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ANALYSIS OF TRENDS OF EXTREME RAINFALL EVENTS USING MANN KENDALL TEST: A CASE STUDY IN PAHANG AND KELANTAN RIVER BASINS

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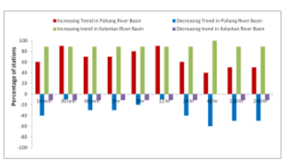
Graphical abstract



Abstract

Climate change leads to changes in rainfall and extreme event. This phenomenon has already begun to transform the rainfall patterns in Malaysia. It was clearly proven when the northern and eastern states of Peninsular Malaysia such as Kelantan, Terengganu, Pahang, Perak and Johor were hit by the catastrophic floods in December 2014, events that have been described as the worst in decades. Although there are a number of studies in climate change and extreme rainfall events in Malaysia, there are still large knowledge gaps about their relationship. Understanding the shifts and predicting changing trends in rainfall distribution is needed for predicting and managing the floods. In this paper, Mann Kendall (MK) test and Sen's Slope estimator are employed to determine the trend of extreme rainfall events of various storm durations in the Pahang and Kelantan river basins. The results indicate that annual maximum daily rainfall for Pahang River basin and Kelantan River basin increased throughout 45 years. Results show that the percentage of stations with statistically significant trend (at 0.05 significance level) in the Kelantan River basin are higher compared to the Pahang River basin. Percentage of stations showing increasing trends were much higher for short duration rainfall (10, 30 and 60 minutes and 3 hours) compared to long duration rainfall (6, 12, 24, 48, 120 and 240 hours). This study will be useful for planning, designing and managing floods and stormwater systems in this area.

Keywords: Extreme rainfall; December 2014 flooding; trend analysis; mann kendall test; sen's slope

Abstrak

Perubahan iklim membawa kepada perubahan hujan dan peristiwa hujan yang melampau. Fenomena ini mula mengubah corak taburan hujan di Malaysia. Ia jelas terbukti apabila Kelantan, Terengganu, Pahang, Perak dan Johor di Semenanjung Malaysia telah dilanda bencana banjir pada Disember 2014, peristiwa yang digambarkan sebagai yang paling teruk dalam beberapa dekad. Walaupun terdapat beberapa kajian dalam perubahan iklim dan peristiwa melampau di Malaysia, masih terdapat jurang pengetahuan yang besar mengenai hubungan ini. Memahami perubahan dan meramalkan perubahan trend dalam taburan hujan diperlukan untuk peramalan dan pengurusan banjir. Dalam kertas ini, Ujian Mann Kendall (MK) dan Slope Sen Estimator digunakan untuk menentukan trend peristiwa hujan melampau pelbagai jangka masa ribut di lembangan sungai Pahang dan Kelantan. Keputusan menunjukkan bahawa hujan tahunan maksimum di lembangan Sungai Pahang dan lembangan Sungai Kelantan meningkat sepanjang 45 tahun. Keputusan menunjukkan bahawa peratusan stesen dengan trend statistik yang signifikan (pada aras keyakinan 0.05) di lembangan Sungai Kelantan adalah lebih tinggi berbanding dengan lembangan Sungai Pahang. Peratusan stesen yang menunjukkan peningkatan trend adalah lebih tinggi untuk tempoh ribut hujan yang singkat (10, 30 dan 60 minit and 3 jam) berbanding tempoh ribut hujan yang panjang (6, 12, 24, 48, 120 dan 240 jam). Kajian ini akan berguna untuk merancang, merekabentuk dan menguruskan banjir dan sistem air ribut di kawasan ini.

Kata kunci: Hujan melampau; banjir Disember 2014; analisa trend; ujian mann kendall; sen's slope

1.0 INTRODUCTION

Climate change can severely impact on hydrological processes, including an increase in rainfall, particularly during extreme events. A report from the International Governmental Panel on Climate Change (IPCC) concluded that climate change leads to changes in rainfall and extreme event [1]. Dore [2] expresses for areas with a mean total rainfall increase, heavy and extreme rainfall events also increase with a large percentage. Loo *et al.* [3] also establish the link between global warming and monsoon rainfall in Southeast Asia. They proved that the distribution of monsoon rainfall is influenced by a number of weather systems such as Arctic Oscillation as complex as Asian topography.

Climate change has already begun to transform the rainfall patterns in Malaysia and extreme floods have become more severe in several states. In 2014, heavy rains since 17 December to 23 December caused catastrophic flooding in the east coast states of Peninsular Malaysia [4,5]. Reports showed that this tragedy is related to climate change. Changing trends in rainfall distribution also give an effect in hydrological analysis related to historical rainfall record. The design of stormwater infrastructure is based on characteristics of a design rainfall driven by a time series of rainfall data. Othman *et al.* [6] used historical rainfall data to identify rainfall depth for sizing and designing stormwater quality control facilities. They found that The East Coast area gives a value of rainfall depth in the range of 20 - 100 mm. Given that East Coast area in Peninsular Malaysia received heavy rainfall due to the impact of North East Monsoon, the probability of extreme rainfall occurrence is higher with the rainfall depth exceeding 100 mm. For this reason, the value of design rainfall depth should take into account the extreme rainfall event to meet the needs of planning, designing and managing stormwater systems in this area.

Extreme rainfall events in Malaysia are becoming more frequent in recent years. It reveals that heavy rain events on the east coast of Peninsular Malaysia have increased over 40 years [7]. Various models also projected that rainfall will continue to increase, which will cause an increase of heavy rainfall events in the East Coast of Peninsular Malaysia [8]. Increased rainfall and extreme rainfall events can increase the frequency of flood events. There are a number of studies in extreme rainfall event over Malaysia but there are still large knowledge gaps with regard to extreme rainfall events [9].

Many researchers in Malaysia use a statistical approach to their study related to investigating changes in intensity and frequency of extreme rainfall events [10, 11] . Syafarina *et al.* [11] used non-parametric test to analyze rainfall trends and found that hourly extreme rainfall events in Peninsular Malaysia showed an increasing trend with notable increasing trends in short temporal rainfall. Since these studies did not provide analysis of extreme rainfall event trend in short storm duration, detailed study on this is needed. Therefore, the main objectives of this paper are (a) to investigate changes in the annual maximum rainfall depth of 24 h duration over Pahang and Kelantan river basins, and (b) to investigate the trend of extreme rainfall events in various storm durations by using Mann Kendall (MK) test and Sen's Slope Estimator.

2.0 STUDY AREA AND METHODOLOGY

The Pahang River basin is located in the eastern part of Peninsular Malaysia between latitudes N 2° 48' 45'' and N 3° 40' 24'' and between longitudes E 101° 16' 31'' and E 103° 29' 34''. The maximum length and breadth of the catchment are 205 km and 236 km respectively. The Kelantan River basin is located in the north eastern part of Peninsular Malaysia between latitudes 4° 40' and 6° 12' North, and longitudes 101° 20' and 102° 20' East whereas the maximum length and breadth of the catchment are 150 km and 140 km respectively. There are a total of 19 rainfall stations from both Pahang River basin and Kelantan River basin which were examined in this study. All rainfall data are obtained from Water Resources Management and Hydrology Division, Department of Irrigation and Drainage (DID) for a period of more than 27 years. Table 1 presents geographic coordinates and periods of data for all rainfall stations and locations of the stations are shown in Figure 1. To ensure the quality control of data sets, homogeneity test was applied to rainfall time series in order to detect breaks. Stations that were identified inhomogeneous were excluded.

Table 1 Geographic coordinates and period of data for rainfall stations

Basin	Station ID	Station Name	Latitude	Longitude	Data Period
Pahang River	3026156	Pos Iskandar	03° 01' 40'N	102° 39' 30'N	1970 - 2014
	3121143	Simpang Pelangai	03° 10' 30'N	102° 11' 50'N	1975 - 2014
	3424081	JPS Temerloh	03° 26' 20'N	102° 25' 35'N	1970 - 2014
	3533102	Rumah Pam Pahang Tua	03° 33' 40'N	103° 21' 25'N	1970 - 2014
	3628001	Pintu Kawalan P/ Kertam	03° 38' 00'N	102° 51' 20'N	1975 - 2014
	3924072	Rumah Pam Paya Kangsar	03° 54' 15'N	102° 26' 00'N	1970 - 2014
	4023001	Kg Sungai Yap	04° 01' 55'N	102° 19' 30'N	1973 - 2014
	4219001	Bukit Betong	04° 14' 00'N	101° 56' 25'N	1974 - 2014
	4223115	Kg Merting	04° 14' 35'N	102° 23' 00'N	1970 - 2014
	4513033	Gunong Brinchang	04° 31' 00'N	101° 23' 00'N	1975 - 2014
Kelantan River	4614001	Brook	04° 40' 35'N	101° 29' 05'N	1982 - 2014
	4819027	Gua Musang	04° 52' 45'N	101° 58' 10'N	1971 - 2014
	4915001	Chabai	05° 00' 00'N	101° 34' 45'N	1988 - 2014
	4923001	Kg. Aring	04° 56' 15'N	102° 21' 10'N	1974 - 2014
	5120025	Balai Polis Bertam	05° 08' 45'N	102° 02' 55'N	1970 - 2014
	5320038	Dabong	05° 22' 40'N	102° 00' 55'N	1971 - 2014
	5322044	Kg. Laloh	05° 18' 30'N	102° 16' 30'N	1971 - 2014
	5522047	SM teknik	05° 31' 55'N	102° 12' 10'N	1970 - 2014
	5718033	Kg. Jeli	05° 42' 05'N	101° 50' 20'N	1971 - 2014

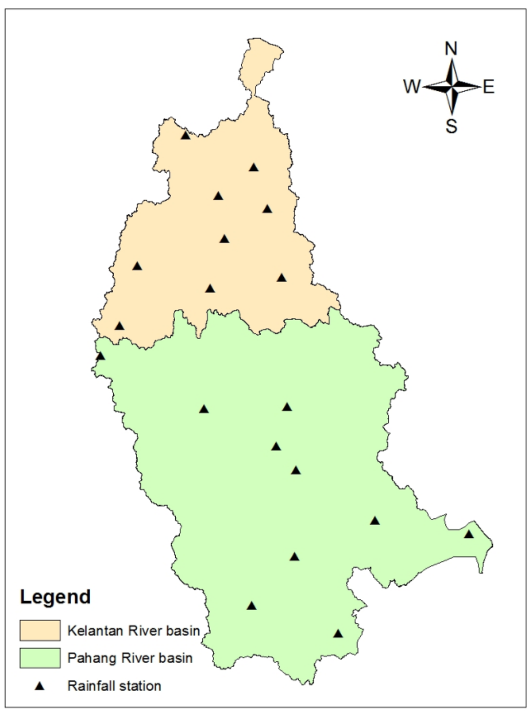


Figure 1 Location of rainfall stations

Extreme rainfall is defined as annual daily maximum rainfall, which is a well-known definition for block-maxima method [12]. The extreme rainfall may not be well captured by using only annual maximum daily rainfall. It is mostly because of extreme rainfall in short duration that potentially leads to an increase in the magnitude and frequency of flash floods in urban areas. Furthermore, extreme rainfall events in Malaysia frequently extend over two days due to the influence of monsoon seasons. Therefore, in addition to the annual maximum daily rainfall, extreme rainfall of ten storm durations (i.e. 10, 30 and 60 minutes, 3, 6, 12, 24, 48, 120 and 240 hours) obtained from Time Dependent Data (TIDEDA) software package were studied in this research. Software used for performing the statistical MK Test and homogeneity test is Addinsoft's XLSTAT 2016. The null hypothesis is tested at 95% confidence level.

MK test is a statistical test widely used to assess the trend in hydrological time series. This test is a non parametric test; therefore, data outliers do not affect the result. The test statistic of MK test, S, is computed as follows:

$$S = \sum_{k=1}^{n-1}\left[\sum_{j=k+1}^{n} sign\left(x_j - x_k\right)\right] \quad (1)$$

$$sign\left(x_j - x_k\right) = \begin{cases} 1, & x_j - x_k > 0 \\ 0, & x_j - x_k = 0 \\ -1, & x_j - x_k < 0 \end{cases} \quad (2)$$

Where x_j and x_k are the sequential data values, n is the number of observations.

In the MK test, the positive test statistic, S indicates increasing trend, whereas the negative test statistic indicates decreasing trends.

The variance for the S statistic is defined by:

$$Var(S) = \frac{n(n-1)(2n+5)}{18} \quad (3)$$

The standardized Z statistic is calculated as follows:

$$z = \begin{cases} \dfrac{S-1}{Var(s)}, S > 0 \\ 0, S = 0 \\ \dfrac{S+1}{Var(S)}, S < 0 \end{cases} \quad (4)$$

The test statistic Z is used to measure the significance of the trends. In fact, the null hypothesis H_o of the MK test assume that there is no trend and is tested against the alternative hypothesis H_1 which assumes that there is a trend [13]. If the calculated z statistic is larger than the critical value at the chosen significance levels, then the null hypothesis is invalid implying the alternative hypothesis which is " there is a trend" is accepted [14]. The magnitude of the trend (β) was calculated using the Sen's slope approach. Sen's non-parametric method estimates the magnitude of the trends in the time series data:

$$T_i = \frac{x_j - x_k}{j - k} \quad (5)$$

In this equation, x_j and x_k correspond to data values at time *j* and *k*. Consider

$$Q_i = \begin{cases} T_{\frac{N+1}{2}} \\ \dfrac{1}{2}\left(T_{N/2} + T_{N+2/2}\right) \end{cases} \quad (6$$

A positive value represents an increasing trend and a negative value represents a decreasing trend over time.

3.0 RESULTS AND DISCUSSION

3.1 Changes In Annual Maximum Daily Rainfall

A series of graphs showing the annual maximum daily rainfall throughout Pahang and Kelantan river basins between 1970 and 2014 are shown in Figure 2. Fitting trend lines show positive magnitude in slope for both river basins, but Kelantan River basin recorded a higher magnitude compared to the Pahang River basin. Highest maximum rainfall in Pahang river basin occurred in the year 1988 with a rainfall depth of 158.80 mm compared to 66.01 mm for the lowest in the year 1974. Kelantan river basin recorded 229.64 mm for the highest in the year of 2014 and 76.78 mm in the year 1989 for the lowest. Based on the graphs, there is a clear upward trend in annual maximum daily rainfall for both the Pahang and Kelantan river basins. As a result of increasing of annual maximum daily rainfall, flood risk also will increase in this area. Pahang and Kelantan received heavy rainfalls during North East Monsoon season and increasing intensities of rainfall during monsoon are not only a source of major flooding, but will also trigger major landslide events. This is because rainfall with high intensities have greater likelihoods of increase in soil loss and sediment movements [15].

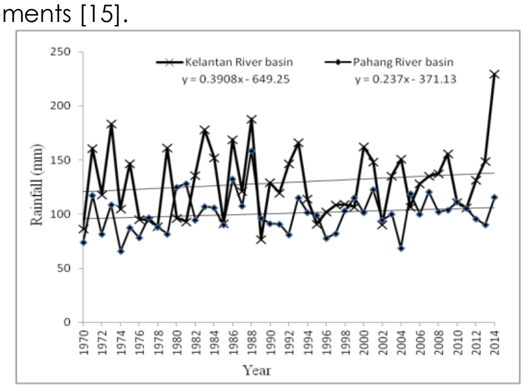


Figure 2 Annual maximum daily rainfall

Table 2 Trend Analysis results

River Basin	Station ID	Short Duration												Long Duration							
		10 min		30 min		60 min		3 hour		6 hour		12 hour		24 hour		48 hour		120 hour		240 hour	
		S	β	S	β	S	β	S	β	S	β	S	β	S	β	S	B	S	β	S	β
	3026156	183	0.13	187	0.24	111	0.24	149	0.41	47	0.11	63	0.13	13	0.03	-50	-0.16	-68	-0.34	-65	-0.41
	3121143	-7	-0.01	95	0.13	-4	-0.01	120	0.28	84	0.26	54	0.14	-33	-0.07	-120	-0.50	-64	-0.37	14	0.11
	3424081	87	0.06	43	0.05	71	0.12	-22	-0.08	83	0.25	114	0.26	-71	-0.16	-10	-0.03	-110	-0.49	-53	-0.30
	3533102	172	0.15	136	0.19	117	0.26	213	0.60	179	0.85	187	1.11	163	1.56	152	1.92	155	2.49	193	4.30
Pahang	3628001	-14	-0.04	104	0.22	119	0.25	35	0.15	52	0.22	84	0.43	79	0.45	50	0.32	23	0.18	-33	-0.42
	3924072	61	0.05	23	0.05	3	0.00	84	0.25	52	0.18	12	0.02	-21	-0.06	-9	-0.03	-58	-0.16	81	0.37
	4023001	-25	-0.01	143	0.19	-5	-0.01	-67	-0.15	-95	-0.33	-105	-0.34	-99	-0.34	-152	-0.54	-116	-0.63	-6	-0.03
	4219001	-5	0.00	-27	-0.04	-37	-0.10	- 65	-0.14	-27	-0.08	-41	-0.11	-41	-0.17	-35	-0.15	11	0.06	-14	-0.06
	4223115	220	0.19	**323***	0.39	**255***	0.42	121	0.32	148	0.48	180	0.64	**228***	0.73	203	0.75	**240***	1.31	**248***	1.83
	4513033	7	0.00	11	0.03	29	0.06	27	0.05	61	0.16	28	0.05	40	0.11	14	0.11	9	0.10	70	0.56
	4614001	**181***	0.22	**168***	0.41	**140***	0.52	**71***	0.37	34	0.16	**79***	0.41	51	0.34	7	0.07	**81***	0.98	**62***	0.99
	4819027	**122***	0.09	78	0.09	**67***	0.11	**72***	0.16	**79***	0.17	44	0.10	-54	-0.20	34	0.09	-17	-0.04	-17	-0.08
	4915001	**87***	0.25	**114***	0.45	42	0.28	**105***	0.75	**71***	0.93	**58***	0.80	**67***	1.21	**47***	0.69	**47***	1.14	8	0.38
	4923001	**134***	0.13	**127***	0.18	53	0.11	**103***	0.32	0	0.00	29	0.15	27	0.16	**145***	1.54	**154***	2.29	**113***	2.36
Kelantan	5120025	**137***	0.11	**124***	0.18	117	0.20	118	0.30	90	0.25	59	0.18	66	0.25	**100***	0.54	**152***	0.96	**176***	1.94
	5320038	106	0.08	72	0.14	**99***	0.28	54	0.12	71	0.16	59	0.23	4	0.02	5	0.07	53	0.47	36	0.56
	5322044	**71***	0.04	78	0.08	29	0.03	26	0.05	**129***	0.29	**105***	0.39	**140***	0.84	**116***	0.88	**132***	1.36	60	0.68
	5522047	**209***	0.15	**144***	0.22	**214***	0.37	**131***	0.45	90	0.40	91	0.74	**119***	0.96	**96***	1.29	**122***	2.81	**172***	3.65
	5718033	-97	-0.06	**-179***	- 0.21	**-122***	-0.26	**-131***	-0.30	**-134***	-0.38	-61	-0.21	1	0.02	**91***	1.03	**93***	1.72	54	1.07

Statistically significant trend was written with bold characters and * (superscripts) correspond to a p value < alpha = 0.05

3.2 Trends Of Extreme Rainfall In Various Durations

In this study, storm durations were classified into two groups: (i) as a short storm duration for duration less than or equal to 3 hours; and (ii) as a long storm duration for a duration equal to or greater than 6 hours. Value of MK test statistic, S and the slope (β) correspond to the Sen's slope estimator were summarized in Table 2. The positive value of S indicates an increasing trend while a negative value indicates a decreasing trend in rainfall. As can be seen, mostly increasing trend were detected in the Pahang River basin while the Kelantan River basin recorded increasing trend in every rainfall station for every storm durations except at rainfall station ID 4819027 and 5718033. Both river basins show apparent differences in terms of percentage of stations indicated statistically a significant trend (in 0.05 significant levels). The results of the trend tests were summarized in Table 3. From hypothesis testing, percentage of stations showing increasing trends were more higher in short storm duration compared to long storm duration. Seventy percent (70%) of rainfall stations in Pahang River basin showing increasing trends in short storm duration, however only ten percent (10%) demonstrating statistically significant trend. None of the stations showed statistically significant decreasing trends. In the Kelantan River basin, statistically significant increasing trends were more noticeable. Sixty-seven percent (67%) of all stations in particular for short and long storm duration indicated statistically significant increasing trends whereas statistically significant decreasing trends were detected only about eleven percent (11%) in short storm duration. Twenty-two percent (22%) of the stations show an increasing trend in short and long storm duration but in insignificant trends.

Results of both statistical tests, MK and Sen's slope estimator were consistent with each other. Table 2 also demonstrates the Sen's Slope, which is also indicating slope magnitude for each storm durations. The Sen's Slope depicts either increasing or decreasing trend and the result is significant with MK trend analysis. As an MK test statistic, S has shown negative trend, similar negative slope has been observed for the Sen's Slope and vice versa.

Table 3 Results of a percentage of the stations showing trends on the trend test

River Basin	Storm Duration	Significant Trends(%)		Insignificant Trends (%)	
		a	b	a	b
Pahang	Short	10	0	60	30
	Long	10	0	30	60
Kelantan	Short	67	11	22	0
	Long	67	0	22	11

a = increasing b = decreasing

Figure 3 shows the percentage of the stations demonstrating decreasing and increasing trends for every storm durations. In the Pahang River basin, the percentage of stations showing increasing trends are much higher for short storm duration, including 6, 12 and 24 hours during long storm duration. On average, sixty-six percent (66%) of all stations showed an increasing rainfall trend and thirty-four percent (34%) showed a decreasing trend. More than fifty percent (50%) of all stations showed an increasing trend in short storm duration. For the Kelantan River basin, eighty - nine percent (89%) of all stations show an increasing trend for all storm durations and hundred percent (100%) of all stations indicated an increasing trend in 48 hour storm duration. On the other hand, only eleven percent (11%) of rainfall stations showed a decreasing trend.

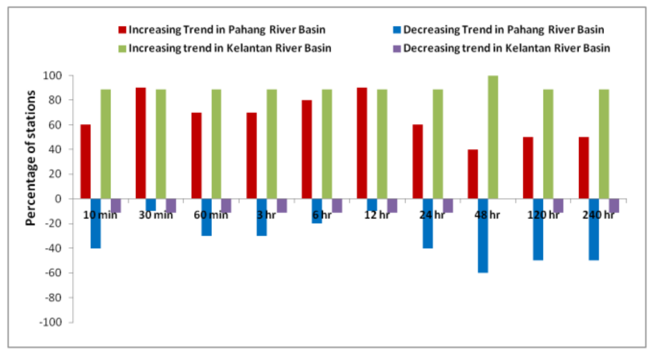


Figure 3 Percentage of stations showing increasing or decreasing trends

4.0 CONCLUSION

This study focused on the investigation of changes and trends of extreme rainfall events in various storm durations by using statistical approach in two river basins: Pahang River basin and Kelantan River basin. The MK test and Sen's Slope Estimator test gave interesting insights about trends of extreme rainfalls in the study area. The major findings and conclusions of this study are as follows:

- Annual maximum daily rainfall in Pahang River basin and Kelantan River basin increase throughout 45 years. Increasing of annual maximum daily rainfall will increase flood risk and indirectly decrease the water quality related to sediment movement. Increasing intensities of rainfall will also lead on increase in soil loss and major landslide events.
- The percentage of stations indicated a statistically significant trend (in 0.05 significant level) in The Kelantan River basin is higher compared to The Pahang River basin. Furthermore, The Kelantan River basin showing increasing trends for all storm durations. Therefore, this study offers a new perspective for engineers and planners in both areas to make decision in planning, designing and managing floods and stormwater systems.

- The percentage of stations showing increasing trends were much higher for short storm durations compared to long storm durations especially in Pahang River basin. It should be noted that the increasing trend in short storm duration rainfall gives an impact on urban drainage and stormwater facilities.

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