Distribution of rainfall events in northern region of Peninsular Malaysia

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Abstract. Understanding of rainfall characteristics is important in designing Best Management Practices (BMPs) facilities. Because of intermittent rainfall, many researches on hydrology employ the concept of rainfall events. The selection of appropriate rainfall events for treatment design is essential to ensure the effectiveness of BMPs systems. Thus, the objective of this study is to identify the distribution of rainfall event using 6-hour Minimum Inter Event Time (MIT) and to identify the extreme rainfall thresholds over the study area. It shows that the rainfall data series consist of a large number of small events and rainfall depth of less than 2.5 mm (Type 1) contributes the highest percentage toward the overall record. About 63% of the rainfall record consists of Type 2 rainfall depth between 2.6 mm to 80 mm and only 1.3% recorded for rainfall event Type 3 with a depth exceeding 80 mm. It was found that the extreme rainfall threshold in Northern region of Peninsular Malaysia vary from 45 mm to 80 mm for R95 indices and 72 mm to 175 mm for R99 indices. These findings could be used as reference for better BMPs facilities design with extreme rainfall adaptation strategies.

1. Introduction
Urbanization increases expansion of urban land uses, yet it correlates with increasing stormwater runoff. Urbanization also results in water contaminants carried out to downstream waterways. Urban stormwater runoff washes out varies pollutants and transports to receiving waters thereby leading to the degradation of water quality [1]. Therefore, stormwater runoff has become a major problem as the condition is poorly managed. To alleviate such a situation, Best Management Practices (BMPs) has been applied to ease the concern for environmental protection. The pervious area is replaced with impervious landscapes with the function of promoting infiltration, reducing peak flow, alleviating stormwater runoff pollution and creating an ecological environment during urban development. According to Sharifi et al. [2], effectiveness of BMPs depends on the volume of runoff which is captured and treated. Therefore, detailed knowledge on volume of runoff in urban catchment is crucial for designing BMPs facilities.

Rainfall is the biggest contributor in producing runoff volume. Rainfall, which occurs as a series of continuous event characterized by different depth, amount, duration, intensity and inter event time. Because of intermittent rainfall, many researches on hydrology employ the concept of rainfall events for hydrology analysis as well as for designing BMPs facilities. Smith [3] investigated the effects of rainfall pattern on runoff production in a rural area and reported that runoff production depends on
event rainfall pattern. Moreover, Ahn et al. [4] used event–based model to overcome the limitations of conventional-design storm methodology and continuous simulation method in flood frequency analysis. Rainfall event was also used in designing stormwater treatment system based on water quality and runoff volume. Liu et al. [5] found that small and frequent rainfall events were more appropriate for stormwater treatment performance efficiency. This highlights the need for prudent selection of rainfall events and appropriate runoff volume for stormwater design based.

Separation of rainfall event from continuous record typically depends on the time chosen in (MIT) [6] or Inter-Event Time Definition (IETD) [7] - which is also referred to as antecedent dry period [8]. MIT is defined as the minimum dry period between two rainfall pulses and is the length of 'no rain' or 'dry period' that make two events independent on each other. Adams et al [9] showed that rainfall event characteristics such as volume, intensity and duration varied according to different MIT. Different MIT provided varying number of rainfall events and shorter MIT have more varied duration and depth compared to rainfall separated by longer MIT [6]. Asquith et al. [10] also identified that an increase of MIT will increase rainfall event depth and have significant impact on the derivation of an Intensity Duration Frequency curve.

Driscoll et al. [11] found that a 6-hour separation time produced the most consistent statistical results when attempting to define individual rainfall event from continuous records. However, Nojumuddin et al. [12] found that 8 hours was the chosen MIT for Johor Malaysia. When considering basin characteristics, MIT values between 1 and 6 hours were suggested for most urban areas [7]. Overall, MIT used for separation of rainfall event ranges from 6 to 8 hours and are widely adopted by many published studies.

It is imperative for adaptation of extreme rainfall event in BMPs facilities be considered as it can assist in future design flows. The rise of global temperature affects the intensity of the extreme rainfall, therefore the study about it is growing. The rainfall thresholds on which a rainfall event can be characterized as extreme vary among country. The different definitions of what is or is not an extreme event are due to the varieties in local features and interaction with the atmospheric circulation. Rainfall depth exceeding 124.4 mm is referred to as extreme rainfall events in India [13]. In the European region, an extreme rainfall threshold differs from region to region and is in the range of 20 mm to 45 mm [14]. They also claimed that the determination of extreme rainfall threshold should be used in different methodologies and indices and the Peaks Over Threshold (POT) method and 99th percentiles indices have been proven to be more efficient in the European region. Evidently, the threshold for extreme rainfall is difficult to set as extreme events are rare and occur on a relatively small and local scale. Despite many studies on this subject being conducted in Malaysia, a large knowledge gap still exists with regard to extreme rainfall threshold and indices. Thus, research on such matters is strongly encouraged.

The objectives of this study are: (1) to identify the distribution of rainfall event using 6-hour MIT and (2) to identify the extreme rainfall thresholds over Northern region of Peninsular Malaysia. These findings could be used as reference for better BMPs facilities design with extreme rainfall adaptation strategies.

2. Methodology

2.1. Study area
Peninsular Malaysia lies in Southeast Asia, has a tropical climate and is located along the latitude between 1° and 6° N and longitude between 100° and 103° E. The surface climate is influenced by southeast monsoon season between May and August and by northeast monsoon season between November and February. The Northern region of Peninsular Malaysia comprises the states of Perlis, Kedah, Penang and Perak and it the driest region especially during the southwest monsoon season. Rainfall stations with more than 20 years of historical data were chosen for this study. It is based on suggestions from United States Environmental Protection Agency (USEPA) which recommended at least 20 to 30-year period of rainfall record for analysing rainfall events [15]. All rainfall data were
obtained from the Water Resources Management and Hydrology Division, Department of Irrigation and Drainage (DID), Malaysia. Most of the rainfall data were obtained using automatic recorded rain gauges. There are 26 rainfall stations examined in this study. Figure 1 presents a distribution of the rainfall stations in the Northern region and geographic coordinates of each station are shown in Table 1. To ensure the quality control of the data set, missing data and homogeneity test were applied to the rainfall time series.

![Figure 1. Distribution of rainfall stations.](image)

**Table 1.** Geographic coordinates of each station.

| Rainfall Stations | Location |
|-------------------|----------|
| **ID** | **Name** | **Latitude** | **Longitude** |
| 6401002 | Padang Katong | 06° 26' 45" | 100° 11' 15" |
| 6402008 | Ngolang | 06° 28' 30" | 100° 14' 50" |
| 6603002 | Padang Besar | 06° 39' 25" | 100° 18' 35" |
| 5507076 | Bt. 27 Jln. Baling | 05° 35' 00" | 100° 44' 10" |
| 5704055 | Kedah Peak | 05° 47' 45" | 100° 26' 20" |
| 5806066 | Jeniang Klinik | 05° 48' 50" | 100° 37' 55" |
| 6103047 | Stor JPS Alor Setar | 06° 06' 20" | 100° 23' 30" |
| 6108001 | Komplek Rumah Muda | 06° 06' 20" | 100° 50' 50" |
| 6206035 | Kuala Nerang | 06° 15' 15" | 100° 36' 45" |
| 6207032 | Ampang Pedu | 06° 14' 25" | 100° 46' 20" |
| 6306031 | Padang Sanai | 06° 20' 35" | 100° 41' 25" |
| 5204048 | Sg. Simpang Ampat | 05° 17' 38" | 100° 28' 50" |
| 5504035 | Lahar Ikan Mati at kepala batas | 05° 32' 05" | 100° 25' 50" |
| 4010001 | JPS Telok intan | 04° 01' 00" | 101° 02' 10" |
| 4207048 | Pejabat JPS. Sitiawan | 04° 13' 05" | 100° 42' 00" |
| 4311001 | Pejabat Dearah Kampar | 04° 18' 20" | 101° 09' 20" |
| 4409091 | Rumah Pam Kubang Haji | 04° 35' 20" | 101° 07' 30" |
2.2. Separation of rainfall event

Visual basic and macro in Microsoft Office Excel is used to develop a program to automatically separate continuous rainfall record into a single event. This program reads the data from a data sheet and automatically detects rainfall event for certain value of MIT. The program would initially separate continuous rainfall data series from excel sheet into a discrete event. Distribution of rainfall events are discussed within three types of rainfall depth as mentioned in previous studies [13, 16]. Table 2 shows the types and classification of the rainfall events. Afterwards, using 6 hours as a value of MIT, the rainfall events are determined. To identify the extreme rainfall thresholds for the study area, two percentile indices were used which is R95 and R99. R95 is total rainfall when exceeding 95th percentile define as a very wet days and R99 is a total rainfall when exceeding 99th percentile define as extremely wet days. The indices were calculated using Excel. Interpolation method has been used to predict the values of unknown locations using collected known location data. Spatial Analyst is used to interpolated extreme rainfall threshold using Ordinary Kriging Method.

| Type             | Classification       | Depth (mm) |
|------------------|----------------------|------------|
| Type 1           | No Runoff            | 0 to 2.5   |
| Type 2           | Light to heavy rainfall | 2.6 to 80 |
| Type 3           | Heavy Rainfall       | < 81       |

3. Results and discussion

3.1. Distribution of rainfall event

Figures 2 reveal the rainfall distribution for the study area. With 6 hours as MIT, total 6224 events were recorded. It shows that rainfall event consists of a large number of small events and the frequency curve decay as the magnitude of rainfall depth increases. A total of 2226 events (35.8%) were recorded for the event with rainfall depth less than 2.5 mm (Type 1) and this type of rainfall does not produce runoff. About 3919 events (63%) of the rainfall records consists of Type 2 (light to heavy rainfall) rainfall depth between 2.6 mm to 80 mm. This type of rainfall is used in the analysis because such small and more frequent rainfall events would be preferred in designing BMPs facilities since the benefits include efficiency in treatment performance, cost effectiveness and possible saving of inland area [5]. For rainfall event in Type 3 (heavy rainfall) with a depth exceeding 80 mm, Northern region recorded a small percentage with only 79 events (1.3%). Although the percentages are small, heavy and extreme rainfall events have become more frequent in recent years. Heavy rainfall events in the East Coast of Peninsular Malaysia have increased in the past 40 years [17]. Therefore, BMPs facilities need to allay the impact of increasing extreme rainfall events.
3.2. Extreme rainfall threshold

Figures 3 and 4 shows the extreme rainfall threshold and spatial interpolation result for R95 indices. The threshold values vary from 45 mm to 80 mm. Minimum thresholds magnitude were observed at station ID 4811075 (Ranc. Belia Perlop) with rainfall depth at 45.4 mm. While, maximum threshold value was found at station ID 5704055 (Kedah Peak) with rainfall depth at 80.1 mm. More specifically, for very wet day (R95), only three stations under study had threshold value below than 50 mm (12.5%). The rest gives a threshold value of more than 50 mm.

Figure 3. Extreme rainfall threshold for R95.

Figure 2. Rainfall distribution for the Northern Region.
Figures 5 and 6 shows the extreme rainfall threshold and spatial interpolation result for R99 indices. For R99 indices, the stations with the highest and lowest threshold remain same as in the R95 indices. Minimum and maximum thresholds magnitude is 72.5 mm and 173.1 mm respectively. For extremely wet day (R99) condition, 83% have a threshold value of over 80 mm and there are seven stations with a threshold value more than 100 mm.

Figure 4. Spatial distribution for R95.

Figure 5. Extreme rainfall threshold for R99.
4. Conclusion

The main objective of the present study was to identify the distribution of rainfall event using 6-hour MIT. It shows that the rainfall data series consist of a large number of small events and rainfall depth of less than 2.5 mm (Type 1) contributes the highest percentage toward the overall record. About 63% of the rainfall record consists of Type 2 (light to heavy rainfall) rainfall depth between 2.6 mm to 80 mm and only 1.3% recorded for rainfall event Type 3 (heavy rainfall) with a depth exceeding 80 mm. Future studies are encouraged to identify distribution of rainfall event using different MIT. It was found that the extreme rainfall threshold in Northern region vary from 45 mm to 80 mm for R95 indices and 72 mm to 175 mm for R99 indices. The results in the case of the 99th percentile indices are much higher compared to 95th percentile indices. Further research is clearly needed to determine the most objective way to identify extreme rainfall threshold using different indices because different indices provide different result. According to Zolina et al. [18] and Leander et al. [19], percentile indices might have some uncertainties due to their outlier. However, for urban drainage, Ambjerg-Nielsen et al. [20] recommended 99.9 percentile and higher for quantiles methods to study about extreme rainfalls. The frequency of extreme rainfall also needs to be studied because it is important in analyzing flood forecasting.

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References

[1] Huang J Tu Z Da P Lin J and Li Q 2010 *Journal of Environmental Sciences* 22(11) 1703-1709
[2] Sharifi S Massoudieh A Kayhanian M 2011 *Water Environment Research* 83(11) 2025-2035
[3] Smith R E 1972 *J. Hydrol.* 17 1-21
[4] Ahn J Cho W Kim T Shin H and Heo J H 2014 *Water* 6(12) 3841-3863
[5] Liu A Guan Y Egodawatta P and Goonetilleke A 2016 *Ecological Engineering* 92 67-72
[6] Shamsudin S Dan'azumi S and Aris A 2010 European Journal of Scientific Research 45(2) 162-167
[7] Joo J Lee J Kim J H Jun H and Jo D 2013 Water 6(1) 45-58
[9] Tian P Li Y and Yang Z 2009 Frontiers of earth Science in China 3(3) 297-302
[10] Adams B J Fraser H G Howard C D D and Hanafy M S 1986 Journal of environmental Engineering 112(5) 827-848
[11] Asquith W H Roussel M C and Cleveland T G 2006 US Geological Survey professional paper 1725
[12] Driscoll E Palhegyi G Strecker E and Shelley P 1989 Analysis of storm event characteristics for selected rain gages throughout the United States (Washington: US Environmental Protection Agency)
[13] Nojumuddin N Yusof F and Yusop Z 2016 Journal of Flood Risk Management 11(S2) 687-699
[14] Pattanaik D and Rajeevan M 2010 Meteorological Applications 17(1) 88104
[15] Anagnostopoulou C and K Tolika 2012 Theoretical and Applied Climatology 107(3-4) 479-489
[16] US Environmental Protection Agency (USEPA) 2009
[17] Babar S and Ramesh H 2014 Journal of Hydraulic Engineering 20(2) 212-221
[18] Mayowa O O Pour S H Shahid S Mohsenipour M Harun S Heryanshah A and Ismail T 2015 Journal of Earth System Science 124(8) 1609-1622
[19] Zolina O Simmer C Belyaev K Kapala A and Gulev S 2009 Journal of Hydrometeorology 10(3) 701-706
[20] Leander R Buishand T A and Tank A K Journal of Climate 27(4) 1365-1378
[21] Arnbjerg-Nielsen K Willems P Olsson J Beecham S Pathirana A Gregersen I B Madsen H and Nguyen V T V 2013 Water Science and Technology 68(1) 16-28