Mapping Extreme Rain Conditions in Sumatra by Influence Global Conditions

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Abstract. Determination of the extreme value category with a specific threshold value for a region with diverse climate characteristics may lead to incorrect extreme characterization. This study aims to determine thresholds of extreme rainfall in Sumatra, identify its spatial patterns and occurrence in Sumatra and examine the link between extreme weather events to global climate phenomena which are the ENSO and the Dipole Mode. The data used in this study are daily rainfall data from 38 stations in Sumatra and indices of global climate phenomena, the dipole mode index (DMI) and the Southern Oscillation Index (SOI). The method used to determine the threshold for extreme value is with a probability of 95% based on their corresponding distribution, cluster analysis and correlation analysis. The expected result is an extreme value for all parts of Sumatra, the extreme character of all clusters by time and region, as well as its relationship with DMI and SOI. Preliminary results obtained that extreme daily rainfall values ranged from 42.4 to 114.7 mm per day. Extreme daily rainfall for western region of Sumatra has an average value higher and more varied than the eastern region. Extreme daily rainfall over northern region has an average value higher and more varied than the southern region. Clustering analysis of 38 observation stations with ward method gets 5 (five) clusters. At least 20 years long periods of ideal data are needed to find the threshold of extreme rainfall over Sumatra region. Threshold of extreme rainfall with long periods of different data showing different values for each station are sometimes larger or smaller that may be caused by different spread of the data for each station.

1. Introduction
Sumatra Island is geographically an island which is above equatorial region surrounded by ocean. Rainfall in Indonesia in general is influenced by the interaction of land, atmosphere and the oceans around it. The phenomenon of positive anomaly of sea surface temperatures in the Indian Ocean to the west and negative anomalies in sea surface temperatures occurred west of Sumatra, resulting in increased rainfall in Sumatra's west coast region known as the Indian Ocean dipole mode (IOD) [1]. There is a negative IOD in most areas of Sumatra causing increased rainfall. In Indonesia the events of floods and severe droughts are always associated with El Niño-Southern Oscillation (ENSO) [2]. The results of research related to extreme rainfall with cumulative distribution function method for Sumatra conducted by Marpaung et al [3] using rainfall data from TRMM and observations indicate that extreme rainfall events with the number of incidence days of 1 to 2 days per annum dominant place. In 1998 and 1999 it appears to increase in extreme rainfall events for a number of days per year.

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incidence greater than 2 days, especially in the water of the West and East Sumatra. This increase is allegedly due to the influence of global phenomenon La Nina and the Dipole Mode. The threshold value of extreme rainfall for Sumatra is 60 to 130 mm / day. Several studies of extreme rainfall also done abroad including Zhang et al [4] that did a study in the valley of the Yangtze River, China. They analyzed daily rainfall data of 150 stations from the 1960-2002 period in the Yangtze River valley. They use extreme climate index of the highest daily rainfall amount of 5-day and 10-day (R5D and R10D) and the maximum daily rainfall at the 95th percentile (prec95p) and the 99th percentile (prec99p). Frequency of R5D and R10D show a downward trend. The phenomenon is more noticeable on the middle of the Yangtze River valley. Moberg [5] analyzed temperature and precipitation for stations in the Western Europe region. They calculated the daily extreme climate index of the data series in the period 1901-2000. They use criteria of extreme climates percentile of 90, 95 and 98 to calculate the index of extreme temperature and precipitation in Western Europe during the winter and summer. The study showed that in winter a trend is warmed (~ 1.0 °C / 100 years) than summer (~ 0.8 °C). In the winter, total rainfall average in 121 stations in Europe showed a significant trend of increased ~ 12% per 100 years. The trend of daily rainfall in the winter with the calculation of the 90th percentile, 95 and 98 also show the same thing. Other studies calculate extreme values using the median quantile regression that was first introduced by Roger Koenker and Gilbert Basset [6]. Some researchers determine the extreme value distributions that use the Generalized Extreme Value (GEV) developed by Jenkinson [7] to model extreme precipitation. This approach is referred to as block maxima using distribution modeling for maximum data at each time interval called the block. Other researchers use the approach of Peak Over Threshold (POT), which was originally introduced in the field of hydrology to define extreme values. POT method uses a threshold value for defining the precipitation with a value exceeding the threshold as extreme precipitation. POT overall uses observational data in modeling extreme precipitation, this is what distinguishes it from the GEV approach. Extreme rainfall events from time to time in Indonesia are more frequent that often leads to loss of property and loss of life. The extreme value issued by BMKG under regulation KBMKG No: Kep.009 Year 2010 is rainfall intensity of 50 mm/day or 20 mm/hour. The determination of threshold values with the extreme categories that limit values for a region as diverse character of the climate was not able to provide characterization of the extreme right. Therefore, this study aims to determine the threshold of extreme rainfall in Sumatra and group them by similarity.

2. Data and Methods

2.1. Research Locations
Location of the study is the island of Sumatra in the form of 18 points stations in Sumatra and surrounding areas.
2.2. Data
The data used in this study are the daily rainfall data of observation stations in the island of Sumatra in the period of 1983-2012.

| No. | Station Id | Name of station          | Station Location                  | Latitude | Longitude | Mean Sea Level | Period     |
|-----|------------|--------------------------|-----------------------------------|----------|-----------|----------------|------------|
| 1   | 96291      | Masgar                   | Pesawar, Lampung                  | -5.172   | 105.18    | 71             | 1996-2012  |
| 2   | 96295      | Raden Inten II           | South Lampung, Lampung            | -5.27    | 105.18    | 81             | 1981-2012  |
| 3   | 96293      | Maritim Panjang          | Bandar Lampung, Lampung           | -5.47    | 105.33    | 1              | 1998-2012  |
| 4   | 96297      | Kota bumi                | North Lampung, Lampung            | -4.836   | 104.87    | 60             | 1994-2012  |
| 5   | 96253      | Fatmawati Airport        | Bengkulu City, Bengkulu           | -3.88    | 102.33    | 16             | 1981-2012  |
| 6   | 96257      | Kepahiyang               | Kepahiyang, Bengkulu              | -3.63    | 102.59    | 517            | 1985-2012  |
| 7   | 96255      | Baai Island              | Baai Island, Bengkulu             | -3.87    | 102.32    | 10             | 1985-2012  |
| 8   | 96223      | Kenten                   | Palembang, South Sumatra          | -3.00    | 104.70    | 8              | 1981-2012  |
| 9   | 96221      | Sutan Mahmud Badarudin II| Palembang, South Sumatra          | -2.90    | 104.70    | 11             | 1981-2012  |
| 10  | 96237      | Depati Amir Airport      | Pangkalpinang, Bangka Belitung    | -2.17    | 106.13    | 33             | 1981-2012  |
| 11  | 96249      | H.A.S Hanandjoedin       | Belitung, Bangka Belitung         | -2.757   | 107.75    | 47             | 1981-2012  |
| 12  | 96247      | Pilang                   | Belitung, Bangka Belitung         | -2.757   | 107.65    | 22             | 1995-2012  |
| 13  | 96191      | Sei Durian               | Muaro Jambi, Jambi                | -1.60    | 103.49    | 34             | 1998-2012  |
| No. | Code   | Name                     | Location                      | Latitude | Longitude | Year 1 | Year 2   |
|-----|--------|--------------------------|-------------------------------|----------|-----------|--------|----------|
| 14  | 96207  | Depati Parbo             | Kerinci, Jambi                | -2.083   | 101.45    | 450    | 1985-2012|
| 15  | 96195  | Sultan Thoha             | Sultan Thoha, Jambi           | -1.634   | 103.64    | 26     | 1983-2012|
| 16  | 96171  | Japura                   | Indra Giri Hulu, Riau         | 00.33    | 102.32    | 19     | 1982-2012|
| 17  | 96109  | Sultan Syarif Kasim      | Pekanbaru, Riau               | 0.324306 | 101.43    | 27     | 1981-2012|
| 18  | 96087  | Hang Nadim               | Batam, Riau Islands           | 1.117    | 104.12    | 28     | 1993-2012|
| 19  | 96089  | Raja Haji Abdullah Airport | Tanjung Balai Karimun, Riau Islands | 01.03    | 103.38    | 1      | 1994-2012|
| 20  | 96091  | Kijang Airport           | Tanjung Pinang, Riau Islands  | 0.6375   | 104.53    | 18     | 1983-2012|
| 21  | 96145  | Tarempa Airport          | Kepulauan Anambas, Riau Islands | 03.20    | 106.25    | 2      | 1991-2012|
| 22  | 96179  | Dabo Airport             | Lingga, Riau Islands          | -0.48    | 104.58    | 29     | 1991-2012|
| 23  | 96167  | Sicincin                 | Sicincin, West Sumatra        | -0.575   | 100.71    | 137    | 1985-2012|
| 24  | 96163  | Minangkabau International Airport | Padang, West Sumatra | -0.793   | 100.29    | 6      | 1982-2012|
| 25  | 96165  | Silaing Bawah            | Padang Panjang, West Sumatra  | 0.317    | 100.40    | 773    | 1996-2012|
| 26  | 96161  | Teluk Bayur              | Kota Padang, West Sumatra     | -0.996   | 100.37    | 2      | 1994-2012|
| 27  | 96031  | Sampali                  | Deli Serdang, West Sumatra    | 3.617    | 98.78     | 25     | 1980-2012|
| 28  | 96033  | Belawan                  | Medan, West Sumatra           | 3.788    | 98.71     | 3      | 1982-2012|
| 29  | 96035  | Kualanamu Airport        | Deli Serdang, North Sumatra   | 3.642    | 98.89     | 23     | 1981-2012|
| No | Postal Code | Location Details | Long | Lat | Year |
|----|-------------|------------------|------|-----|------|
| 30 | 96037       | Tuntungan, Deli Serdang, North Sumatra | 3.501 | 98.56 | 86 | 1991-2012 |
| 31 | 96039       | Parapat, Simalungun, North Sumatra | 2.694 | 98.92 | 1061 | 1997-2012 |
| 32 | 96073       | F.L Tobing, Tapanuli Tengah, North Sumatra | 01.55 | 98.88 | 10 | 1981-2012 |
| 33 | 96075       | Binaka, Gunung Sitoli - Nias, North Sumatra | 1.165 | 97.71 | 175 | 1982-2012 |
| 34 | 96001       | Cut Bau Maimun Saleh Airport, Sabang, Nanggroeu Aceh Darussalam | 0.269 | 95.35 | 126 | 1981-2012 |
| 35 | 96009       | Malikusaleh Airport, Aceh Utara, Nanggroeu Aceh Darussalam | 5.228 | 96.93 | 28 | 1983-2012 |
| 36 | 96011       | Sultan Iskandar Muda Airport, Aceh Besar, Nanggroeu Aceh Darussalam | 5.521 | 95.42 | 20 | 1982-2012 |
| 37 | 96015       | Tjut Nyak Dien Meulaboh Airport, Nagan Raya, Nanggroeu Aceh Darussalam | 4.049 | 96.25 | 3 | 1982-2012 |
| 38 | 96017       | Indrapuri, Aceh Besar, Nanggroeu Aceh Darussalam | 05.40 | 95.46 | 51 | 1995-2012 |

2.3. Method

2.3.1. Cluster analysis

Cluster analysis is part of a multivariate analysis with the purpose to categorize objects based on the characteristics of its observations, where each object in the same group have a level of closeness and similarity between one another [8]. The result of cluster analysis is the formation of groups that have a degree of similarity and heterogeneity of high inter-cluster. Nazaripour and Khosravi [9] classify the intensity of daily rainfall in Zahedan, Iran with Ward cluster analysis method. Techniques within the Ward’s method calculate the sum of the squares between the two groups for all variables. Ward’s equation is as follows:

$$d(r, s) = \frac{n_r n_s d_{rs}^2}{n_r + n_s}$$  \hspace{1cm} (1)

- \(d(r, s)\) : distance
- \(d_{rs}\) : distance between \(r\) and \(s\)
- \(n_r\) : group-\(r\)
- \(n_s\) : group-\(s\)
2.3.2. Analysis of Opportunities

In determining the threshold of extreme rainfall that contains zero millimeters of rainfall, the chances are calculated by the method of distribution of mixture [10], namely:

\[ H(x) = q + p P_x(X) \]  \hspace{1cm} (2)

where:
- \( H(x) \) : probability distribution for a mixture of rain recedes value that exceeds \( x \) for \( x \geq 0 \)
- \( q \) : zero chance of rain events
- \( p \) : probability of rain events greater than zero, \( p = 1 - q \)
- \( P_x(X) \) : probability of rain events by gamma cumulative distribution opportunities \( (x > 0) \)

2.3.3. Data Length Determination

The steps in determining the length of the data that is used to find the value extreme are:

1. Find a station that has a data length more than 30 years
2. Divide data into several periods where each period is a multiple of five years
3. Determine the extreme value of each station
4. Create scatter plot graph
5. Determine the value that is closest to the ticket

3. Result and Discussion

3.1. Analysis Cluster

Results of grouping rainfall stations in Sumatra based extreme value with threshold of each month are five clusters (figure 2).

![Dendrogram of rainfall station groups in Sumatra Island.](image)

Figure 2. Dendrogram of rainfall station groups in Sumatra Island.

Based on the analysis results it is obtained that in cluster 1 there are 7 stations, 9 stations in cluster 2, 10 stations in cluster 3, 7 stations in cluster 4 and 5 stations in cluster 5. Groups of rain stations are shown in table 2.
Table 2. Station groups based on the extreme threshold.

| No. | Station Id | Name of station              | Cluster |
|-----|------------|------------------------------|---------|
| 1   | 96291      | Masgar                       | 1       |
| 2   | 96295      | Raden Inten II               | 2       |
| 3   | 96293      | Maritim Panjung              | 3       |
| 4   | 96297      | Kota bumi                    | 2       |
| 5   | 96253      | Fatmawati Airport            | 4       |
| 6   | 96257      | Kepahiyang                   | 2       |
| 7   | 96255      | Baai Island                  | 4       |
| 8   | 96223      | Sutan                        | 2       |
| 9   | 96221      | Mahmud Badarudin II          | 1       |
| 10  | 96237      | Depati Amir Airport          | 5       |
| 11  | 96249      | H.A.S Hanandjoedin           | 1       |
| 12  | 96247      | Pilang                       | 4       |
| 13  | 96191      | Sei Durian                   | 5       |
| 14  | 96207      | Depati Parbo                 | 3       |
| 15  | 96195      | Sultan Thoha                 | 3       |
| 16  | 96171      | Japura                       | 4       |
| 17  | 96109      | Sultan Syarif Kasim          | 3       |
| 18  | 96087      | Hang Nadim                   | 1       |
| 19  | 96089      | Raja Haji Abdullah Airport   | 3       |
| 20  | 96091      | Kijang Airport               | 2       |
| 21  | 96145      | Tarempa Airport              | 1       |
| 22  | 96179      | Dabo Airport                 | 3       |
| 23  | 96167      | Sicincin Minangkabau         | 2       |
| 24  | 96163      | International Airport Silaing Bawah | 5   |
| 25  | 96165      | Bayur Bay                    | 4       |
| 26  | 96161      | Sampali                      | 2       |
| 27  | 96031      |                             |         |
| 28  | 96033      | Belawan                      | 4       |
| 29  | 96035      | Kualanamu Airport            | 3       |
| 30  | 96037      | Tuntungan                    | 5       |
| 31  | 96039      | Parapat F.L Tobing Sibolga  | 3       |
| 32  | 96073      | Binaka                       | 2       |
| 33  | 96075      |                             |         |
| 34  | 96001      | Cut Bau M. Saleh Airport     | 4       |
| 35  | 96009      | Malikussaleh Airport         | 1       |
| 36  | 96011      | Sultan Iskandar Muda Airport | 2       |
| 37  | 96015      | Tjut Nyak Dien Airport       | 3       |
| 38  | 96017      | Indrapuriri                  | 5       |

The pattern of rainfall threshold in cluster 1 shows that the threshold value is the highest rainfall in January. The pattern of rainfall threshold in cluster 2 in figure 4 shows that the threshold value is the highest precipitation in February. The pattern of rainfall threshold in cluster 3 shows that the threshold values are the high rainfall in August in contrast to cluster 1 and cluster 2. The pattern of rainfall threshold in cluster 4 shows that the limit values are high in June and August and the lowest is in April. The pattern of rainfall threshold in cluster 5 shows that the extreme rainfall has two peaks, where the first peak occurs in February and the second peak occurs in August (figure 3).
Figure 3. The pattern of extreme monthly rainfall in (a) Cluster I; (b) Cluster II; (c) Cluster III; (d) Cluster IV; (e) Cluster V.

3.2. Analysis of Opportunities

Figure 4 shows that the extreme daily rainfall values range from 42.4 to 114.7 mm. Extreme value of daily rainfall in western region of Sumatra has an average value higher and more varied than the eastern region. While the northern region of Sumatra has an extreme value of daily rainfall is higher than in the south.

Figure 4. Threshold of extreme rainfall in Sumatra island (1998-2012).
3.3. Analysis of Data Period

Minimum length of data period is very important as a reference in determining the length of data that is ideal for calculating the thresholds of extreme rainfall. Determination of a minimum length of the data period was done by taking a sample of rainfall observation data over 30 years. After sorting the data from 38 stations in Sumatra, seven stations that have long data period for 35 years are Raden Inten II Lampung, Fatmawati Bengkulu, Kenten South Sumatra, Sutan Mahmud Badarudin II South Sumatra, Depati Amir Bangka Belitung, Sampali North Sumatra, Kualanamu North Sumatra.

Figure 5. Graph of the average threshold of each period.

Figure 5 shows that the period approaching the intersection line is the 4th period (1978-1997) so that it can be concluded that long periods of minimum rainfall data taken in seeking the minimum threshold require extreme data over 20 years. After sorting, as many 18 stations have data more than 20 years including Raden Inten II, Fatmawati, Kenten, Sutan Mahmud Badarudin II, Depati Amir, HAS Hanandjoedin, Sultan Thoha, Japura, Minangkabau International Airport, Sampali, Belawan, Kualanamu F.L Tobing Sibolga, Binaka, Kijang, Cut Bau Maimun Saleh, Sultan Iskandar Muda and Tjut Nyak Dien Meulaboh.

As many 28 stations have data at least 30 years. These stations include Raden Inten II, Fatmawati, Kepahiyang, Baai Island, Kenten, Sutan Mahmud Badarudin II, Depati Amir, HAS Hanandjoedin, Depati Parbo, Sultan Thoha, Japura, Sultan Syarif Kasim, Hang Nadim, Kijang, Tarempa, Dabo, Sicincin, Minangkabau International Airport, Sampali, Belawan, Kualanamu, Tuntungan, F.L Tobing, Sibolga, Binaka, Cut Bau Maimun Saleh, Malikussaleh, Sultan Iskandar Muda and Tjut Nyak Dien Meulaboh.

Table 3. Calculation of minimum data length using the 7 observation stations.

| Period | TEN | Extreme Values |
|--------|-----|----------------|
|        |     | Raden inten | Fatmawati | Kenten | SMB II | Depati amir | Sampali | Kualanamu | Average |
| Period 1 | 1978-1982 | 64.57 | 77.00 | 71.52 | 58.04 | 59.88 | 64.37 | 66.63 | 66.00 |
| Period 2 | 1978-1987 | 70.93 | 81.92 | 70.00 | 65.65 | 59.77 | 64.74 | 72.27 | 69.33 |
| Period 3 | 1978-1992 | 73.28 | 83.77 | 71.16 | 62.21 | 59.35 | 66.81 | 68.52 | 69.30 |
| Period 4 | 1978-1997 | 73.30 | 98.00 | 72.00 | 63.73 | 59.40 | 66.15 | 67.40 | 71.43 |
| Period 5 | 1978-2002 | 73.30 | 84.00 | 74.00 | 75.16 | 59.11 | 67.28 | 69.17 | 71.72 |
| Period 6 | 1978-2007 | 72.33 | 98.00 | 75.00 | 75.80 | 58.40 | 71.71 | 70.38 | 74.52 |
| Period 7 | 1978-2012 | 72.05 | 96.81 | 77.00 | 75.60 | 58.30 | 77.00 | 69.21 | 75.28 |
4. Summary and Concluding Remarks
Clustering analysis of 38 observation stations with the ward method results 5 (five) clusters. Each cluster has a different pattern every month. Extreme daily rainfall in the region of Sumatra has a value ranging from 42.4 to 114.7 mm. Extreme daily rainfall over western region of Sumatra has an average value higher and more varied than the eastern region. Extreme daily rainfall over the northern region has an average value higher and more varied than the southern region. Threshold of extreme rainfall with long periods of different data showing different values for each station are sometimes larger or smaller that may be caused by different spread of the data for each station.

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