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ANALYSIS OF EXTREME RAINFALL INDICES IN PENINSULAR MALAYSIA

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Abstract

Extreme rainfall events are the main cause of flooding. This study aimed to examine seven extreme rainfall indices, i.e. extreme rain sum (XRS), very wet day intensity (I95), extremely wet day intensity (I99), very wet day proportion (R95), extremely wet day proportion (R99), very wet days (N95) and extremely wet days (N99) using Mann-Kendall (MK) and the normalized statistic Z tests. The analyses are based on the daily rainfall data gathered from Bayan Lepas, Subang, Senai, Kuantan and Kota Bharu. The east coast states received more rainfall than any other parts in Peninsular Malaysia. Kota Bharu station recorded the highest XRS, i.e. 648 mm. The analyses also indicate that the stations in the eastern part of Peninsular Malaysia experienced higher XRS, I95, I99, R95 and R99 as compared to the stations located in the western and northern part of Peninsular Malaysia. Subang and Senai show the highest number of days for wet and very wet (N95) as compared to other stations. Other than that, all stations except for Kota Bharu show increasing trends for most of the extreme rainfall indices. Upward trends indicate that the extreme rainfall events were becoming more severe over the period of 1960 to 2014.

Keywords: Extreme rainfall indices, trend of extreme event, Mann-Kendall test, monsoon rainfall

Abstrak

Peristiwa hujan terlampau adalah penyebab utama bencana banjir. Kajian ini bertujuan untuk mengkaji tujuh indeks hujan yang melampau, iaitu jumlah hujan yang melampau (XRS), keamatan hari yang basah (I95), keamatan hari yang sangat basah (I99), hari yang sangat basah bahagian (R95), sangat hari basah bahagian (R99), hari yang sangat basah (N95) dan hari-hari yang sangat basah (N99). Makalah ini membincangkan mengenai perubahan indeks tersebut berdasarkan data hujan harian dikumpulkan dari Bayan Lepas, Subang, Senai, Kuantan dan Kota Bharu menggunakan ujian Mann-Kendall (MK) dan ujian statistik normal Z. Negeri-negeri pantai timur menerima lebih banyak hujan daripada mana-mana bahagian lain di Semenanjung Malaysia. Kota Bharu mencatatkan anggaran XRS tertinggi iaitu 648 mm. Selain itu, analisis indeks hujan melampau menunjukkan bahawa stesen di bahagian timur Semenanjung Malaysia mencatatkan nilai XRS, I95, I99, R95 dan R99 yang lebih tinggi berbanding stesen-stesen yang terletak di bahagian barat dan utara Semenanjung Malaysia. Subang dan Senai menunjukkan bilangan tertinggi hari untuk basah dan sangat basah (N95) berbanding stesen-stesen lain. Selain daripada itu, semua stesen kecuali Kota Bharu menunjukkan peningkatan bagi kebanyakan indeks hujan yang melampau. trend yang meningkat menunjukkan bahawa peristiwa-peristiwa hujan yang melampau telah menjadi lebih teruk sepanjang tempoh 1960-2014.

Kata kunci: indeks hujan melampau , trend acara yang melampau, ujian Mann- Kendall, hujan monsun

1.0 INTRODUCTION

Currently, global warming and climate change are among the topics that received considerable attention from researchers around the world. Scientists, policy makers and governments will continue to investigate the characteristics of this phenomenon. Extreme weather events include floods, droughts and rainstorms. Global warming cause erratic changes in rainfall and temperature patterns [1]. Flooding and extreme droughts resulted in many casualties in the aspects of anthropology, hydrology and economics. For example, frequent flash floods and delay harvesting are often associated with the increase in the amount of rainfall and the frequency of extreme rainfall events. Similarly, drought exposed us to the risk of fire.

Extreme rainfall events are expected to occur each year at sites located in areas with tropical climate, which indirectly affected by the impact of monsoons. Most of the rainfall events in Malaysia are multi-days and this is the main cause of flooding [2]. About 29,720 km^2 or 9% of the total area in Malaysia is estimated to be exposed to flood, which indirectly affects 4.9 million people, i.e. about 21% of the total population [3]. Several researchers performed extensive hydrological modelling on major events such as the Kota Tinggi floods in 2006 [4], Lui in 2009 and 2010 [5] and Semenyih in 2013 [6].

In order to detect the changes in extreme rainfall trends using daily rainfall data, scientists suggest different ways to estimate the indices of extreme rainfall. There are at least 23 methods to define threshold or indices explaining extreme rainfall events [7]. Similarly, [8] suggested 11 indices to define extreme rainfall. Extreme events indices can also be found in [9] and [10]. Previous study on the trend of eight extreme rainfall in Malaysia was performed by [11], while the trend and variability of temperature were examined by [12]. However, this study used the data from the year 1971 to 2005. Therefore, it is time to re-examine these indices using more recent rainfall data. Similar studies were performed by other researchers in South Pacific region [13], Swat River Basin, Pakistan [14] and Ethiopia [15].

Changes in the probability of extreme rainfall events give significant impact to various sectors such as engineering, urban planning and other activities, where traditionally the climate is considered to be unchanged. This assumption states that the climate is changing, but these changes are more likely to be persistent (World Meteorology Organization, 2009). Generally, each region show different trends. Therefore, it is likely that the regional scale is different from the global climate change at present.

The objectives of this study are to estimate and analyze the trends of seven extreme rainfall indices, namely the extreme rain sum (XRS), very wet day intensity (I95), extremely wet day intensity (I99), very wet day proportion (R95), extremely wet day proportion (R99), very wet days (N95) and extremely wet days (N99). Daily rainfall data from Bayan Lepas, Subang, Senai, Kuantan and Kota Bharu were used in this study. These stations were chosen because they represent major cities in Peninsular Malaysia, i.e. among the most populated areas in the country.

This study utilized the daily rainfall data measured at several gauging stations in Peninsular Malaysia, i.e. Bayan Lepas, Subang, Senai, Kuantan and Kota Bharu. The details of these stations are given in Table 1, while the locations are shown in Figure 1. The daily rainfall data were obtained from the Department of Meteorology, Malaysia and the Department of Irrigation and Drainage. These stations were selected because they provide long and reliable data, i.e. up to 50 years with no missing values.

2.0 METHODOLOGY

The data were found to be homogeneous using the Von Neumann ratio test. A wet day is defined as a day with a rainfall amount of at least 0.1 mm. The indices considered in this study are extreme rain sum (XRS), very wet day intensity (I95), extremely wet day intensity (I99), very wet day proportion (R95), extremely wet day proportion (R99), very wet days (N95) and extremely wet days (N99). The definitions of these indices are given in Table 2.

Extreme events are represented as 95th and 99th percentile. We defined the average of total rainfall exceeding 95th percentile as very wet day intensity and exceeding the 99th percentile as extremely wet day. Similarly, the number of days that daily rainfall exceeds 95th and 99th percentiles were referred to as extreme frequency indices.

A non-parametric test, known as Mann-Kendall was used in this study to detect increasing or decreasing trend for all seven extreme indices. The annual values were evaluated as an ordered time series. The Mann-Kendall test statistic, *S* is calculated using the formula given in equation 1

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

where x_j and x_k are the annual values in years *j* and *k*, *j*>*k*, respectively and

$$sgn(x_j - x_k) = \begin{cases} 1 \; if \;\; x_j - x_k > 0 \\ 0 \; if \;\; x_j - x_k = 0 \\ -1 \; if \;\; x_j - x_k < 0 \end{cases}$$

Following this, the normalized statistic test *Z* is estimated using equation 2

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}} \; if \; S > 0 \\ 0 \; if \;\; S = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}} \; if \;\; S < 0 \end{cases} \qquad (2)$$

where *VAR(S)* is the variance of *S*, estimated using equation 3

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5) \right] \qquad (3)$$

where *q* is the number of tied groups and t_p is the number of data values in the p^{th} group.

The trends from all rainfall gauging stations were then compared to examine changes in extreme rainfall events with respect to location. The results are given in the next section.

Figure 1 Locations of Rainfall Gauging Stations

Table 1 Rainfall Gauging Stations

Location	Coordinate (Lat., Long.)	Altitude above mean sea level (m)	Period	Duration (years)
Bayan Lepas	5° 18' N, 100° 16' E	2.5	1960-2014	55
Subang	03° 07' N, 101° 33' E	16.5	1960-2014	55
Senai	1° 38' N, 103° 40' E	37.8	1975-2014	40
Kuantan	3° 46' N, 103° 13' E	15.2	1965-2014	50
Kota Bharu	6° 10' N, 102° 18' E	4.4	1960-2014	55

Table 2 Definition of Extreme Rainfall Indices

Definition (unit)	Indicator name (ID)
The maximum cumulative total rainfall collected during a wet spell in a year (mm)	Extreme rain sum (XRS)
Average intensity of events greater than or equal to the 95th percentile (mm)	Very wet day intensity (I95)
Average intensity of events greater than or equal to the 99th percentile (mm)	Extremely wet day intensity (I99)
Percentage of total rainfall from events greater than or equal to the 95th percentile (%)	Very wet day proportion (R95)
Percentage of annual total rainfall from events greater than or equal to the 99th percentile (%)	Extremely wet day proportion (R99)
Frequency of daily rainfall exceeding the 1985-2004 mean 95th percentile (days)	Very wet days (N95)
Frequency of daily rainfall exceeding the 1985-2004 mean 99th percentile (days)	Extremely wet days (N99)

3.0 RESULTS AND DISCUSSION

3.1 Extreme Rainfall Indices

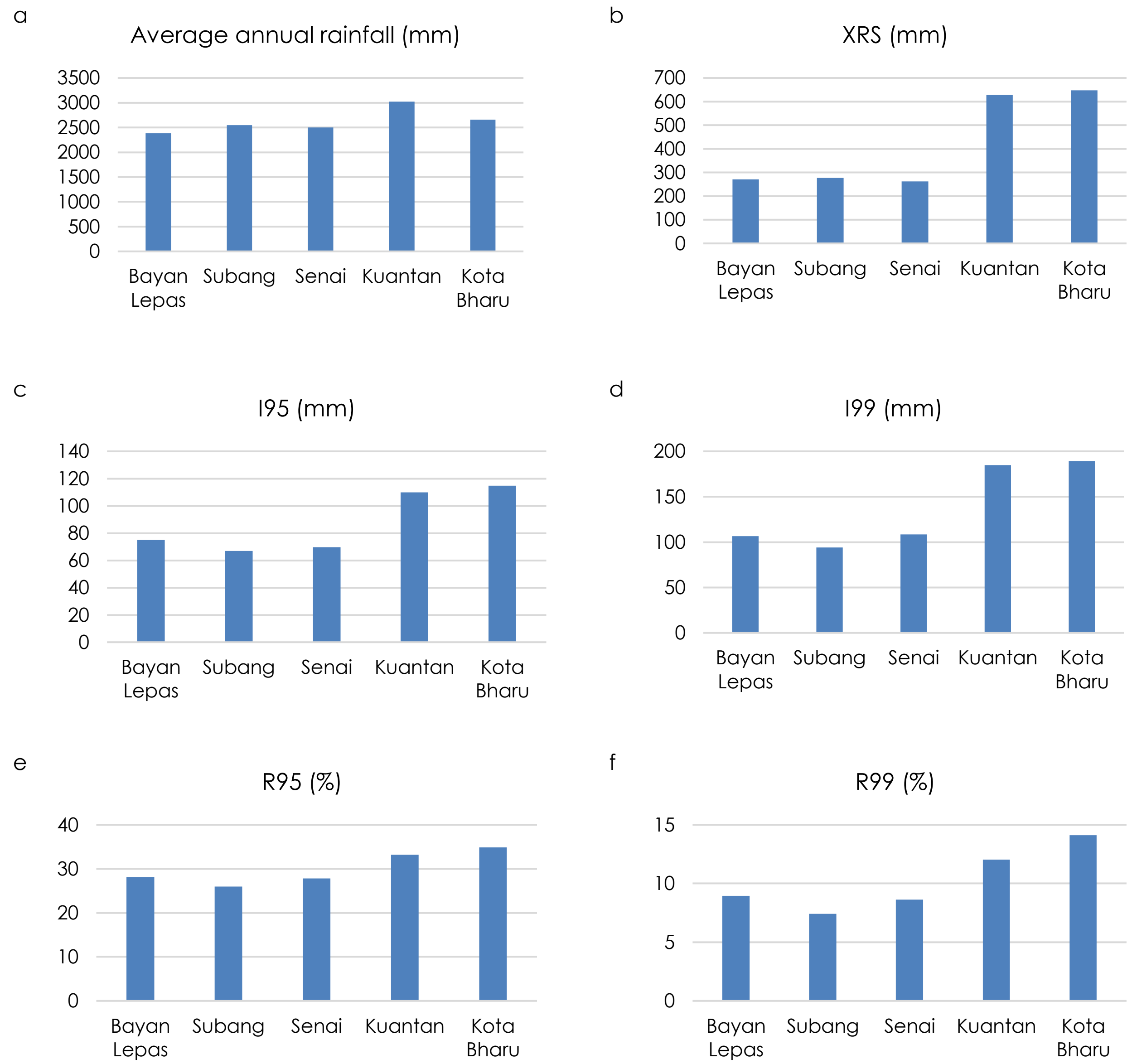
The average annual total rainfall and mean average of all seven indices are presented in Figures 2(a) to 2(h). Average total annual rainfall for all stations are between 2300 to 3000 mm. The stations located in the east coast part of Peninsular Malaysia, i.e. Kuantan and Kota Bharu received the most rainfall in a year. These locations are prone to flooding, especially during northeast monsoon that occurs in the months of November to February. Bayan Lepas received the least amount of rainfall, while Subang and Senai received about the same quantity each year.

The amount of maximum accumulated rainfall in a year (XRS) varies from 263 to 648 mm, as shown in Figure 2(a). Kota Bharu station recorded the highest XRS, followed by Kuantan and Subang which recorded 627 mm and 278 mm, respectively. Generally, the stations located in the east coast part recorded higher values compared to the northern, central and western regions of Peninsular Malaysia. The same results were obtained for other indices except for the N95 and N99 indices, where stations in the eastern part of Peninsular Malaysia recorded the highest values, while Subang was estimated to be the lowest. Significant values were estimated for I95, I99, R95 and R99 for the stations located in the eastern part. This finding shows that the occurrence of extreme rainfalls are frequent in these areas.

3.2 Changes of Trends In Extreme Rainfall

The Mann-Kendall (MK) and the normalized statistic Z tests were used to detect the changes of trend in extreme rainfall. A positive (negative) value of Z indicates an upward (downward) trend. The results are given in Table 3. The results are given at a significance level of greater than 0.1, unless stated otherwise. Kuantan is the only station that shows increasing trends for all seven extreme rainfall indices, while Kota Bharu shows decreasing trends for all indices except for R95 and N99. For XRS index, two stations, i.e. Subang and Kuantan show increasing trends, while other stations show decreasing trend. For I95 and I99 indices, all stations except Kota Bharu experience increasing trends. Other indices, i.e. R95, R99, N95 and N99 show increasing trends at most of the stations. Specifically, Bayan Lepas, Subang, Senai and Kuantan show increment in N95 index, but opposite result was estimated for Kota Bharu.

Overall, all indices show upward trends at all stations except for Kota Bharu. However, upward trends for R95 and N99 for Kota Bharu indicate that the extreme rainfall events were becoming more severe over the period of 1960 to 2014.



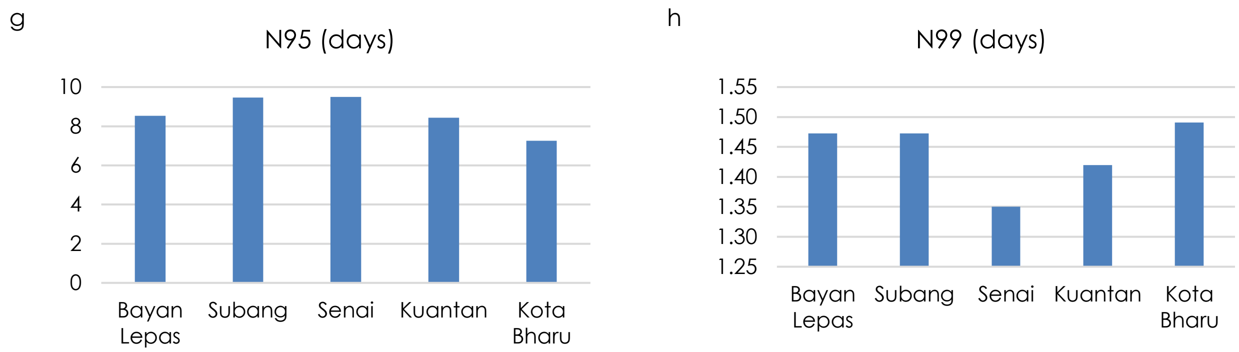


Figure 2 (a) Average total annual rainfall and mean average extreme rainfall indices of Bayan Lepas, Subang, Senai, Kuantan and Kota Bharu (b) XRS (c) I95 (d) I99 (e) R95 (f) R99 (g) N95 and (h) N99

Table 3 Mann-Kendall test results for extreme rainfall indices

Station	XRS		I95		I99		R95		R99		N95		N99	
	Z	MK	Z	MK	Z	MK	Z	MK	Z	MK	Z	MK	Z	MK
Bayan Lepas	-0.44	DT	0.07	UT	0.04	UT	1.71+	UT	1.10	UT	0.26	UT	-0.49	DT
Subang	2.93**	UT	1.77+	UT	1.32	UT	-0.80	DT	-1.28	DT	2.43*	UT	1.18	UT
Senai	-0.36	DT	2.13*	UT	1.50	UT	0.24	UT	0.90	UT	2.13*	UT	2.83**	UT
Kuantan	1.27	UT	0.92	UT	0.84	UT	0.23	UT	0.57	UT	1.07	UT	0.90	UT
Kota Bharu	-0.25	DT	-0.22	DT	-0.28	DT	0.13	UT	-0.33	DT	-0.10	DT	0.34	UT

UT is upward trend; DT is downward trend; *trend at α=0.05 level of significance; **trend at α=0.01 level of significance; +trend at α=0.1 level of significance

4.0 CONCLUSIONS

The east coast states received more rainfall than any other parts in Peninsular Malaysia. However, the number of rainy days at Kuantan and Kota Bharu are lesser than other study areas. These findings concluded that the magnitude of extreme rainfalls are more severe in the east coast part of Peninsular Malaysia.

The analyses of extreme rainfall indices indicate that the stations in the eastern part of Peninsular Malaysia experienced higher cumulative total of rainfall (XRS), extreme intensity (I95 and I99) and percentage of the total annual rainfall equal or exceeding 95th and 99th percentile (R95 and R99) as compared to the stations located in the western and northern part of Peninsular Malaysia. In addition, for the highest number of days for wet and very wet (N95), Subang and Senai show the highest amount compared to other stations. Other than that, all stations except for Kota Bharu show increasing trends for most of the extreme rainfall indices. Upward trends indicate that the extreme rainfall events were becoming more severe over the period of 1960 to 2014.

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