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Rainfall Changes over Java Island, Indonesia

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Abstract
Trends and patterns of extreme rainfall over Java Island, Indonesia were studied here for the period 1981-2010. The 9 low land and 10 mountainous gauges in respect to northern plain and southern mountainous area were selected after passing criteria such as gross error check, the restriction of at least 90% completed series, and homogeneity test. Some of recommended WMO/CLIVAR extreme indices were calculated annually and seasonally to express the frequency and its intensity. The total rainfall trend (PRCP), the frequency of heavy (R20mm) and very heavy (R50mm), and the simple daily intensity index (SDII) have been analyzed. The significance temporal trend was further assessed using the non-parametric Mann-Kendal test. The result showed that the extreme rainfall event over Java Island is depicted by an incoherent pattern which is spatially distributed across the island and is proportional between positive and negative trend with statistically not significant trend as a dominant changing. From annual extreme indices, it has been revealed that Banyuwangi, Malang, Tuban, Cilacap, and Jakarta Halim and Priok show a consistent increasing trend, while Jember, Probolinggo, Tegal, Semarang, Solo, Cirebon, Ciamis, and Serang show a consistent decreasing trend. Seasonal analyses exhibited a prominent negative trend during peak of dry season (JJA) with high coherency among nineteen stations and for some cases these decreases are followed by increasing SON rainfall indices which generate a hypothesis of a shifted rainfall from JJA to SON. Further analyses of seasonal indices have also detected some stations with a consistently increased DJF rainfall and decreased JJA rainfall e.g. Yogyakarta, Cilacap, Bogor, and Jakarta Priok which may lead a higher risk of hydro-meteorological hazard. Variability analyses on monthly rainfall series showed that the large scale phenomena such as ENSO may play an important role in the occurrence of extreme rainfall event.
Keywords: rainfall, trend, pattern, Java Island

1. Introduction

Extreme rainfall events give negative impact to the environment since they are frequently followed by secondary disastrous events such as landslides and floods. In the rural area, the extreme rainfall events are potential to damage agricultural area while in the urban area, the extreme rainfall events often cause problem of flood because the sudden large amount of rainfall could not be accommodated by drainage system (Carvalho *et al.* 2002).

Extremes of climate are an expression of the natural variability, actually (Trenberth *et al.* 2007). To date, these events become a serious issue because their frequency and intensity is expected being change. It is confirmed by the Intergovernmental Panel on Climate Change (IPCC) that human influences on climate lead to change in frequency and intensity of extreme weather events (Trenberth *et al.* 2007). Some extremes are expected to become more frequent, more widespread and/or more intense. Thus, the demand for information of extreme weather is growing (WMO 2009).

In the high latitude, the trend was clearly detected. Easterling *et al.* (2000) summarized some studies on change of extreme rainfall events over the world. The increasing trend was detected in Asian part of Russia, Southern Canada, Coastal region of New South Wales and Victoria (Australia), Norway, Northern Japan and South-western South Africa while the decreasing trend was detected in Sothern Japan, North-eastern China, Ethiopia and Equatorial East Africa. In the tropic area the conclusion is difficult to be drawn. The detected trend is less spatially coherent. Over Malaysia Peninsular, there was different trend between eastern and western region as detected by Suhaila *et al.* (2010). In Thailand, two regions, Andaman Sea and Thailand Gulf showed different changing as well (Atsamon *et al.* 2009). This work is aimed to characterize the trend of extreme rainfall events over Java Island, particularly within last three decades. Data used for the study are explained in the next session followed by session for method, result and discussion and finally conclusion.

2. Data and Study Area

Two packaged of historical rainfall data in daily resolution spanning the period 1981 – 2010 (last three decades) were utilized to generate a set of extreme indices. First dataset comprising of seven rain gauges with very complete series was taken from Supari *et al.* (2012). These stations are operated by local government. The second data set mainly for west and central java was taken from the list of rain stations which are operated by BMKG. Rain stations were selected if passing strict quality control.

Firstly, the series was check for gross error such as not standard code, duplication cases and spatial outlier. Second, the missing value test was run. Only series with at least 90% complete are involved in the analysis. The last, the homogeneity of series was checked using hybrid method proposed by Winjgaard *et al.* (2003) This method applies four absolute homogeneity tests to detect the shift within series. Those four absolute tests are the Standard Normal Homogeneity Test (SNHT), the Pettit test, the Buishand Range test and the Von Neumann test. The SNHT test is sensitive to detect break in the beginning and the end of series. The Pettit test and Buishand range test are sensitive to identify break in the middle of series while Von Neumann test detect a beak without information of location. Instead of using annual total, the annual number of wet days is selected as parameter to test to figure out the characteristic of daily rainfall data. In total, 19 rain stations with an average of 3.7 % missing observation were chosen as shown in Table 1.

Considering densely populated area, Java Island (Figure 1) is interesting to be examined since the occurrence of extreme rainfall events will impact significantly to this region. For national view, it is the centre for economic activity and centre for agricultural product as well.

3. Method

Four of the 11 core rainfall-related indices recommended by the WMO - CCL/CLIVAR/ ETCCDMI (WMO 2009) were used to assess the changes in extremes for Java Island entirely. Those four indices are expected to capture the change of intensity and frequency of extreme events i.e. the total rainfall (Rtot), the frequency (number of days) of heavy (R20mm, day with rainfall exceeding 20mm) and very heavy (R50mm, day with rainfall exceeding 50mm), and the simple daily intensity index (SDII, a ratio of total precipitation with number of wet days). Those indices were calculated both annually and seasonally.

Trend of extreme rainfall events was examined using non parametric Mann-Kendal test (MK test) which is defined at 0.001, 0.01, 0.05 and 0.1 significance level. MK test is known as less sensitive method to outliers and normality assumptions and is frequently used by meteorologist to detect trend, for instance in Zang *et al.* (2001) and Fu *et al.* (2010). The test was run under the null hypothesis that there is no monotonic trend in the series.

The statistic of Mann-Kendal test (S) is given by the following:

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

where ,

$$sign(x_j - x_k) = \begin{cases} 1, \text{if } x_j - x_k > 0 \\ 0, \text{if } x_j - x_k = 0 \\ -1, \text{if } x_j - x_k < 0 \end{cases} \tag{2}$$

The statistic S is standardized then relative to its variance following the formula,

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var\ (S)}} & , if\ S > 0 \\ 0 & , if\ S = 0 \\ \dfrac{S+1}{\sqrt{Var\ (S)}} & , if\ S < 0 \end{cases} \tag{3}$$

A positive (negative) value of Z indicates an upward (downward) trend. The magnitude of changing as presented by the slope was estimated using Theil–Sen's estimator. This method has been widely used in identifying the slope of the trend in the hydrological data series (Deni at al. 2010).

The slope of trend was calculated as the median of pair-wise slopes, given by following formula:

$$b = median\left(\frac{x_j - x_i}{j - i}\right)\ for\ i = 1, \dots \dots \dots, n\ and\ i < j \tag{4}$$

$$for\ i = 1, \dots \dots \dots, n\ and\ i < j$$

where b is the estimate of the slope of the trend and x_i and x_j is the ith and jth observation. The detected changing was defined being consistent if at least three of four calculated indices showing similar trend.

Using GIS tools, the spatial pattern of detected trend was analyzed by mapping the magnitude of slope. Point pattern analysis was chosen as a mapping method with respect to density of rain station network used in the study. To get more obvious changing, the magnitude of slope was plotted in ten years time scale (per decade).

4. Results and Discussions

4.1 Annual Changes

For total annual rainfall (Rtot), 10 of 19 rain gauges show decreasing trend of which one of them exhibits significant trend (Station of Jember). No significant increasing trend is generally found (Figure 2 left panel).

Changes in total annual rainfall among 19 rain gauges vary from –170 to 82 mm/decade. Cluster of increasing rainfall is observed over the greater Jakarta (refers to a well known area of Jabodetabek) while that of decreasing trend is presented in the eastern part of West Java Province. However, for the rest Java, the spatial pattern of coherency remains unclear.

A significant decreasing trend discovered in Jember indicates that this region tends to becomes drier during the last 30 years, with a rate of 162.5 mm/decade, four times than decreasing trend over the island in which in general, drying is shown by regional average total precipitation which has a decreasing rate of 40.6 mm/decade (Figure 2 right panel). A remarkable decrease can be found in 1982 and 1997, while positive response in 1995 and 1998. Similar response is also shown by Jember rain station. Signals of interannual to decadal variability of total precipitation can also be detected.

The greater Jakarta shows an increasing trend for frequency of moderate to heavy rainfall (R20mm). The decreasing trend was observed mainly in the central part of Java Island. In the west part of East Java Province, the change was dominated by increasing trend (Figure 3 left panel). Over the area, we detect two rain stations with statistically significant change i.e. rain station of Serang with a significant negative trend and Tuban with a significant positive trend.

Indeed the regional average gives a not significantly decreasing rate of -0.6 days/decade; and a significant negative trend of Serang station counts for almost five times than that average reduction wet-days (Figure 3 right panel). In the regional context, reducing this extreme frequency is shown markedly in 1982, 1997 which are probably associated with ENSO/El Nino events. Changes of moderate to heavy rainfall in Serang follow this inter-annual modulation. However, increasing number of days of precipitation exceeding 20 mm in Tuban is not associated with those changes in regional average and less sensitive to inter-annual modulation mentioned previously. It seems that Tuban experienced drier in the past and becoming wetter nowadays.

Similarly, reducing moderate to heavy rainfall days is also shown in very heavy rainfall R50mm index, in general. The assessment for R50mm records that 63 % of tested stations (12 out of 19) demonstrate decreasing trend. Two of those decreasing stations were even found with significant trend e.g. Station of Cirebon and Jember (Figure 4 left panel). A very steep slope with -2.2 days/decade of decreasing trend even markedly observed in Jember (Figure 4 right panel). The increasing trend was only found not significantly in the Jakarta area, Cilacap, Yogyakarta, Tuban, Malang and Banyuwangi. Again, frequency of extreme of the single station such as Jember can be associated with ENSO events; however, the amplitude of extremes does not express a sameness magnitude. Generally, averaged index over the island seems to be influenced by ENSO events i.e., in 1982 and 1997.

The result of spatial trend assessment for daily rainfall intensity (SDII) found apparently isolated trend. The cluster of negative trend was identified in the Eastern part of West Java and most of Central Java while cluster of positive trend was observed in Jakarta and surrounding area and western part of East Java as well (Figure 5 left panel). This spatial pattern is quite similar with that for moderate to heavy rainfall. Average daily intensity changes throughout time are relatively small. It is observed that only 1 mm/day has increased during the last 30 years (Figure 5 right panel). However, a relatively large increase is found in Surabaya with increasing rate of 1.85 mm/day/decade. Tuban, Malang and Jakarta indicate similar trend with varying slope's magnitude (not shown).

The summary of assessment of annual indices (Table 2) informs some places with consistent trend for at least three indices. Banyuwangi, Malang, Tuban, Cilacap, and Jakarta (Halim and Priok) are detected showing a consistent increasing trend, while Jember, Probolinggo, Tegal, Semarang, Solo, Cirebon, Ciamis, and Serang are regions with consistent decreasing trend.

Overall, annual analysis results do not show a consistent (general) changes spatially over the island, as well as detail information in which season those changes are take place. Generally, it seems that east-west variation (in line with prevailing wind) is more detectable than north-south variation (topographic dis-similarity). Therefore a denser observation detecting trend analyses is needed to achieve more reliable spatial changes assessment.

4.2 Seasonal Changes

From the assessment of total seasonal rainfall, we noted that rainfall over Jakarta area is increasing during peak of wet season (DJF). The decreasing of DJF rainfall followed by increasing MAM rainfall over Central Java is another remarkable finding (Figure 6). Rain station of Jatiwangi (Cirebon) and Jember were observed decreasing for all seasons.

We found that frequency of moderate to heavy rainfall within the period of peak of dry season (JJA) is decreasing over Java Island entirely. This change is proven by 15 stations where 3 of them were identified with significant decreasing trend (Figure 7). Similar with previous index, we observed a decreasing trend for frequency of moderate to heavy rainfall during DJF over central Java followed by increasing trend during MAM.

The result of assessment for frequency of heavy rainfall revealed that the decreasing trend is dominant finding within JJA season (Figure 8). Over Jakarta and Serang, we observed positive trend in DJF but negative trend in JJA. The study found the significant positive trend within DJF i.e. rain station of Cilacap and Tuban but no station with significant positive trend for other seasons.

The most remarkable result from seasonal analysis of daily intensity is a consistent positive trend over Jakarta and its surrounding within DJF and MAM (Figure 9). The similar pattern was observed over west part of East Java as well. Over the whole island, 5 tested stations show significant positive trend in DJF. Rain stations of Jember shows negative trend for all seasons with significant trend within DJF and MAM.

The analysis of seasonal indices revealed some considerable results. Over Malang, Cilacap and Jakarta-Priok the decreasing trend detected within JJA is followed by an increasing trend in SON which is probably a signal of shifted seasonal rainfall. The analysis also detects some areas where the heavy rainfall is increasing during DJF leading higher frequency of floods and landslide and in contrast, it is decreasing during JJA which lead to a higher risk of drought. Those areas are Yogyakarta, Cilacap, Bogor, and Jakarta-Priok.

4.3 Links to natural climate variability events

The analysis of annual changes which revealed decreasing and increasing trends are related with inter-annual/decadal climate phenomena, as well as seasonal characteristics of extreme in which being wetter in the wet season and drier in the dry season suggest to look at its links with ENSO.

Figure 10 describes a monthly rainfall data of Cilacap and Jakarta - Tanjung Priok station using temporal cross section technique together with annual sum of daily precipitation >95th percentile (R95p) index. Two plots indicate that the frequency and intensity of extremes might be driven by large scale phenomena such as ENSO. Monthly precipitation of Cilacap Station shows that the wet month events occur frequently in SON (similar with heavy rainfall frequency changes in section 4.2). Excessive amount of monthly precipitation which probably has extreme rainfall contribution seems to happen during La Nina year, while an extended dry condition is associated with El Nino year. The graph also displays clear signal of five-yearly variation which probably related to the ENSO cycle. Similar result is described in Tanjung Priok station where rainfall daily intensity tends to increase during the DJF. However, the magnitudes of those events for each station do not show a parallel response and could not be explained by ENSO events only (Figure 10 right panel).

5. Conclusion

It is clear from study that there is evidence of considerable change in extreme precipitation over Java Island during 1981 – 2010. Even though not significant trend is major finding, some places and seasons are observed showing consistent trend for all indices. The negative trend of JJA rainfall, both for intensity and frequency is the most interesting result because of its high spatial coherency. A general decreasing trend over the entire island, in general, leads to a higher risk of drought that matter in agricultural activities and raise water scarcity problem. In contrast, increased trend of daily intensity indicates a tendency of higher extreme in its amplitude or frequency leading of floods and landslide.

There is evidence that variability of extreme events in precipitation is associated with large-scale climate variability such as ENSO, however the magnitude of those events for particular places do not show a coherence response and could not be explained by considering natural variability only.

Overall, spatial analysis do not show a consistent (general) changes spatially over the island. It seems that spatial variation remains unclear. Therefore, future work employing denser observation detecting trend analyses is needed to achieve more reliable spatial changes assessment.

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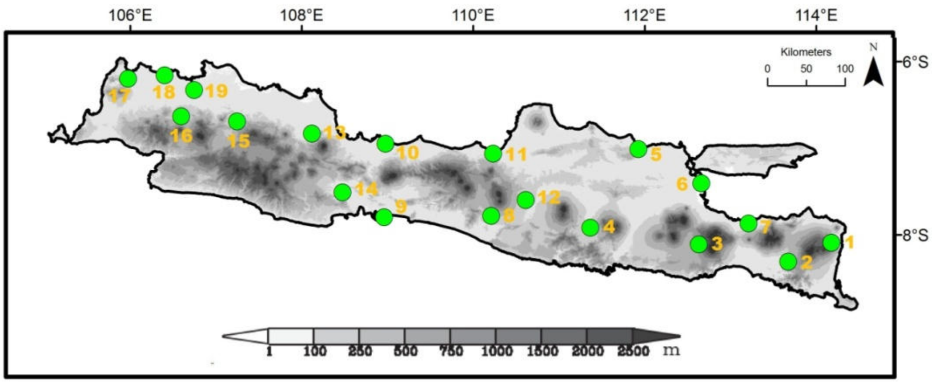

Figure 1. The study area and its topographic setting. Green dots denote location of rain station. Label of stations refer to Table 1

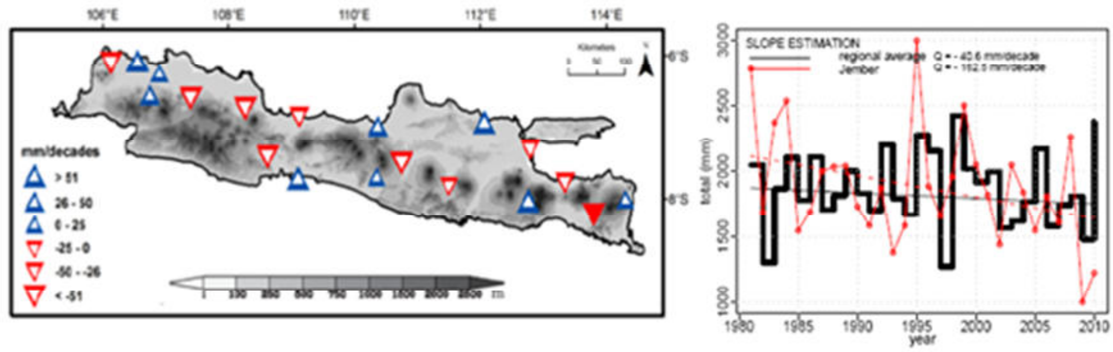

Figure 2. (Left) Spatial distribution of detected trend for total annual rainfall (Rtot, unit: mm/10 years) and (right) slope estimation of regional averaging associated index together with slope estimation of selected (significant trend) station. Upward pointing triangles show increasing trends, downward pointing triangles represent decreasing trends. Significant changes ($p \leq 0.1$) are indicated by filled symbols. Red colour coding indicates drying trends, blue indicates trends towards wetter conditions.

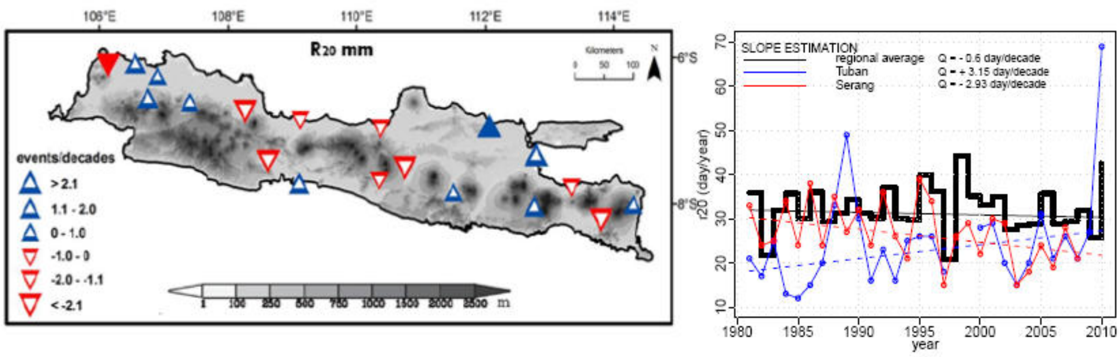

Figure 3. As Fig 2 but for annual frequency of moderate to heavy rainfall (R20mm, unit: days/10 years).

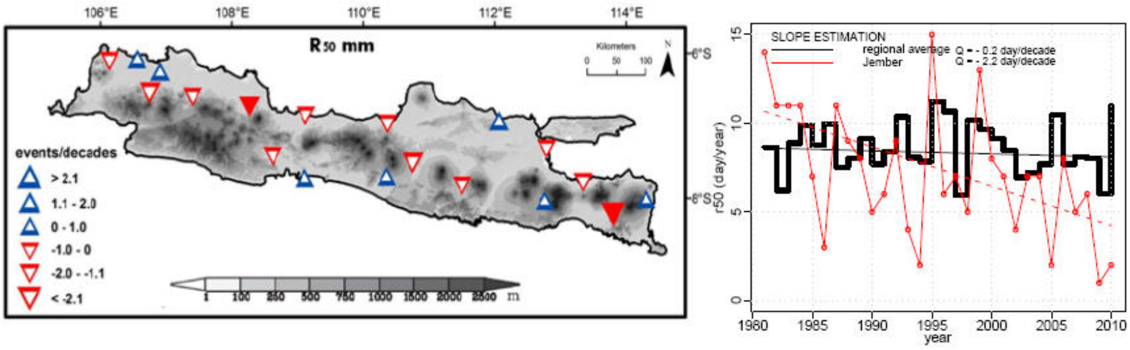

Figure 4. As Fig 2 but for annual frequency of heavy rainfall (R50mm, unit: days/10 years).

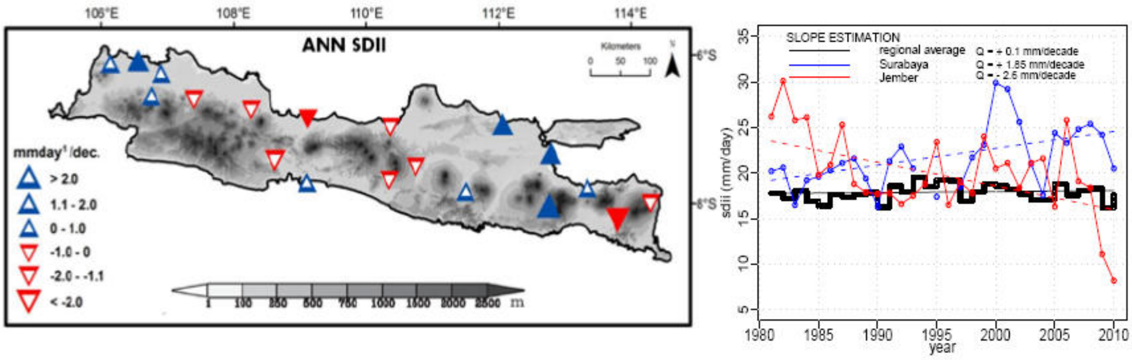

Figure 5. As Fig 2 but for daily rainfall intensity (SDII, unit: mm.day-1/10 years).

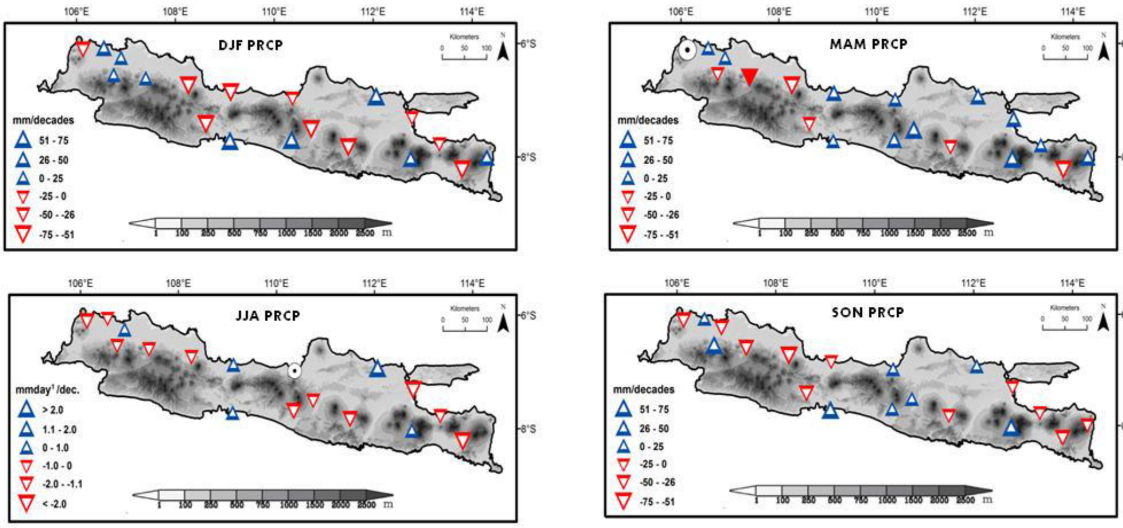

Figure 6. Spatial pattern of detected trend for total seasonal rainfall. Left top for DJF, right top for MAM, left bottom for JJA and right bottom for SON. Legends are interpreted as in Fig. 2

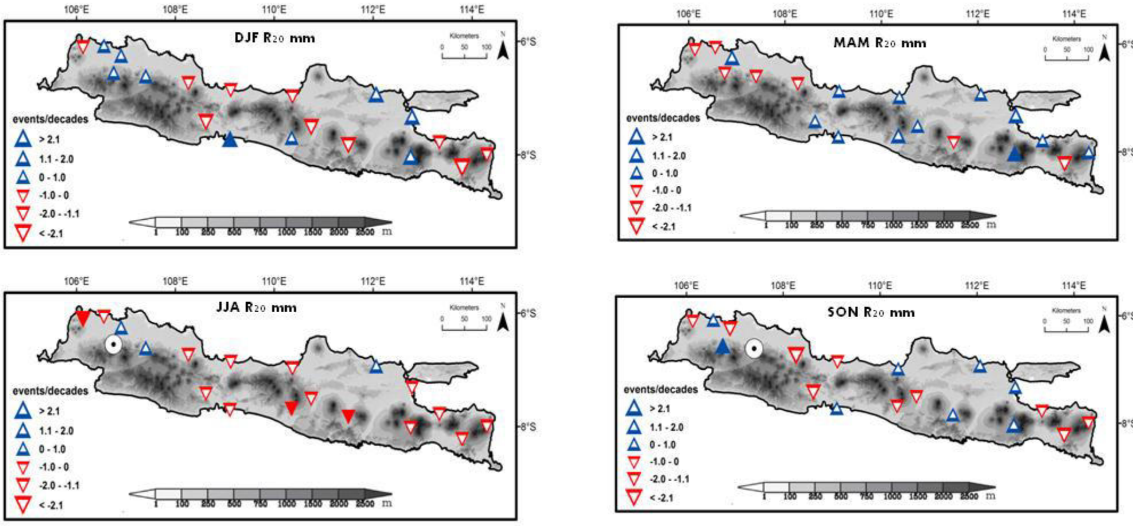

Figure 7. As Fig 6 but for seasonal frequency of moderate to heavy rainfall.

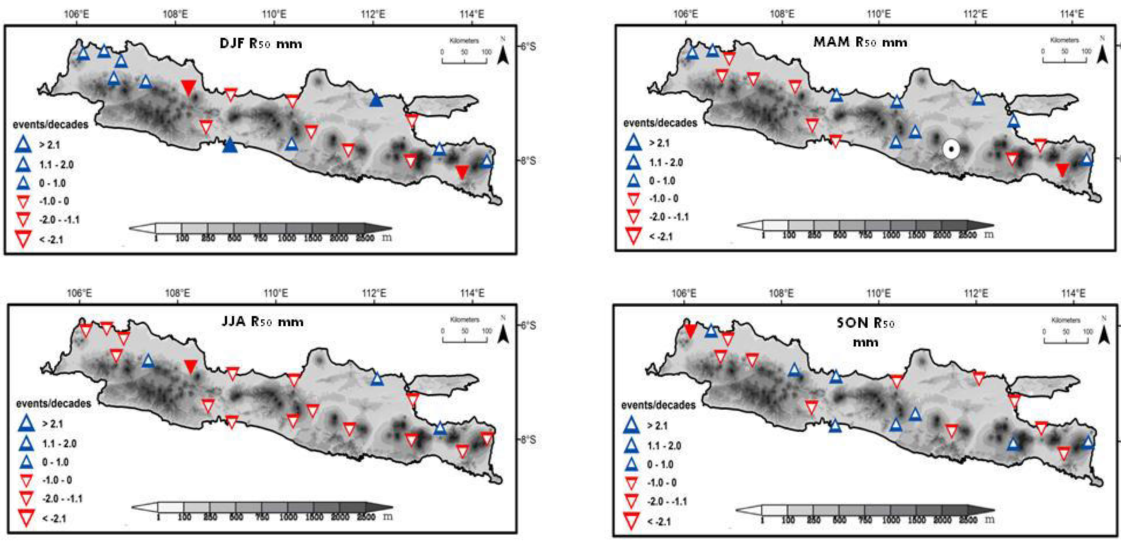

Figure 8. As Fig 6 but for seasonal frequency of heavy rainfall.

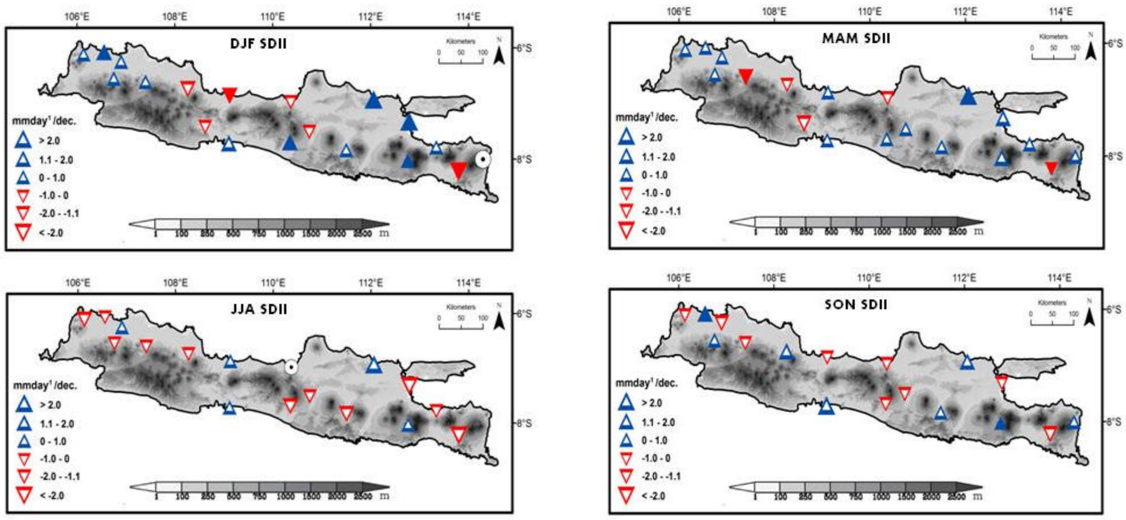

Figure 9. As Fig 6 but for seasonal analysis of daily rainfall intensity.

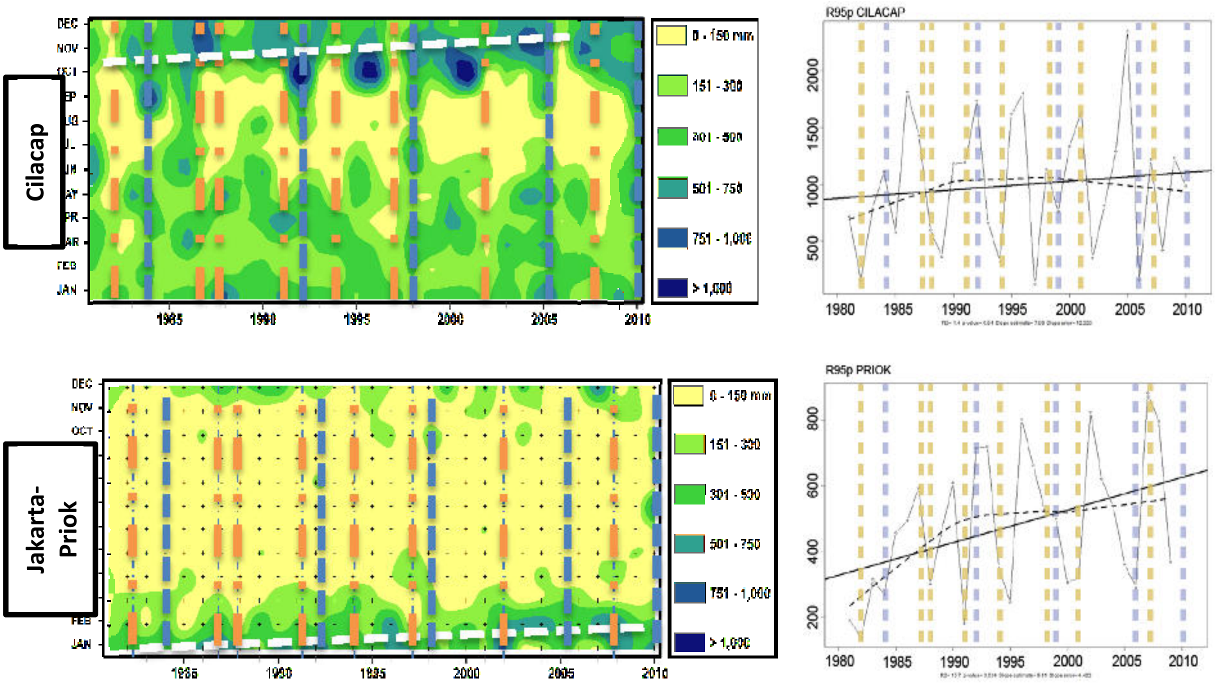

Figure 10. Temporal cross section of Cilacap (top) and Tanjung Priok (below) monthly rainfall data (left) together with annual contribution from very wet days (R95p) index derived from daily precipitation series. Blue (orange) dashed vertical line indicate well known La Nina (El Nino) year.

Table 1. List of assessed stations

PROVINCE	*DISTRICT*	*RAIN STATION*	*CODE*	*LAT*	*LONG*	*MV (%)*
EAST JAVA	*Banyuwangi*	*Sidomulyo*	*1*	*-8.01*	*114.30*	*0.3*
	Jember	*Karang Kedawuh*	*2*	*-8.23*	*113.80*	*0.0*
	Malang	*Poncokusumo*	*3*	*-8.03*	*112.76*	*0.3*
	Ponorogo	*Babadan*	*4*	*-7.84*	*111.50*	*4.1*
	Tuban	*Tuban*	*5*	*-6.93*	*112.06*	*0.5*
	Surabaya	*Wonorejo - Rungkut*	*6*	*-7.33*	*112.79*	*1.1*
	Probolinggo	*Adiboyo*	*7*	*-7.79*	*113.34*	*0.6*
YOGYAKARTA	*Sleman*	*Beran*	*8*	*-7.70*	*110.35*	*0.3*
CENTRAL JAVA	*Cilacap*	*BMKG Cilacap*	*9*	*-7.72*	*109.11*	*0.0*
	Tegal	*BMKG Tegal*	*10*	*-6.87*	*109.12*	*3.3*
	Semarang	*Semarang*	*11*	*-6.98*	*110.37*	*0.0*
	Solo	*Adisumarmo Airport*	*12*	*-7.52*	*110.75*	*0.0*
WEST JAVA	*Cirebon*	*BMKG Jatiwangi*	*13*	*-6.75*	*108.27*	*7.2*
	Ciamis	*Bantardewa*	*14*	*-7.43*	*108.62*	*7.8*
	Bandung	*Bandung_Cemara*	*15*	*-6.61*	*107.40*	*5.0*
	Bogor	*BMKG Dermaga*	*16*	*-6.55*	*106.75*	*8.3*
BANTEN	*Serang*	*Serang*	*17*	*-6.12*	*106.13*	*6.7*
JAKARTA	*Jakarta*	*BMKG Tanjung priok*	*18*	*-6.08*	*106.56*	*0.6*
	Jakarta	*Halim - Airport*	*19*	*-6.25*	*106.90*	*7.8*

Table 2. The output of trend assessment for annual indices. Plus symbol (minus) refers to positive trend (negative). Double symbols mean significant trend.

CODE	*RAIN STATION*	*Rtot*	*R20mm*	*R50mm*	*SDII*
1	*Sidomulyo*	+	+	+	-
2	*Karang Kedawuh*	(--)	-	(--)	(--)
3	*Poncokusumo*	+	+	+	(++)
4	*Babadan*	-	+	-	+
5	*Tuban*	+	(++)	+	(++)
6	*Wonorejo - Rungkut*	-	+	-	(++)
7	*Adiboyo*	-	-	-	+
8	*Beran*	+	-	+	-
9	*BMKG Cilacap*	+	+	+	+
10	*BMKG Tegal*	-	-	-	(--)
11	*Semarang*	+	-	-	-
12	*Adisumarmo Airport*	-	-	-	-
13	*BMKG Jatiwangi*	-	-	(--)	-
14	*Bantardewa*	-	-	-	-
15	*Bandung_Cemara*	-	+	-	-
16	*BMKG Dermaga*	+	+	-	+
17	*Serang*	-	(--)	-	+
18	*BMKG Tanjung priok*	+	+	+	(++)
19	*Halim - Airport*	+	+	+	+

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