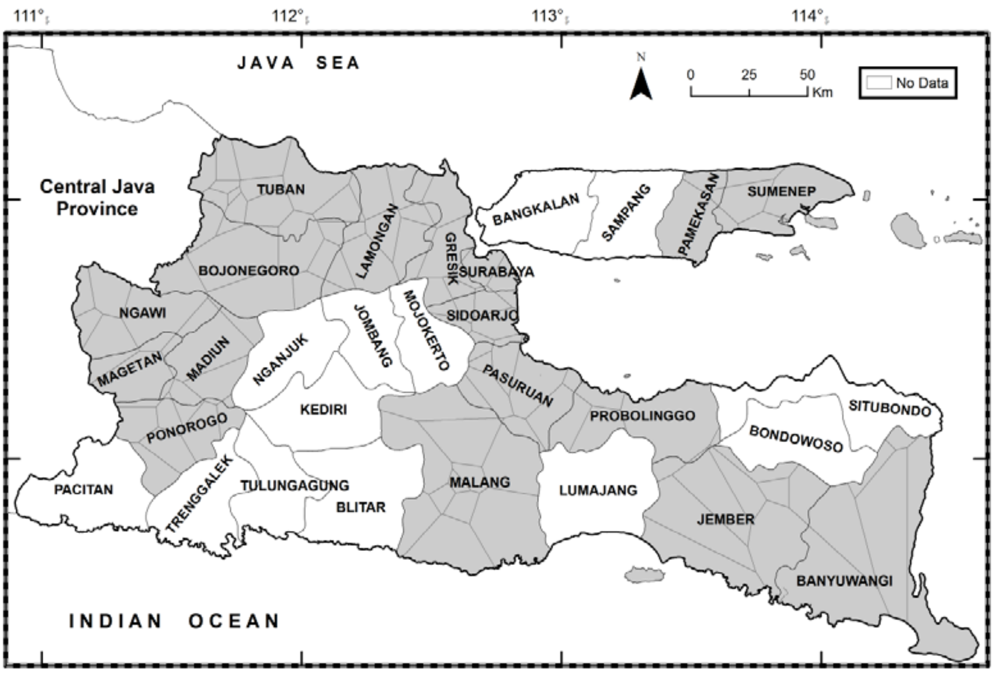


Figure 14. Thiessen polygons for study area used for severity analysis

Table 5. The matrix used for generating severity index. Green cell refer to less severe, yellow to moderate and red to more severe

		R90p		
		1	2	3
R50mm	1	2	3	4
	2	3	4	5
	3	4	5	6

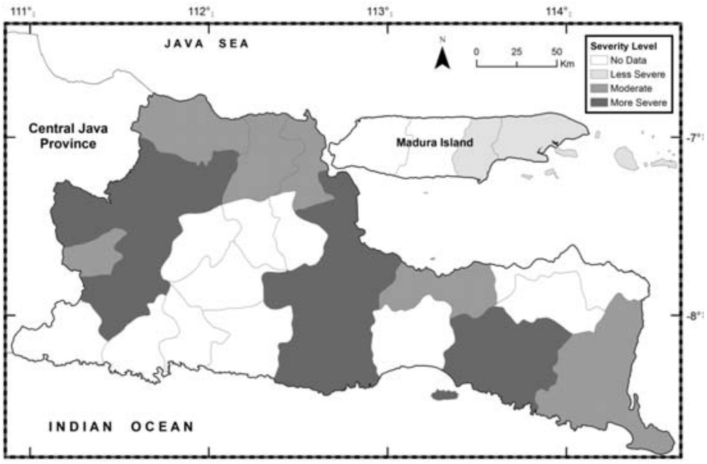


Figure 15. The severity level of extreme rainfall events analyzed per district

Discussion

The analysis of daily rainfall observations within period of 1981 – 2010 over East Java Province shows that general characteristics of extreme rainfall events could be recognized. The link has been detected between fix threshold and site specific threshold of extreme rainfall events used in the study. Comparing fix and site specific threshold, shows that a fix threshold of 100 mm developed by *BMKG* probably related to an event with 5 year return period. For this return period, the daily rainfall amount is around 115 mm in average over study area. Thus, the fix threshold of 100 mm is reasonable to describe frequency of extreme which is commonly rare. risk for occurring disaster generated by extreme rainfall. Those thirteen stations are Pasewaran, Ledokombo (Jember), Jembrung (Pasuruan), Kalipare (Malang), Lembeyan (Magetan), Tretes (Bojonegoro), Mundri, Kejuron, Widang (Tuban), Karangbinangun, Blawi, Pangkatrejo (Lamongan) and Panokawan (Sidoarjo).

Left-bottom box on the other hand, represent stations which were found as increasing series in R20mm but they were identified as decreasing series in R50mm. Thus, in the future one could expect high frequency of moderate rainfall and low frequency of heavy rainfall. Those six stations are Renes (Jember), Poncokusumo (Malang), Lamongan (Lamongan), Wonorejo-Rungkut (Surabaya), Prambon and Sidoarjo (Sidoarjo).

Table 6. Contingency table showing inter-index relation (R20mm and R50mm) given in the number of gauge. NSD = not sig. decrease, NSI = not sig. increase and NT = no trend

		Rainfall > 50 mm					
		NSD	***SD***	***NSI***	***SI***	***NT***	***Total***
Rainfall > 20 mm	***NSD***	26	6	11	1	1	45
	SD	2	5	1			8
	NSI	5		16	2		23
	SI	1		1	4		6
	NT	1		1			2
	Total	35	11	30	7	1	84

Summarizing from trend assessment for individual station given in session 4.2., the trend assessment also successfully detected the stations whose trend is significant and consistent for at least three extreme indices. This consistent trend was observed both for significant positive trend and significant negative trend.

Station Glundengan (Jember, ID: 6), Sukowono (Jember, ID: 11), Bangil (Pasuruan, ID: 17), Prigen (Pasuruan, ID: 22), Dampit (Malang, ID: 26), Poncokusumo (Malang, ID: 32), Kebonharjo (Tuban, ID: 55), Tuban (Tuban, ID: 62) and Station Simo (Surabaya, ID: 73) were detected increasing significantly and consistently. The detail of extreme indices for which the trend assessment shows significant increasing trend, is shown in Table 7.

Table 7. List of stations which are consistently increasing. Sig. = Significant positive

ID	GAUGE	R20mm	R50mm	R90p	CWD	RX1d	RX5d	SDII	RTOT
7	GLUNDENGAN	Sig.	Sig.	Sig.	-	-	-	-	Sig.
11	SUKOWONO	Sig.	Sig.		-	-	-	-	Sig.
17	BANGIL	Sig.	Sig.	Sig.	-	Sig.	Sig.	-	Sig.
22	PRIGEN	-	-	Sig.	Sig.	Sig.	Sig.	-	Sig.
26	DAMPIT	-	-	Sig.	-	Sig.	-	-	-
32	PONCOKUSUMO	Sig.	-	-	-	-	Sig.	-	-
55	KEBONHARJO	-	Sig.	Sig.	-	-	-	-	-
62	TUBAN	Sig.	-	Sig.	-	-	-	-	-
73	SIMO	Sig.	Sig.	Sig.	-	-	Sig.	-	Sig.

For consistently significant decreasing trend, the assessment identified 12 rain stations e.g. Station Karang Kedawuh (Jember, ID: 7), Wirolegi (Jember, ID: 12), Bululawang (Malang, ID: 25), Ngilo (Ponorogo, ID: 36), Tretes (Ngawi, ID: 46), Cawak (Bojonegoro, ID: 48), Leran (Bojonegoro, ID: 50), Sendang (Tuban, ID: 59), Babat (Lamongan, ID: 64), Benjeng (Gresik, ID: 71), Bluto (Sumenep, ID: 82) and Station Kebonagung (Sumenep, ID: 83). Table 7-3 shows extreme indices where the assessment detected consistently significant decreasing trend for those stations.

Table 8. List of stations which are consistently decreasing. Sig. = Significant negative

ID	GAUGE	R20mm	R50mm	R90p	CWD	RX1d	RX5d	SDII	RTOT
7	KRNG KEDAWUH	-	Sig.	Sig.	-	Sig.	-	Sig.	Sig.
12	WIROLEGI	Sig.	Sig.	Sig.	-	-	-	Sig.	Sig.
25	BULULAWANG	-	Sig.	Sig.	-	-	-	Sig.	-
36	NGILO	Sig.	-	-	-	-	Sig.	Sig.	Sig.
46	TRETES	Sig.	Sig.	-	-	-	-	-	Sig.
48	CAWAK	-	-	-	-	-	Sig.	Sig.	Sig.
50	LERAN	Sig.	Sig.	Sig.	-	Sig.	Sig.	Sig.	Sig.
59	SENDANG	Sig.	Sig.	Sig.	Sig.	-	-	Sig.	Sig.
64	BABAT	Sig.	Sig.	Sig.	-	Sig.	Sig.	Sig.	Sig.
71	BENJENG	Sig.	-	Sig.	-	-	-	-	Sig.
82	BLUTO	-	Sig.	Sig.	-	Sig.	Sig.	Sig.	-
83	KEBONAGUNG	-	Sig.	Sig.	-	Sig.	-	Sig.	-

Spatial distribution of the stations showing consistent trend is presented in Figure 16. The consistent negative trend was observed in District of Ponorogo, Ngawi, Bojonegoro, Gresik and Sumenep. There was no significant positive trend found in those districts. This condition could lead serious problem in the future related to probability of drought. In district of Surabaya and Pasuruan the significant positive trend was found for at least 5 indices which potentially lead to high risk of hydro-meteorological disaster. For Surabaya, flooding will probably become serious hazard since it is the populous urban area. Whereas for Pasuruan, the consistently significant positive trend probably lead to high frequency of landslide since Pasuruan is located in the slope of Mount Arjuno. In Tuban, Malang and Jember, the consistent positive and negative trend was found together.

In general, both for frequency and intensity indicators, the not-significant trend is dominant temporal change. Only few number of station showing significant trend. This finding is coherent with the assessment of extreme rainfall events done by *Suhaila et al*, [2010] for Peninsular Malaysia. They found that only few stations show significant trend while the dominant is not-significant trend. Taking place in South East Asia region, these two studies confirms that trend of extreme rainfall events in this region is not really clear. The current study also agreed with study of *Manton et al,* [2001] when assessing trend in Asia Pacific Region. They found that the extreme rainfall indices showed less spatial consistency over the region.

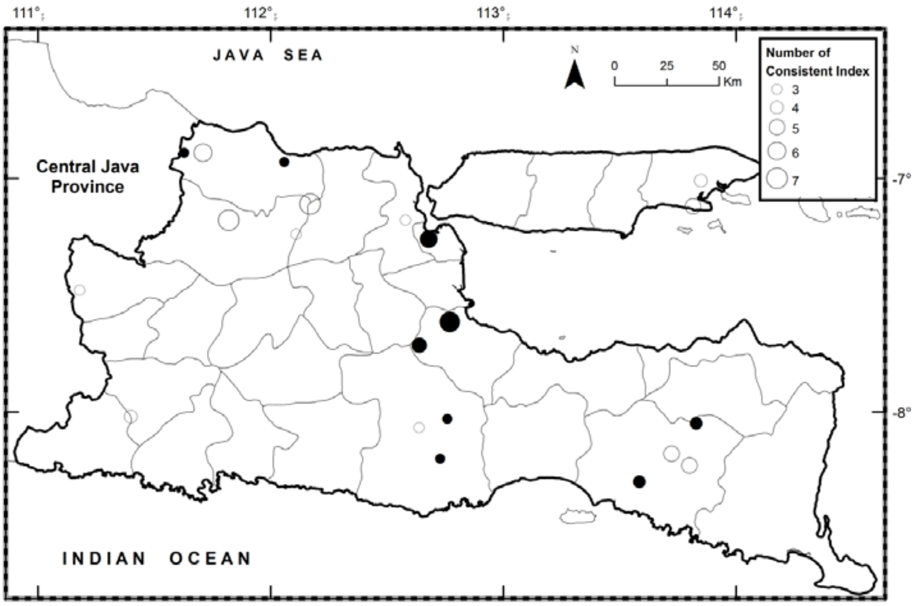


Figure 16. Stations showing consistent trend. Open circles symbolize negative trend, filled circles for positive trend

The districts found with more severe extreme rainfall events should get priority concerning to minimize the risk. Some of those areas are located in the slope area which topographically is high risk for landslide event. For District of Surabaya and Pasuruan, this condition could become serious since the trend was detected significantly increasing. Relating the severity map to the area affected by hydro-meteorological disasters, the good link was found for District of Ngawi, Madiun, Malang and Jember. Classified as places of more severe extreme rainfall events, those areas experienced serious disasters during last ten years.

CONCLUSION

Conclusion

Some remarkable finding could be concluded from the study as follows:

1. Evaluated using historical data of disaster, a fix threshold designed by BMKG is reasonable to describe extreme events. For East Java Province, in average, a fix threshold of 100 mm represents the daily rainfall amount with 5 year return period. The threshold corresponding to the local characteristic could be defined by using percentile threshold and also by extreme value distribution.
2. The spatial pattern of extreme rainfall events over East Java Province both for frequency indicator and intensity indicator is generally characterized by low value in the coastal area and in the valley and high value in the mountainous area. The north coast (District of Tuban, Lamongan and Gresik) and Madura Island recorded low frequency and low intensity while the south part of study area which is dominated by mountainous area observed high frequency and intensity of extreme rainfall events (including District of Malang, Pasuruan, Probolinggo and Jember). The control of topography was found being most significant for maximum length of wet spell and being lesser significant for daily rainfall intensity.
3. In general, the trend of extreme rainfall events detected from the study is dominated by not-significant trend. However, some

places with consistently significant trend could be recognized. In the west part of province, the consistently significant negative trend was observed in District of Ponorogo, Ngawi, Bojonegoro and Gresik. This was also found in District of Sumenep, in Madura Island, the east part of province. The consistently significant positive trend, on the other hand, was seen in District of Surabaya and Pasuruan. In District of Tuban, Malang and Jember, the consistently significant positive trend was identified together with consistently significant negative trend while for other districts, consistent trend was not found. Thus for province level, the trend is not really clear.

4. The frequency of rainfall exceeding 50 mm and exceeding 90th percentile calculated as climatological mean, could be used to quantify the severity of extreme rainfall events using technique of regional analysis. Weighted by thiessen polygons, the application of the method successfully identified the most severe extreme rainfall events which occur over District of Ponorogo, Madiun, Ngawi, Bojonegoro, Malang, Pasuruan, Surabaya, Sidoarjo and Jember.

Recommendation

Based on limitation of the study, the following recommendations were formulated for further extreme rainfall assessment.

1. Since the data period is crucial, using longer records of rainfall data will produce more actual trend.
2. The quality is the main problem on processing rainfall data in Indonesia. There should be a single standard procedure applied for all series including gross error check, adjustment to missing value and temporal-spatial consistency check as well.
3. The assessment should be extended to other provinces to get comprehensive review of trend of extreme rainfall events across the country.
4. Local Government of Ponorogo, Ngawi, Bojonegoro and Gresik should be aware to the possibility of drought in the future due to significant decreasing trend not only for extreme rainfall but also for moderate rainfall and annual total as well. Whereas Local Government of Surabaya and Pasuruan should be aware to the increasing of possibility of hydro-meteorological hazard due to significant increasing trend of extreme rainfall events detected there.

APPENDIX

The historical data of hydro-meteorological disasters over East java Province, 2002 – 2008

ID	DISASTER	DISTRICT	YYYY	MM	DD	RAINFALL (mm)	STATION	CASUALTIES
1	FLOOD	SITUBONDO	2002	2	5	243	Baderan	21
2	FLOOD	BONDOWOSO	2002	2	25	210	Wringin	17
3	FLOOD	MALANG	2003	11	22	312	Clumprit	3
4	LANDSLIDE	MOJOKERTO	2004	2	3	225	Pacet	4
5	FLOOD AND FLOOD	BLITAR	2004	12	3	350	Lodoyo	14
6	LANDSLIDE	TRENGGALEK	2005	12	11	255	trenggalek	1
7	FLOOD AND LANDSLIDE	JEMBER	2006	1	1	178	Klatakan	92
8	FLOOD AND LANDSLIDE	MALANG	2006	1	24	120	rejoagung	1
9	FLOOD AND LANDSLIDE	TRENGGALEK	2006	4	19	165	Bagong	18
10	FLOOD AND LANDSLIDE	PACITAN	2007	12	26	231	Bandar	2
11	FLOOD AND LANDSLIDE	PONOROGO	2007	12	26	263	Ponorogo	4
12	LANDSLIDE	TRENGGALEK	2007	12	26	234	Pule	2
13	FLOOD	MALANG	2007	12	26	225	dampit	4
14	FLOOD AND LANDSLIDE	NGAWI	2007	12	26	246	Kedung Urung	15
15	FLOOD	BONDOWOSO	2008	2	8	275	Talep	1
16	FLOOD	SITUBONDO	2008	2	8	254	Baderan	12
17	LANDSLIDE	MAGETAN	2009	3	10	178	Barat_PU	1
18	LANDSLIDE	TULUNGAGUN G	2010	11	21	109	Kalidawir	2
19	LANDSLIDE	BLITAR	2010	4	28	153	Wlingi	2
20	LANDSLIDE	TRENGGALEK	2010	5	5	66	Bendungan	8
21	FLOOD AND LANDSLIDE	TULUNGAGUN G	2010	10	30	124	Sumberpan dan	3
22	FLOOD	MADIUN	2010	12	6	120	Gombal	1

Source: *BNPB*, Gov. of East Java Province and *BMKG*

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