Spatial Analysis of Rainfall Return Period and Probable Maximum Precipitation over Central Java - Indonesia

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Abstract. Most of the lowlands and coastal area in Indonesia are highly affected by flood hazards, particularly Central Java Area. The flood hazards are often associated with extreme precipitation that occur in long duration. This research aims to identify the spatial distribution of extreme precipitations based on daily rain gauge precipitation data over Central Java. Daily precipitation data from 1998-2010 were obtained from rain gauge stations from Indonesian Bureau of Meteorology, Climatology, and Geophysics (BMKG). Extreme precipitation identification taken by precipitation threshold, return period rainfall, and probable maximum precipitation (PMP). The results indicate that extreme precipitation occurs mainly in the lowlands and coastal areas over the northern and southern part of Central Java. The distribution of extreme precipitation could be utilized to map the susceptible area affected by floods, such as Tegal, Pekalongan, Kendal, Semarang, Demak, Purworejo, Kebumen, Kutoarjo, Gombong, and Cilacap.

1. Introduction
Extremely high precipitation intensity, have been known for long time ago to contribute to precipitation driven hazards in Indonesia. Most of the precipitation driven hazards in Indonesia are related to extreme precipitation [1–5]. Very high precipitation intensity occurred by that time, which then generated flood and damaged thousands settlement and agriculture in Java Island [6,7]. At present, Indonesia has become the third countries with the highest vulnerability of flood hazard in Asia [6]. Identification of extreme precipitation and its relation to hazards give more importance to the conducted research since Indonesia is one of five countries with highest number of people affected by flooding in Southeast Asia. This condition is even worse since Indonesia placed the first rank in the term of number of people killed by flood hazard in Southeast Asia (Figure 1).
The number of hydrometeorological hazards in Indonesia, especially floods, is increasing from year to year. Development of built-up area and deforestation are one of the main sources [8]. The IPCC Report gives an indication toward the increase of extreme weather in Indonesia for the following century [9]. Further analysis using several climate scenarios has shown not only declined onset in the beginning of rainy season, but also higher precipitation in rainy season and less in dry season [10,11]. Therefore, this condition will trigger higher flood hazard and drought as the vice versa. At present, flood is not only suffering in the area alongside the riverbank, but coastal area as well [1,12,13]. The impacts are predicted to be higher in the future. It is predicted that the damages and losses due to precipitation driven hazards in Java Island will be increasing in the future due to climate change [10].

The aim of this research is to provide information related extreme precipitation distribution in Central Java, which become one of the main sources to flood hazard. This study is very closely related to planning and management of coastal area and watershed. It provides information related to extreme precipitation and flood susceptibility as the main subject to be managed. In relation with heavy rainfall, watershed area, as a physical boundary, is important to manage in reducing the flood hazard. The main function of watershed as a boundary are; (1) it divides the area based on physical characteristic (mountain crests), (2) it acts as one hydrologic system related to the input-process-output, and (3) it acts as an ecosystem unit [14]. Identifying the spatial pattern of heavy rainfall as an input to watershed related process could help the local government, especially watershed management board (BPDAS), to manage and implement programs in flood risk reduction [15].

2. Methods

2.1. Data
Extreme precipitation event is one of the major sources for devastating phenomena in the world. The occurrence of flash floods, increasing thunder frequency, strong surface wind, and other atmosphere specific phenomena is often lead by extreme precipitations [16–18]. In Indonesia, the economic losses due to flood hazard generated by extreme precipitation are the prior. In urban area, the losses are mainly generated from the damages at settlement area and infrastructures. In addition to urban area, the damages of flood in rural area are the major source for agriculture production.

Daily rainfall data is obtained from the Indonesian Bureau of Meteorology, Climatology, and Geophysics (BMKG) from Central Java Province and Yogyakarta Province. The rain gauge data is available from 1998 and 2010 and contains about 70 ground stations the two provinces. The stations is selected based on the data availability (by considering the number of missing data) and their position to support the spatial distribution and coverage. This is particularly because the recorded data, in term
of spatial distribution are uneven in the research area. There are areas that have high density of data, particularly over lowland. However, over mountainous region, the stations are less dense.

2.2. Research Method

In identifying the extreme precipitation events, several indices have been developed by several researchers and specific organization. Basically, the technique in identifying the frequency of the extreme precipitation can be classified into two groups, namely by using (1) fix thresholds and (2) site specific thresholds. World Meteorological Organization/WMO [19] published several indices for identifying the extreme rainfall. The fixed threshold of 0 mm (R20mm) and 50 mm (R50mm) daily rainfall is usually used by WMO. Moreover, site specific threshold using 90th and 95th percentile (R90p and R95p) also often used. By using the R90p for example, the precipitation higher to the 90th percentile value is considered as extreme.

Extreme precipitations also can be observed through the intensity in addition to its frequency. The techniques are including maximum daily rainfall (RX1d), five days consecutive maximum cumulative rainfall (RX5d), and total annual rainfall (RTOT). Site specific threshold also developed based on the rainfall intensity, especially by using the percentile values or 1 to 25-years return period rainfall.

In this research, the term of extreme precipitation is selected based on the intensity by using return period analysis for daily precipitation (mm/day). The extreme specified here are namely 5 years & 10 years return period, and probable maximum precipitation (PMP). Therefore, the identification of the extremes is taken without regarding to its duration or frequency. The return period rainfall are determined by Equation 1.

\[ X_T = X + K_T S \] (1)

Where \( X_T \) is return period rainfall, \( X \) is the mean value, \( K_T \) is a value obtained from distribution table, and \( S \) is the standard deviation. The return period rainfall is obtained from the calculation is then compared with the observation using Chi-test and Kolmogorov-Smirnov test. The calculation above is conducted using Microsoft excel table. To calculate probable maximum precipitation (PMP), the calculation in Equation 2 to 4 is taken.

\[ X_m = X_p + K_m S_p \] (2)
\[ X_p = X_n f_1 f_2 \] (3)
\[ S_p = S_n f_3 f_4 \] (4)

Where \( X_m \) is the Probable maximum precipitation (PMP), \( K_m \) is the function of rainfall duration compared with the average daily annual maximum precipitation, \( X_n \) is the averaged daily annual maximum precipitation, and \( f_1 \) to \( f_4 \) are the adjustment factor based on the number of maximum data and length of observation.

3. Results

The research was conducted in Central Java Region - Indonesia. Indonesia is an archipelago in the tropics, which consists of one-third of land, and two-third of ocean. There are several major islands in Indonesia. Java is one of the major island located at the south-west of the country. This study area is characterized with monsoonal type climatology. The monsoonal region is highly influenced by southeast Asian monsoon flowing northwest in October-March (rainy season) and vice versa in April-September (dry season). High level of humidity during rainy season usually produces large amount of precipitation and reach maximum during December to February.

Peak of rainy season that particularly occurred in December to February (DJF) produce rainfall that reached up to 400 mm/month. In dry season, distinct condition can be found, in which less precipitation occurred. In June-August (JJA), no precipitations were received. Precipitation is increasing with higher elevation, especially at the central part. Mountainous areas trigger orographic rainfall that forces moist air move upward the mountain where condensation occurs. In average,
precipitation in the mountainous area often reach more than 2,500 mm/year, while over the lowlands, the precipitation could be lower than 1,500 mm/year.

Spatial analysis of extreme precipitation intensity measured using 5 years return period precipitation, 10 years return period precipitation, and probable maximum precipitation (PMP). To validate the result of return period rainfall, analysis of Chi test (Table 1) and Kolmogorov-Smirnov test were taken (Table 2). The result indicates that merged data produce higher extremes compared to satellite estimates.

Table 1. Chi-test result of the return period rainfall (source: data analysis)

| Station ID | Chi-test p-value | Significance (p-value >0.05) | Station ID | Chi-test p-value | Significance (p-value >0.05) |
|------------|------------------|------------------------------|------------|------------------|------------------------------|
| 1          | 0.99             | Significant                  | 30         | 1.00             | Significant                  |
| 2          | 0.54             | Significant                  | 31         | 0.98             | Significant                  |
| 3          | 0.71             | Significant                  | 32         | 0.98             | Significant                  |
| 4          | 0.97             | Significant                  | 33         | 1.00             | Significant                  |
| 5          | 0.93             | Significant                  | 34         | 1.00             | Significant                  |
| 6          | 0.91             | Significant                  | 35         | 1.00             | Significant                  |
| 7          | 0.72             | Significant                  | 36         | 0.51             | Significant                  |
| 8          | 1.00             | Significant                  | 37         | 0.98             | Significant                  |
| 9          | 0.98             | Significant                  | 38         | 0.99             | Significant                  |
| 10         | 0.87             | Significant                  | 39         | 0.99             | Significant                  |
| 11         | 0.38             | Significant                  | 40         | 0.91             | Significant                  |
| 12         | 0.71             | Significant                  | 41         | 0.89             | Significant                  |
| 13         | 1.00             | Significant                  | 42         | 1.00             | Significant                  |
| 14         | 0.99             | Significant                  | 43         | 0.44             | Significant                  |
| 15         | 0.45             | Significant                  | 44         | 0.59             | Significant                  |
| 16         | 0.95             | Significant                  | 45         | 0.48             | Significant                  |
| 17         | 0.30             | Significant                  | 46         | 0.99             | Significant                  |
| 18         | 1.00             | Significant                  | 47         | 0.92             | Significant                  |
| 19         | 1.00             | Significant                  | 48         | 0.99             | Significant                  |
| 20         | 1.00             | Significant                  | 49         | 0.38             | Significant                  |
| 21         | 0.42             | Significant                  | 50         | 0.99             | Significant                  |
| 22         | 0.37             | Significant                  | 51         | 0.83             | Significant                  |
| 23         | 0.97             | Significant                  | 52         | 0.91             | Significant                  |
| 24         | 0.81             | Significant                  | 53         | 0.27             | Significant                  |
| 25         | 1.00             | Significant                  | 54         | 0.22             | Significant                  |
| 26         | 0.74             | Significant                  | 55         | 0.93             | Significant                  |
| 27         | 0.94             | Significant                  | 56         | 0.68             | Significant                  |
| 28         | 0.61             | Significant                  | 57         | 0.89             | Significant                  |
| 29         | 0.99             | Significant                  | 58         | 0.97             | Significant                  |
Table 2. Kolmogorov-Smirnov (K-S) result of the return period rainfall (source: data analysis)

| Station ID | K-S test value | Significance (DK < 0.34) | Station ID | K-S test value | Significance (DK < 0.34) |
|------------|----------------|--------------------------|------------|----------------|--------------------------|
| 1          | 0.08           | Significant              | 30         | 0.08           | Significant              |
| 2          | 0.15           | Significant              | 31         | 0.23           | Significant              |
| 3          | 0.23           | Significant              | 32         | 0.15           | Significant              |
| 4          | 0.15           | Significant              | 33         | 0.15           | Significant              |
| 5          | 0.08           | Significant              | 34         | 0.15           | Significant              |
| 6          | 0.08           | Significant              | 35         | 0.08           | Significant              |
| 7          | 0.15           | Significant              | 36         | 0.08           | Significant              |
| 8          | 0.08           | Significant              | 37         | 0.08           | Significant              |
| 9          | 0.08           | Significant              | 38         | 0.23           | Significant              |
| 10         | 0.08           | Significant              | 39         | 0.08           | Significant              |
| 11         | 0.08           | Significant              | 40         | 0.08           | Significant              |
| 12         | 0.08           | Significant              | 41         | 0.23           | Significant              |
| 13         | 0.00           | Significant              | 42         | 0.08           | Significant              |
| 14         | 0.08           | Significant              | 43         | 0.08           | Significant              |
| 15         | 0.15           | Significant              | 44         | 0.15           | Significant              |
| 16         | 0.23           | Significant              | 45         | 0.15           | Significant              |
| 17         | 0.08           | Significant              | 46         | 0.08           | Significant              |
| 18         | 0.15           | Significant              | 47         | 0.31           | Significant              |
| 19         | 0.08           | Significant              | 48         | 0.15           | Significant              |
| 20         | 0.00           | Significant              | 49         | 0.23           | Significant              |
| 21         | 0.23           | Significant              | 50         | 0.15           | Significant              |
| 22         | 0.15           | Significant              | 51         | 0.15           | Significant              |
| 23         | 0.08           | Significant              | 52         | 0.08           | Significant              |
| 24         | 0.08           | Significant              | 53         | 0.15           | Significant              |
| 25         | 0.08           | Significant              | 54         | 0.15           | Significant              |
| 26         | 0.23           | Significant              | 55         | 0.23           | Significant              |
| 27         | 0.15           | Significant              | 56         | 0.31           | Significant              |
| 28         | 0.15           | Significant              | 57         | 0.23           | Significant              |
| 29         | 0.15           | Significant              | 58         | 0.15           | Significant              |

For 5-years return period, extreme precipitations reached up to 200 mm/day, and with 100 to 150 mm/day in average. Lower 5-years return period rainfall are found in Central-East parts of the study area, which are less than 100 mm/day. However 100 to 150 mm/day return period rainfall still dominated the study area. It can be seen in the figure that higher extremes also occurred in the Northeast part and lower middle part of the study area (Figure 2).
Extreme of 10-years return period also produce similar result with 5-years return period. Higher return period rainfall found in the South part of the study area. Different pattern found, in which higher extremes also occurred in the North part. Maximum 10-years return period rainfall reached up to 200 mm/day and higher than 250 mm/day (Figure 3).
The PMP data shows that it can reach 400 mm/day to 1200 mm/day. Similar extreme precipitation pattern that has been identified from 5 years return period, 10 years return period, and PMP indicates that several areas have higher extreme compared to other location. The distribution of extreme precipitation is generally higher in coastal area, especially in North part and South part of Central Java. This pattern is in opposite with the annual precipitation where it is generally lower in the coastal and lowland area, but higher at the mountainous area (Figure 4).

Figure 4. Probable Maximum Precipitation (Source: data analysis)

4. Discussion and Conclusion
The result of the research obtained from several previous studies indicate the relationship between higher rainfall intensity with increasing elevation. However, the previous research does not mention the difference between distribution of annual precipitation and heavy precipitation. This research shows that opposite precipitation pattern from extreme precipitation and annual precipitation in the study area exists. In the study area of Central Java, highest annual precipitation often found in the peak of mountainous area. The annual precipitation often exceed 2000 mm/year. This condition is in contrast with extreme precipitation intensity which is higher in coastal area and decreasing with increasing elevation as described before. It can be inferred that the controvert pattern is possibly generated by different precipitation generation processes between coastal and mountainous area.

There is variation of extreme precipitation from the study area of Central Java. Analysis using 5-years return period rainfall, 10-years return period rainfall, and probable maximum precipitation (PMP) indicates that extreme precipitation generally occurred in the lowlands and coastal areas. At the north, the area adjacent to Java Sea have higher extreme probability. The areas for example are Pekalongan, Kendal, Semarang, and Demak. While at the south part of the study area adjacent to the Indian Ocean, the area with higher probability of extreme are for example Purworejo, Kebumen, Kutoarjo, Gombong, and Cilacap.
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