TRGS/1/2015/USM/01/1

BORANG TRGS BANJIR - P2(PROGRAM)

YEAR	2015

KEMENTERIAN PENDIDIKAN MALAYSIA

FINAL REPORT
GERAN PENYELIDIKAN PENGURUSAN BENCANA BANJIR
Laporan Akhir Skim Geran Penyelidikan Transdisiplinari (TRGS)

Tahun 2015

A. PROGRAM INFORMATION

YEAR: 2015/2016

RESEARCH TITLE: Integrated assessment of extreme rainfall-runoff on flood hazard, water quality and microbial variability, and enhancement of standard operating procedures (SOP) for flood disaster awareness: Case study of Sungai Pahang River Basin

THEME CODE: 1.0 **SUBTHEME CODE: 1.3**

(Please refer attachment)

Please Tick (√)

PHASE:	01: Pre-Disaster	√	02: During Disaster	√	03: Post-Disaster	√
AREA:	01: Preventive	√	02: Preparedness	√	03: Rescue anf Recovery	√
	04:Adaptation		05: Mitigation	√		

THEME: Holistic solution to flood disaster based on Integrated River Basin Management
SUB THEME: Flood and flood disaster

RECEIVED 14 JUN 2016 RCMO USM

START DATE: 1/4/2015
END DATE (EXPECTED): 30/4/2016

PROJECT STATUS: (ACTIVE / TERMINATED / COMPLETED)

PROGRAM LEADER: Prof. Dr. Nor Azazi Zakaria
I/C NUMBER: 630411-03-5045

B. PROGRAM ACHIEVEMENT

ACHIEVEMENT PERCENTAGE				
Program progress according to milestones achieved up to this period	0 - 25%	26 - 50%	51 - 75%	76 - 100%
Percentage (please state #%)				100%
RESEARCH OUTPUT				

Number of articles/ manuscripts/ books *(Please attach the First Page of Publication)*	**Indexed Journal**	**Non-Indexed Journal**
	6, 1 submitted, 1 drafted manuscript	
Conference Proceeding *(Please attach the First Page of Publication)*	**International**	**National**
	7	4
Intellectual Property *(Please specify)*	1 Book & 1 Book Chapter	
Number and title of Policy Paper / SOP / Technology Solution *(Please specify)*	1. 2. 3.	

HUMAN CAPITAL DEVELOPMENT					
Human Capital	**Number**				**Others** (please specify)
	On-going		**Graduated**		
Citizen	Malaysian	Non Malaysian	Malaysian	Non Malaysian	
No. PHD STUDENT	4				
No. MASTER STUDENT	2				
No. RA/RO	4		1		
Total	10		1		

C. EXPENDITURE

Budget Approved *(Peruntukan diluluskan)* : **RM 660,360.00**
Amount Spent *(Jumlah Perbelanjaan)* : **RM 655,647.23**

Balance *(Baki)* : **RM 4,712.76**
Percentage of Amount Spent *(Peratusan Belanja)* : **99.29 %**

Date *Tarikh* : **10/6/2016**

Project Leader's Signature: *Tandatangan Ketua Projek*

F. COMMENTS, IF ANY/ ENDORSEMENT BY RESEARCH MANAGEMENT CENTER (RMC)
(Komen dan Pengesahan oleh Pusat Pengurusan Penyelidikan)

....

....

....

Name:
Nama:

Signature:
Tandatangan:

30/12/10

Date:
Tarikh:

PROF. DR LEE KEAT TEONG
Pejabat Pengurusan dan Kreativiti Penyelidikan
Universiti Sains Malaysia

BORANG TRGS BANJIR - P4 (PROJECT 4)

YEAR	2015

KEMENTERIAN PENDIDIKAN MALAYSIA

FINAL REPORT
GERAN PENYELIDIKAN PENGURUSAN BENCANA BANJIR
Laporan Akhir Skim Geran Penyelidikan Transdisiplinari (TRGS)
Tahun 2015

A. PROJECT INFORMATION

YEAR: 2015/2016

RESEARCH TITLE: RAINFALL DISTRIBUTION IN 5 STATES SINCE 1967 FLOOD UNTIL 2014 FLOOD: DETECTING THE CLIMATE CHANGE EFFECT

THEME CODE:1.0 **SUBTHEME CODE: 1.1**
(Please refer attachment)

Please Tick (√)

PHASE:	**01: Pre-Disaster**	√	**02: During Disaster**		**03: Post-Disaster**	
AREA:	**01: Preventive**	√	**02: Preparedness**		**03: Rescue anf Recovery**	
	04:Adaptation		**05: Mitigation**			

START DATE: 1/4/2015
END DATE (EXPECTED): 30/4/2016

PROJECT STATUS: (~~ACTIVE / TERMINATED~~ / COMPLETED)

PROJECT LEADER: Prof. Dr. Nor Azazi Zakaria
I/C / PASSPORT NUMBER: 630411-03-5045

PROJECT MEMBERS : (including GRA/RA/RO)
1. Prof. Dr. Aminuddin Ab Ghani
2. Dr. Lee Lai Kuan
3. Dr. Lau Tze Liang
4. Chang Chun Kiat
5. Mohamad Afizi Jamadin (RA)

B. PROJECT ACHIEVEMENT *(Prestasi Projek)*

ACHIEVEMENT PERCENTAGE				
Project progress according to milestones achieved up to this period	**0 - 25%**	**26 - 50%**	**51 - 75%**	**76 - 100%**
Percentage (please state #%)				**100**

RESEARCH OUTPUT		
Number of articles/ manuscripts/ books *(Please attach the First Page of Publication)*	**Indexed Journal**	**Non-Indexed Journal**
	2	

Conference Proceeding *(Please attach the First Page of Publication)*	**International**	**National**
		1
Intellectual Property *(Please specify)*	-	
Number and title of Policy Paper / SOP / Technology Solution *(Please specify)*	-	

HUMAN CAPITAL DEVELOPMENT					
Human Capital	**Number**				**Others** (please specify)
	On-going		**Graduated**		
Citizen	Malaysian	Non Malaysian	Malaysian	Non Malaysian	
No. PHD STUDENT	1				
Student Fullname: IC / Passport No: Student ID: Date of appointment:	Mazlina Alang Othman 761015-08-6246 S P-RED0001/13(R) 01-09-2013				
No. MASTER STUDENT					
Student Fullname: IC / Passport No: Student ID: Date of appointment:					
No. RA/RO	1				
Student Fullname: IC / Passport No: Student ID: Date of appointment:	Mohamad Afizi Jamadin 850804-10-5969 - 01-06-2015				
Total	2				

C. EXPENDITURE *(Perbelanjaan) as Borang K1(RMC)*

Budget Approved *(Peruntukan diluluskan)*	:	**RM 133,100.00**
Amount Spent *(Jumlah Perbelanjaan)*	:	**RM 132,910.88**
Balance *(Baki)*	:	**RM 189.12**
Percentage of Amount Spent *(Peratusan Belanja)*	:	**99.86 %**

D. SUMMARY OF RESEARCH FINDINGS *(Ringkasan Penemuan Projek Penyelidikan)*
Important findings of the current study are summarized as follows: **1. Annual maximum daily rainfall in Perak, Kelantan, Terengganu and Pahang River basin increase throughout 45 years, meanwhile decreasing trend were detected in Johor river basin. 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 to increases in soil loss and major landslide events.** **2. Percentage of stations showing significant increasing trends were more higher in short storm duration for Perak, Pahang and Johor river basin. However, Kelantan and Terengganu river basins show higher percentages in significant increasing trends for long storm durations. It should be noted that the increasing trend in short storm duration rainfall gives an impact on urban drainage and stormwater facilities. Studies dealing with extreme rainfall in urban areas in Malaysia is still rather limited, and detailed studies related to extreme rainfall in short storm durations should be taken into consideration in the future.**
E. PROBLEMS / CONSTRAINTS IF ANY *(Masalah/ Kekangan sekiranya ada)*
The duration of the project was too short. Another field work study during the flood events for data verification is suggested.
Date : **10/6/2016** *Tarikh* **Project Leader's Signature:** *Tandatangan Ketua Projek*
F. COMMENTS, IF ANY/ ENDORSEMENT BY RESEARCH MANAGEMENT CENTER (RMC) *(Komen dan Pengesahan oleh Pusat Pengurusan Penyelidikan)*
.... **Name:** *Nama:* **Signature:** *Tandatangan:* PROF. DR LEE KEAT TEONG Pejabat ... Penyelidikan Universiti Sains Malaysia **Date:** 20/6/16 *Tarikh:*

Jurnal
Teknologi

Full Paper

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

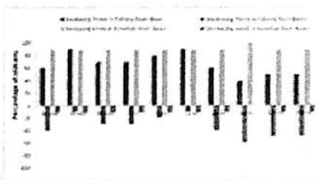
Mazlina Alang Othman[a]*, Nor Azazi Zakaria[b], Aminuddin Ab. Ghani[c], Chun Kiat Chang[d] and Ngai Weng Chan[e]

[a,b,c,d]River Engineering and Urban Drainage Research Centre (REDAC), Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Malaysia
[e]School of Humanities, Universiti Sains Malaysia, 11800 Penang, Malaysia

Article history
Received
7 March 2016
Received in revised form
xx
Accepted
xx

*Corresponding author
emona1510@gmail.com

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). The findings of the 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). Hasil 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

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

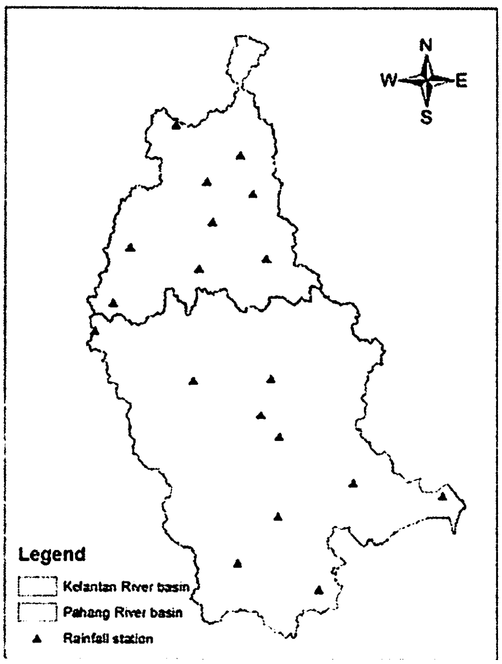


Figure 1 Location of rainfall stations

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:

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

(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:

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

(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_0 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:

$$T_i=\frac{x_j-x_k}{j-k}$$

(5)

(5)

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

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

(6)

(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].

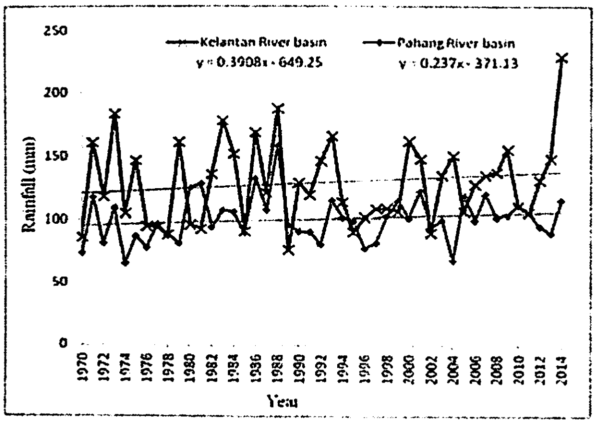


Figure 2 Annual maximum daily rainfall

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
Pahang	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
	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
Kelantan	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
	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	Duration	Statistically Significant Trends		Insignificant Trends	
		a	b	a	b
Pahang	Short storm	10	0	60	30
	Long storm	10	0	30	60
Kelantan	Short storm	67	11	22	0
	Long storm	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.

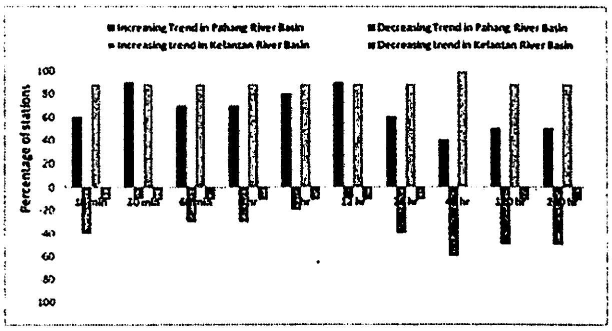


Figure 3 Percentage of stations showing increasing or decreasing trends

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.

Acknowledgement

The authors would like to acknowledge the financial assistance from the Ministry of Higher Education Malaysia under the TRGS 2015 Flood Management Grant No. 203/REDAC/6767003 entitled "Model-Based Morphological Prediction for Large Scale River Basin in Raising Flood Protection Levels for Sungai Pahang". Special thanks also to Water Resources Management and Hydrology Division, Department of Irrigation and Drainage, Malaysia for providing the historical rainfall data for this study.

References

[1] Climate change 2014 synthesis report summary for policymakers. Web. <https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf> (Accessed 27 Feb 2016).

[2] Dore, M.H. 2005. Climate change and changes in global precipitation patterns: what do we know?. *Environment International*. 31(8): 1167-1181.

[3] Loo, Y.Y., Billa, L. and Singh, A. 2015. Effect of climate change on seasonal monsoon in Asia and its impact on the variability of monsoon rainfall in Southeast Asia. *Geoscience Frontiers*. 6(6): 817-823.

[4] Ismail. M. G., Chan, N.W., Zakaria, N.A. and Ab. Ghani, A. 2015. A review of standard operating procedures (SOP) used in flood relief operations during the December 2014 flood in Pahang. Proseedings Transformasi Sosial 2015. Fakulti Kemanusiaan, Seni & Warisan Universiti Malaysia Sabah, 18-27.

[5] Chan, N.W., Samat, N., Lai, K. L. and Ab. Ghani, A. 2015. Role of Citizen Science in Responding to Flood Disasters: A Case Study from Malaysia. *International Conference on "Towards Urban water Security in Southeast Asia: managing the Risks of Extreme Events"*. Phnom Penh, Asian Institute of Technology, 227-238.

[6] Othman, M.A., Ab. Ghani, A., Foo, K.Y. and Chang, C.K. 2015. Effect of Minimum Inter Event Time on Water Quality Capture Volume. *E-proceedings of the 36th IAHR World Congress* 28 June – 3 July, 2015, The Hague, the Netherlands.

[7] Mayowa, O.O., Pour, S.H., Shahid, S., Mohsenipour, M., Harun, S.B., Heryansyah, A. and Ismail, T., 2015. Trends in rainfall and rainfall-related extremes in the east coast of peninsular Malaysia. *Journal of Earth System Science*, 124(8):1609-1622.

[8] NAHRIM. 2006. *Final report: Study of the impact of climate change on the hydrologic regime and water resources of peninsular Malaysia.*

[9] Tangang, F., Liew, J.N., Salimun, E., Sei, K.M., Le, L.J. and Muhamad, H. 2012. Climate change and variability over Malaysia. *Sains Malaysiana*. 41(11): 1355-1366.

[10] Suhaila, J., Deni, S.M., Zin, W.W. and Jemain, A.A. 2010. Trends in peninsular Malaysia rainfall data during the southwest monsoon and northeast monsoon seasons: 1975–2004. *Sains Malaysiana*. 39(4): 533-542.

[11] Syafrina, A.H., Zalina, M.D. and Juneng, L. 2015. Historical trend of hourly extreme rainfall in Peninsular Malaysia. *Theoretical and Applied Climatology*. 120(1-2): 259-285.

[12] Gumbel, E.J., 1958 .*Statistics of Extremes*. Columbia University Press, New York.

[13] Önöz, B. and Bayazit, M. 2003. The power of statistical tests for trend detection. *Turkish Journal of Engineering and Environmental Sciences*. 27(4): 247-251.

[14] Yilmaz, A.G. and Perera, B.J.C. 2013. Extreme rainfall nonstationarity investigation and intensity-frequency-duration relationship. *Journal of Hydrologic Engineering*. 19(6): 1160-1172.

[15] Römkens, M.J., Helming, K. and Prasad, S.N. 2002. Soil erosion under different rainfall intensities, surface roughness, and soil water regimes. *Catena*. 46(2):103-123..

Jurnal
Teknologi

Full paper

Trend Analysis in Extreme Rainfall in Various Storm Duration : A Case Study in Perak River Basin and Pahang River Basin.

M.A.Othman,[a,*] N.A. Zakaria,[a] A. Ab Ghani,[b] C.K. Chang[c]

[a, b,c,d] *River Engineering and Urban Drainage Research Centre (REDAC), Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Malaysia*

*Corresponding author: emona1510@gmail.com

Article history

Received XXXX
Received in revised form XXXX
Accepted XXXX

Graphical abstract

Abstract

Climate change gives impact on extreme hydrological events especially in extreme rainfall. A study on intensity and frequency of extreme rainfall events is essential in helping decision makers to take proactive measures in the context of climate change. Mann Kendall (MK) test was used in this study to investigate the trend of extreme rainfall events in various storm duration. The results indicates the percentage of stations showing increasing trends were much higher for storm duration 10,30 min and 1, 3, 6, and 12 hours. However, for long storm duration (24, 48, 120 and 240 hours), stations located in Pahang river basin gives percentage increasing and decreasing in similar trend. The Mann Kendall test, on other hand, demonstrates that three stations in Perak river basin noticeable trend in the series. The findings in this paper 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

Abstrak

Perubahan iklim memberi kesan ke atas aktiviti hidrologi terutamanya kepada hujan yang melampau. Kajian tentang kekuatan dan kekerapan peristiwa hujan melampau adalah penting dalam membantu pembuat keputusan mengambil langkah-langkah proaktif dalam menghadapi perubahan iklim. Ujian Mann Kendall(MK) telah digunakan dalam kajian ini untuk mengkaji trend peristiwa hujan melampau dalam pelbagai tempoh ribut hujan. Keputusan menunjukkan peratusan stesen yang mempamirkan peningkatan trend lebih tinggi untuk tempoh ribut 10,30 min dan 1, 3, 6, dan 12 jam. Walau bagaimanapun, bagi tempoh ribut yang panjang (24, 48, 120 dan 240 jam), stesen terletak di lembangan Sungai Pahang memberikan peratusan peningkatan dan pengurangan dalam trend yang sama. Ujian Mann Kendall, menunjukkan bahawa tiga stesen di lembangan Sungai Perak memberi trend yang ketara dalam siri ini. Hasil kajian dalam kertas kerja ini akan berguna untuk merancang, mereka bentuk dan menguruskan banjir dan sistem air ribut hujan di kawasan ini.

Kata kunci: Hujan Melampau; Banjir Disember 2014; Analisa Trend; Ujian Mann Kendall

1.0 INTRODUCTION

Climate change gives impact on extreme hydrological events. As a result of global warming, late 20th century face the increase in frequency of extreme rain storm[1]. More frequent in extreme rainfall events also can lead to high flows in streams, rivers and drainage systems, which can cause flooding, erosion, mobilization of contaminants and downstream sedimentation. In addition to that, hydrological model structure uncertainty becomes more important under more extreme climate change scenarios[2]. In Malaysia, extreme rainfall event is a leading cause of extreme flood and becomes more severe in several states. The flood that occurred in southern Peninsular Malaysia during mid-December 2006 to late January 2007 is a good example of such a devastating extreme event. In year 2014, heavy rains since 17 December has caused severe flooding and this flood have been described as the worst floods in decades. There are a number of studies in extreme rainfall event over Malaysia but there are still large knowledge gaps with regards to extreme event[3].

Trend analysis has been used to investigate changes in intensity and frequency of extreme rainfall events. Due to the important of trend analysis, the number of studies investigating trends in extreme event has grown rapidly worldwide. Rajevan et al, used trend analysis of extreme rainfall events over India using 104 years and found that increasing trend of extreme rainfall events in the last five decades could be associated with the increasing trend of sea surface temperatures and surface latent heat flux over the tropical Indian Ocean. They also suggests that the coherent relationship between Indian Ocean and extreme rainfall events increase the risk of major floods over central India[4]. In Malaysia, hourly rainfall data between the years 1975 and 2010 across the Peninsular Malaysia were analyzed for trends in hourly extreme rainfall events[5]. The result increasing trend between the years 1975 and 2010 with notable increasing trends in short temporal rainfall was observed during inter-monsoon season. It also shows that convective rain during this period contributes higher intensity rains which can only be captured using short duration rainfall series.

This paper contributed to better understanding of the relationship between extreme rainfalls in various storm duration. Therefore, the main objective of this study is to investigate the trend of extreme rainfall events in various storm duration by using statistical approach.

■2.0 DATA AND METHOD

Perak and Pahang is among of the states that hit by floods crisis in December 2014. For that reason, 9 rainfall stations in Perak river basin and 10 rainfall stations in Pahang river basin were examined in this study. All rainfall data were obtained from Water Resources Management and Hydrology Division, Irrigation and Drainage (DID) for the period more than 10 years. Table 1 present geographic coordinate and period of data for all rainfall stations.

Table 1 Geographic coordinate and period of data for rainfall stations.

Basin	Station ID	Station Name	Latitude	Longitude	Data Period
Perak River	4010001	JPS Telok Intan	04° 01' 00'N	101° 02' 10'N	1970 - 2015
	4209093	JPS Telok Sena	04° 15' 20'N	100° 54' 00'N	1970 - 2015
	4409091	Rumah Pam Kubang Haji	04° 27' 40'N	100° 54' 05'N	1970 - 2015
	4708084	Ibu Bekalan Talang	04° 46' 30'N	100° 53' 40'N	1970 - 2015
	4811075	Rancangan Belia Perlop	04° 53' 35'N	101° 10' 30'N	1975 - 2015
	5210069	Stn Pemereksaan Hutan	05° 17' 55'N	101° 03' 30'N	1970 - 2015
	5411066	Kuala Kenderong	05° 25' 00'N	101° 09' 15'N	1972 - 2015
	5610063	Kg Lalang	05° 36' 15'N	101° 04' 50'N	1971 - 2015
	5710061	Dipensari Kroh	05° 42' 30'N	101° 00' 00'N	1970 - 2015
Pahang River	3026156	Pos Iskandar	03° 01' 40'N	102° 39' 30'N	1970 - 2015
	3121143	Simpang Pelangai	03° 10' 30'N	102° 11' 50'N	1975 - 2015
	3424081	JPS Temerloh	03° 26' 20'N	102° 25' 35'N	1970 - 2015
	3533102	Rumah Pam Pahang Tua	03° 33' 40'N	103° 21' 25'N	1970 - 2015
	3628001	Pintu Kawalan P/ Kertam	03° 38' 00'N	102° 51' 20'N	1975 - 2015
	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 - 2015
	4219001	Bukit Betong	04° 14' 00'N	101° 56' 25'N	1974 - 2015
	4223115	Kg Merting	04° 14' 35'N	102° 23' 00'N	1970 - 2015
	4513033	Gunong Brinchang	04° 31' 00'N	101° 23' 00'N	1975 - 2015

Table 2 Mann Kendall test statistic, S results

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
Perak River	4010001	303*	203	200	184	165	163	160*	121	39	70
	4209093	63	293*	329*	292*	213*	200	194	180	87	92
	4409091	184	232*	220*	105	178*	162*	131	67	159	120
	4708084	-50	124	52	167	148	138	116	103	-28	113
	4811075	165	238*	128	68	91	77	-21	-10	19	102
	5210069	165	327*	260*	125	13	12	-2	38	157	158*
	5411066	-7	-21	-59	-44	-30	-21	-63	-52	-100	44
	5610063	5	-115	-161	-19	10	4	-128	243*	-60	5
	5710061	161	297*	155	120	178	162*	173	101	179*	224
Pahang River	3026156	183	187	111	149	47	63	13	-50	-68	-65
	3121143	-7	95	-4	120	84	54	-33	-120	-64	14
	3424081	87	43	71	-22	83	114	-71	-10	-110	-53
	3533102	172	136	117	213	179	187	163	152	155	193
	3628001	-14	104	119	35	52	84	79	50	23	-33
	3924072	61	23	3	84	52	12	-21	-9	-58	81
	4023001	-25	143	-5	-67	-95	-105	-99	-152	-116	-6
	4219001	-5	-27	-37	-65	-27	-41	-41	-35	11	-14
	4223115	220	323*	255*	121	148	180	228*	203	240*	248*
	4513033	7	11	29	27	61	28	40	14	9	70

* (superscripts) correspond to p value < alpha = 0.05.

Mann Kendall Test

The Mann Kendall (MK) test were employed for trend detection of extreme rainfall (annual maximum rainfall) in this study. 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:

$$S=\sum_{i=1}^{n-1}\left[\sum_{i+1}^{n} sign(T_j-T_i)\right]$$

$$Sign(x_j-x_i)=\begin{cases}1\ if\ T_j-T_i>0\\ 0\ if\ T_j-T_i=0\\ 1\ if\ T_j-T_i<0\end{cases}$$

where *Tj* and *Ti* 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:

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

The standardized Z statistic is calculated as follows:

$$Z=\begin{cases}\frac{S-1}{Var(S)}\ for\ S>0\\ 0\ for\ S=0\\ \frac{S+1}{Var(S)}\ for\ S<0\end{cases}$$

The test statistic Z is used to measure of significance of the trends. In fact, the null hypothesis Ho of the MK test assume that there is no trend and tested against the alternative hypothesis H1 which assume that there is a trend. If the calculated z statistic is larger than critical value at the chosen significance levels, then the null hypothesis is invalid implying the alternative hypothesis which is "there is trend" is accepted.

Applying nonparametric tests to detect trends can significantly affect the results. Therefore, it is essential to consider serial correlation or autocorrelation, defined as the correlation of a variable with itself over successive time intervals, prior to testing for trends. In order to consider the effect of autocorrelation, Hamed and Rao suggest a modified Mann-Kendall test, which calculates the autocorrelation between the ranks of the data after removing the apparent trend. The adjusted variance is given by:

$$Var(S)=\frac{1}{18}[N(N-1)(2N+5)]\frac{N}{NS^*}$$

$$\frac{N}{NS^*}=1+\frac{2}{N(N-1)(N-2)}\sum_{i=1}^{p}(N-i)(N-i-1)(N-i-2)\rho_s(1)$$

N is the number of observations in the sample, NS* is the effective number of observations to account for autocorrelation in the data, ρs (i) is the autocorrelation between ranks of the observations for lag i, and p is the maximum time lag under consideration.

Annual maximum rainfall data of ten storm duration (i.e. 10, 30 minutes and 1, 3, 6, 12, 24, 48, 120 and 240 hours) obtained from TIDEDA software package. Software used for performing the statistical MK test is Addinsoft's XLSTAT 2015.

3.0 RESULTS AND DISCUSSION

The MK test was applied to all stations for trend detection. The test was done at 5% significant level of two - tailed test. In the MK test, the positive test statistic, S indicates increasing trend, whereas the negative test statistic indicates decreasing trends. Interpretation of the results also has to do with hypothesis of the analysis.

H_0: There is no trend in the series

H_a: There is a trend in the series

If computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis (H0) and indicated there is no trend in a series. And if computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H_0. Rejection the null hypothesis implies acceptance of the alternative hypothesis and indicated there is a trend in the series.

For better understanding about the trend in various storm duration, the analysis was conducted into two groups of storm duration as short (i.e. less than or equal to 3 hours) and long (i.e. equal to or greater than 6 hours) durations. Output are presented in Table 1 where it shows a mix of increasing and decreasing trends at different stations and storm durations.

Trend detection in short storm durations

At Perak river basin, increasing trends were found mostly of the stations. Anyhow, station ID 5411066 shows decreasing trends in every short storm duration. At Station ID 4708084 and 5610063, decreasing trends were found in 10 min and 30, 60 min and 3 hour respectively. Hypothesis test indicates 'There is trend in the series' for six stations in 30 min storm duration. This is clearly shown by bigger value of S and p-value is lower than the significance level alpha =0.05. Three stations also indicates that 'there is a trend in a series' in 60 min storm duration and only one station indicates trend in 10 min and 3 hours. Increasing trends were detected at Station ID 3026156, 3533102, 3924072 and 4513033 in Pahang river basin, while station ID 4219001 implies decreasing trend. In other stations, a mix of increasing and decreasing trends occurred in different short storm duration. In hypothesis test, only two stations indicates 'There is trend in the series' and it occurred in 30 and 60 min.

Trend detection in long storm durations

The Perak river basin exhibited increasing trends in mostly of the long storm durations except for station ID 4708084, 4811075, 5411066 and 5610063. Similar in short duration, Station ID 5411066 shows decreasing trends in every long duration. In hypothesis testing, two station indicates 'There is trend in the series' in 6 and 12 hours and only one station indicates statistically significant trend in 24, 48, 120 and 240 hours. At Pahang river basin, mostly station indicates decreasing trend particularly in 24, 48, 120 and 240 hours. Hypothesis test indicates 'There is trend in the series' only for stations ID 4223115 (24, 120 and 240 min storm duration).

Figure 1 shows the percentage of the stations demonstrating decreasing and increasing in extreme rainfall for every storm durations. The percentage of stations showing increasing trends were much higher for both basin for storm duration 10,30 min and 1, 3, 6, and 12 hours. However, for long storm duration (24, 48, 120 and 240 hours) rainfall stations located in Pahang river basin gives percentage increasing and decreasing in similar trend.

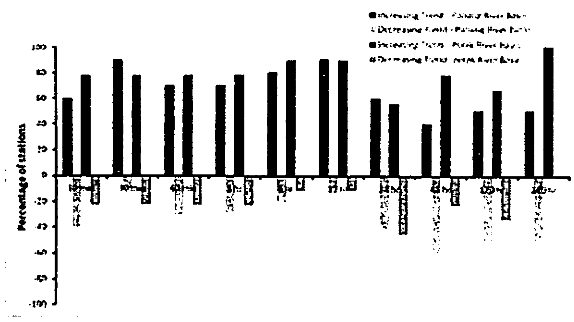


Figure 1 Percentage of stations showing increasing or decreasing trends

As conclusion, for short storm duration, mostly rainfall stations at Perak and Pahang river basin indicates increasing in trends. However, for long storm duration, rainfall stations at Perak river basin indicate increasing trends and rainfall stations at Pahang river basin shows decreasing trends. From hypothesis test, 30 min storm duration implies 'there is trend in series' for mostly of the station compare to other storm duration. This must be noted especially in the design of structures associated with flood control. Floods produced by short-duration rainfall are often more hazardous because of the difficulty in providing sufficient warning and mobilizing emergency response[6].

On further analyzing the S statistic, there are three station at Perak river Basin (station ID 4209093, 4409091 and 5710061) and one station at Pahang river basin (Station ID 4223115) shows a bigger value of S compare to other stations. From hypothesis test, it indicates that 'There is trend in the series' . This clearly shows that extreme rainfall event is influenced by monsoon in Malaysia. This also becomes evident that geographical factor is must be taken into consideration. The S statistic, however is not very strong for other stations implying that the trend is not as strong compared to that four stations.

■4.0 CONCLUSION

Trend analysis can be used to investigate changes in intensity and frequency of extreme rainfall events. The MK test gives interesting insight about trend of extreme rainfall in Perak river basin and Pahang river basin. In general, there was conformity that statistically significant trend were much higher for short storm duration. The MK test, on other hand, demonstrates that three stations in Perak river basin noticeable trend in the series. This study, therefore, offers new perspective to engineers and planners in helping them to make decision for planning, designing and managing floods and stormwater systems in this area. The MK test also can be applied to other rainfall stations for the purpose of trend analysis.

Acknowledgement. The authors would like to acknowledge the financial assistance from the Ministry of Higher Education Malaysia under the TRGS 2015 Flood Management Grant No. 203/REDAC/6767003 entitled "Model-Based Morphological Prediction for Large Scale River Basin in Raising Flood Protection Levels for Sungai Pahang". Special thanks also to Water Resources Management and Hydrology Division, Department of Irrigation and Drainage, Malaysia for providing the historical rainfall data for this study

References

(1) IPCC, 2007. *Climate Change 2007: The Physical Science Basis. Summary for Policymakers, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC Secretariat, Geneva, Switzerland.

(2) J. Dams, J. Nossent, T. Belay Senbeta, P. Willems, O. Batelaan. 2015. *Journal of Hydrology*

(3) F. T. Tangang, L. Juneng, E. Salimun, K. M. Sei, L. J. Le, and H. Muhamad. 2012. *Sains Malaysiana*, 41(11), 1355–1366.

(4) M. Rajeevan, Jyoti Bhate, and A. K. Jaswal. 2008. *Geophysical Research Letters*, VOL. 35, L18707.

(5) A. H. Syafrina & M. D. Zalina & L. Juneng.2015. *Theor Appl Climato* 120:259–285.

(6) Ahern, M., Kovats, R. S., Wilkinson, P., Few, R., & Matthies, F. 2005. *Epidemiologic reviews*, 27(1), 36-46.

Analysis of trends of extreme rainfall events using Mann Kendall Test: a case study for five major basins in Peninsular Malaysia

Nor Azazi Zakaria[1], Maslina Alang Othman[2], Aminuddin Ab. Ghani[3], Chun Kiat Chang[4],

[1,2,3,4] River Engineering and Urban Drainage Research Centre (REDAC), Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Malaysia.

ABSTRACT

Intensity and frequency of extreme rainfall events are on the rise due to the impact of climate changes. This phenomenon leads to rainfall-derived floods and have been described as one of the most costly and dangerous natural hazards worldwide. This scenario was clearly proven when Northern and Eastern states of Kelantan, Terengganu, Pahang, Perak and Johor in Peninsular Malaysia were hit by the floods crisis in December 2014. There are a number of studies related to climate change and extreme event occurrence in Malaysia but there is still a large knowledge gap pertaining that. Therefore, the focus of this study is to investigate the trend of extreme rainfall events in various storm duration for five river basins affected by the flood event in 2014. Mann Kendall (MK) test and Sen's Slope estimator were employed to determine the trend of extreme rainfall events of various storm durations (i.e. 10, 30 and 60 minutes, 3, 6, 12, 24, 48, 120 and 240 hours). All rainfall data were obtained from the Department of Irrigation and Drainage (DID) for the period of more than 25 years and software used for performing the statistical MK test is Addinsoft's XLSTAT 2015. As a result, annual maximum daily rainfall in Perak, Kelantan, Terengganu and Pahang river basin were increase throughout 45 years, meanwhile decreasing trend were detected in the Johor river basin. From the hypothesis test, percentage of stations showing significant increasing trends were more higher in short storm durations for Perak, Pahang and Johor river basin. However, Kelantan and Terengganu river basins show higher percentages in significant increasing trends for long storm durations. The findings in this paper 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.

1. Introduction

Climate change can severely impact hydrological processes, including increase in precipitation, particularly during extreme events. A change in frequency and distribution of percipitation event can cause variations in annual and seasonal precipitation. Generally, in areas with increase in mean total precipitation, heavy and extreme precipitation events also increase with a large percentage (Dore, 2005). Changes in extreme events can effect environment and human activities, threatening to human health and safety.

Climate change has already begun to transform the rainfall patterns in Malaysia and extreme floods have become more severe in several states. One recent extreme flood event occoured in 2014 which wreaked havoc in Malaysia. It happened when heavy rain since 17 December have caused catastrophic flooding in the east coast states of Peninsular Malaysia (Chan et al., 2015; Ismail et al., 2015). Recently, extreme rainfall events in Malaysia are becoming more frequent and it revealed that heavy rain events on the east coast of Peninsular Malaysia have increased over 40 years (Mayowa et al., 2015). 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 (NAHRIM, 2006). Increased rainfall and extreme rainfall events can increase the frequency of flood events.

Changing trends in rainfall distribution also effects hydrological analysis related to historical rainfall record. The design of stormwater infrastructure is based on characteristics of design rainfall driven by time series of rainfall data. Alang Othman et al. (2015) used historical rainfall data to identify rainfall depth for sizing and designing stormwater quality control facilities. The outcome from the study is that East Coast region provides a value of rainfall depth in the range 20 - 100 mm. Given that the East Coast region received heavy rainfall due to the impact of North East Monsoon, the probability of extreme rainfall occurrence in this region is more frequent with 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 designing stormwater systems in this area.

Many researchers in Malaysia use statistical approach to their study related to investigating changes in intensity and frequency of extreme rainfall events (Suhaila et al. 2010, Syafarina et al. 2015). There are a number of studies in extreme rainfall event over Malaysia but there are still large knowledge gap with regards to extreme events (Tangang et al., 2012). Syafarina et al. (2015) analysed trends in hourly extreme rainfall events in Peninsular Malaysia by using non parametric Mann Kendall (MK) test and reported that the positive trend of extreme rainfall is stronger during the North East Monsoon season while negative trend is most observed during the South West Monsoon. They also point out that hourly extreme rainfall events in Peninsular Malaysia showed an increasing trend with notable increasing trends in short temporal rainfall being observed during the inter-monsoon season. Convective rain during this period contributes higher intensity rains which can only be captured using short duration rainfall series. Given that these studies focus on the hourly extreme rainfall event, detailed study on short storm duration and long storm duration is needed. It is because of extreme rainfall in short storm durations 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.

The aim of the present work is (a) to investigate changes in the annual maximum rainfall depth of 24-hour duration over five major basins, and (b) to investigate the trend of extreme rainfall events in various storm duration by using Mann Kendall test and Sen's Slope Estimator. The study helps to improve the understanding of rainfall distribution and trend over five major basins which can contribute to sustainable development within the study area.

2. Method and Study Area

Peninsular Malaysia encompasses between the latitude1°–7°N and 100°–103°E is shown in Figure 1. The climate of the Peninsula is governed by the regime of the northeast and southwest monsoons. The northeast monsoon blows from October to March, and is responsible for the heavy rains which hit the east coast of the peninsula and frequently cause widespread floods. On the other hand, the month of June and July during southwest monsoon are the driest period. Extreme rainfall has hit Peninsular Malaysia in 2014, and causes extreme flood event in five major basins: Perak, Kelantan, Terengganu, Pahang and Johor river basin. Therefore, the trends of extreme rainfall event in these basins are investigated in this study. Rainfall data for a period more than 25 years basins are obtained from Water Resources Management and Hydrology Division, Department of Irrigation and Drainage (DID, Malaysia. To ensure the quality control of data sets, homogeneity test was applied to rainfall time series in order to detect breaks. Stations that identified inhomogeneous were excluded from this study. Hence, there are 34 rainfall stations from five major basins were examined in this study. Table 1 presents geographic coordinates and periods of data for all rainfall stations and locations of the stations are shown in Figure 1.

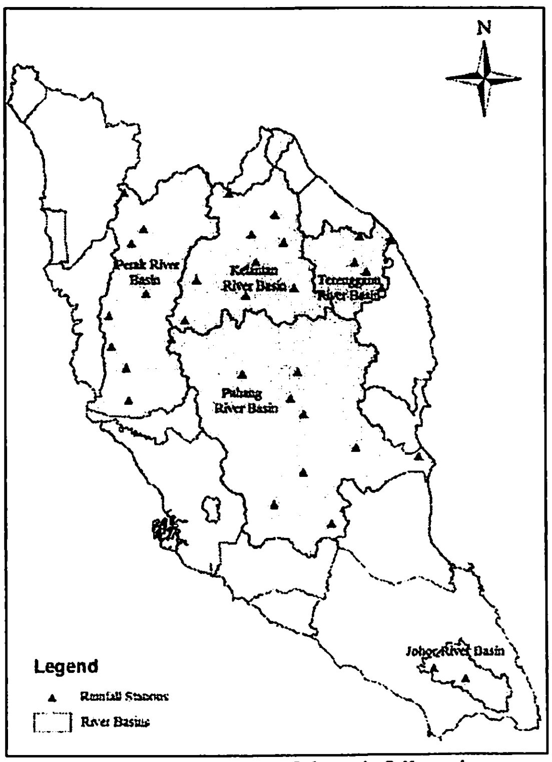


FIGURE 1. Location of the rainfall stations

TABLE 1: Geographic coordinates and periods of data

Basin	Station ID	Station Name	Latitude	Longitude	Data Period
Sungai Perak	4010001	JPS Telok Intan	04° 01' 00'N	101° 02' 10'N	1970 – 2014
	4209093	JPS Telok Sena	04° 15' 20'N	100° 54' 00'N	1970 – 2014
	4409091	Rumah Pam Kubang Haji	04° 27' 40'N	100° 54' 05'N	1970 – 2014
	4708084	Ibu Bekalan Talang	04° 46' 30'N	100° 53' 40'N	1970 – 2014
	4811075	Rancangan Belia Perlop	04° 53' 35'N	101° 10' 30'N	1975 – 2014
	5210069	Stn Pemereksaan Hutan	05° 17' 55'N	101° 03' 30'N	1970 – 2014
	5411066	Kuala Kenderong	05° 25' 00'N	101° 09' 15'N	1972 – 2014
	5710061	Dipensari Kroh	05° 42' 30'N	101° 00' 00'N	1970 - 2014
Sungai Kelantan	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
Sungai Terengganu	4930038	Kg. Menerong	04° 56' 20'N	103° 03' 40'N	1971 - 2014
	5029034	Kg. Dura	05° 04' 00'N	102° 56' 30'N	1971 - 2014
	5128001	Sg. Gawi	05° 08' 35'N	102° 50' 40'N	1983 - 2104
	5328044	Kg. Sg. Tong	05° 21' 20'N	102° 53' 10'N	1971 - 2014
	5331048	Setor JPS Kuala Terengganu	05 19' 05'N	103° 08' 00'N	1970 - 2014
Sungai Pahang	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
Sungai Johor	1737001	Sek. Men. Bkt. Besar	01° 45' 50'N	103° 43' 10'N	1974 - 2014
	1834001	Stesen Tele. Ulu Remis	01° 50' 45'N	103° 28' 30'N	1989 - 2104

2.1 Mann Kendal test and Sen's Slope Estimator

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:

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

Purchase Requisition ▶ Purchase Order ▶ Suppliers ▶ Maintenance ▶ Financials ▶ Coda Info ▶ Reports ▶ Admin ▶

UserCode: JPNP / USMKCTLIVE / PREDAC **Program Code: Votebook9100** **Current Program : Votebook (Header)**

Current Date : 14/06/2016 9:13:56 AM **Version: 15.124, Last Updated at 10/06/2016** **DB: 13.00, 9/18/2010 VB: 13.01, 3/14/2011** **Switch Language : English /Malay**

Wildcard : eg. Like 100%, Like 10%1, Like %1

Element 1: 203 Element 2: % Element 4: PREDAC

Element 5: 6767001 Year: 2016 Search Export to Excel

Detail	Excel	Budget Rule	Budget Control	Account Description	Budget Account Code	Roll over	Budget	Cash Received	Advanced	Commit	Actual	Available	Percentage
Detail	Excel	421	L	Pembangunan Penyelidikan	203.111.0.PREDAC.6767001	2,070.73	250.00	0.00	0.00	0.00	2,217.90	102.83	41.13%
Detail	Excel	422	L	Pembangunan Penyelidikan	203.221.0.PREDAC.6767001	10,751.77	0.00	0.00	0.00	0.00	10,668.18	83.59	0.00%
Detail	Excel	422	L	Pembangunan Penyelidikan	203.227.0.PREDAC.6767001	2,462.34	0.00	0.00	0.00	0.00	2,394.60	67.74	0.00%
Detail	Excel	422	L	Pembangunan Penyelidikan	203.228.0.PREDAC.6767001	25,290.00	-1,750.00	0.00	0.00	0.00	23,682.00	-142.00	8.11%
Detail	Excel	422	L	Pembangunan Penyelidikan	203.229.0.PREDAC.6767001	11,423.36	1,400.00	0.00	0.00	1,860.00	10,930.36	33.00	2.36%
Detail	Excel	425	L	Pembangunan Penyelidikan	203.552.0.PREDAC.6767001	0.00	100.00	0.00	0.00	0.00	56.04	43.96	43.96%
		9999		GrandTotal		51,998.20	0.00	0.00	0.00	1,860.00	49,949.08	189.12	0.00%

TRGS/1/2015/USM/01/1

BORANG TRGS BANJIR - P2(PROGRAM)

YEAR	2015

KEMENTERIAN PENDIDIKAN MALAYSIA

FINAL REPORT
GERAN PENYELIDIKAN PENGURUSAN BENCANA BANJIR
Laporan Akhir Skim Geran Penyelidikan Transdisiplinari (TRGS)

Tahun 2015

A. PROGRAM INFORMATION

YEAR: 2015/2016

RESEARCH TITLE: Integrated assessment of extreme rainfall-runoff on flood hazard, water quality and microbial variability, and enhancement of standard operating procedures (SOP) for flood disaster awareness: Case study of Sungai Pahang River Basin

THEME CODE: 1.0 **SUBTHEME CODE:** 1.3

(Please refer attachment)

Please Tick (√)

PHASE:	01: Pre-Disaster	√	02: During Disaster	√	03: Post-Disaster	√
AREA:	01: Preventive	√	02: Preparedness	√	03: Rescue anf Recovery	√
	04:Adaptation		05: Mitigation	√		

THEME: Holistic solution to flood disaster based on Integrated River Basin Management
SUB THEME: Flood and flood disaster

RECEIVED 14 JUN 2016 RCMO USM

START DATE: 1/4/2015
END DATE (EXPECTED): 30/4/2016

PROJECT STATUS: (ACTIVE / TERMINATED / COMPLETED)

PROGRAM LEADER: Prof. Dr. Nor Azazi Zakaria
I/C NUMBER: 630411-03-5045

B. PROGRAM ACHIEVEMENT

ACHIEVEMENT PERCENTAGE				
Program progress according to milestones achieved up to this period	0 - 25%	26 - 50%	51 - 75%	76 - 100%
Percentage (please state #%)				100%
RESEARCH OUTPUT				

Number of articles/ manuscripts/ books *(Please attach the First Page of Publication)*	**Indexed Journal**	**Non-Indexed Journal**
	6, 1 submitted, 1 drafted manuscript	
Conference Proceeding *(Please attach the First Page of Publication)*	**International**	**National**
	7	4
Intellectual Property *(Please specify)*	1 Book & 1 Book Chapter	
Number and title of Policy Paper / SOP / Technology Solution *(Please specify)*	1. 2. 3.	

HUMAN CAPITAL DEVELOPMENT					
Human Capital	**Number**				**Others** (please specify)
	On-going		**Graduated**		
Citizen	Malaysian	Non Malaysian	Malaysian	Non Malaysian	
No. PHD STUDENT	4				
No. MASTER STUDENT	2				
No. RA/RO	4		1		
Total	10		1		

C. EXPENDITURE

Budget Approved *(Peruntukan diluluskan)* : **RM 660,360.00**
Amount Spent *(Jumlah Perbelanjaan)* : **RM 655,647.23**

Balance *(Baki)* : **RM 4,712.76**
Percentage of Amount Spent *(Peratusan Belanja)* : **99.29 %**

Date : **10/6/2016**
Tarikh

Project Leader's Signature:
Tandatangan Ketua Projek

F. COMMENTS, IF ANY/ ENDORSEMENT BY RESEARCH MANAGEMENT CENTER (RMC)
(Komen dan Pengesahan oleh Pusat Pengurusan Penyelidikan)

....

....

....

Name:
Nama:

Signature:
Tandatangan:

Date:
Tarikh:

PROF. DR LEE KEAT TEONG
Pejabat Pengurusan dan Kreativiti Penyelidikan
Universiti Sains Malaysia

30/12/10