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RAINFALL ANALYSIS OF THE KELANTAN BIG YELLOW FLOOD 2014

Nor Eliza Alias[a*], Hazim Mohamad[b], Wan Yoke Chin[c], Zulkifli Yusop[d]

[a]Department of Hydraulic and Hydrology, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[c]Department of Mathematical Sciences, Faculty of Science, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[d]Resource Sustainability Research Alliance, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

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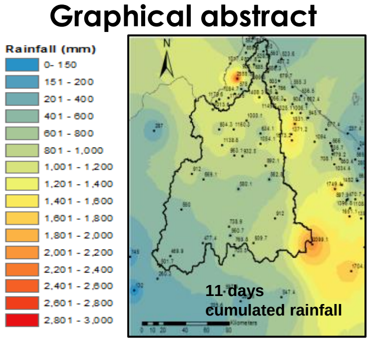
*Corresponding author
noreliza@utm.my

Graphical abstract



Abstract

In December 2014, Kelantan was hit by the worst flood ever recorded. Did the rainfall exceed historical records, how rare are they and what causes them? This paper answers these questions. Estimation of the return periods uses the GEV distribution model and stations with more than 25 years records. Spatial distribution plots of the cumulated rainfall depths were constructed using IDW interpolation method. Four major outcomes are: 1) Spatial rainfall patterns show high amounts of rainfall accumulated by phases (Phase 1- daily rainfall up to 300 mm; Phase 2- daily rainfall up to 500 mm); 2) record breaking rainfall events occurred at 9 stations significantly at Gunung Gagau (1598.9 mm compared to 976.5 mm 7-day cumulated rainfall). Many stations upstream of the river basin experienced ARIs near and over 100 years and several experienced more than 200 years; and 4) Enhanced rainfall were experienced due to the combined effect of the monsoon season, Madden Julian Oscillation and temperature below anomalies at the Siberian High.

Keywords: Extreme rainfall; flood disaster; freq. analysis; spatial distribution

Abstrak

Pada Disember 2014, Kelantan dilanda banjir besar. Adakah hujan ketika itu mencipta rekod baru, apakah kala kembali nya dan punca hujan ekstrim tersebut. Kala kembali hujan dikira menggunakan modal *Generalized Extreme Value* (*GEV*) dengan data-data hujan yang melebihi rekod 25 tahun. Analisa menggunakan kaedah interpolasi IDW mendapati: 1) Taburan spatial hujan lebat berlaku dalam dua fasa (Fasa 1- hujan harian sehingga 300 mm; Fasa 2- hujan harian sehingga 500 mm) ; 2) 9 stesen merekodkan nilai tertinggi baru dimana Gunung Gagau melangkau jauh dari rekod iaitu 1598.9 daripada 976.5 mm kumulatif 7-hari hujan); 3) Banyak stesen di hulu lembangan mengalami hujan berkala kembali menhampiri dan melebihi 100 tahun dan beberapa mengalami lebih 200 tahun; dan 4) Hujan esktrim berlaku pada Disember 2014 kerana gabungan faktor monsoon Timur Laut, Osilasi Madden Julian dan suhu rendah dari biasa di Siberia.

Kata kunci: Hujan ekstrim; banjir; analisis kekerapan; taburan spatial

1.0 INTRODUCTION

The Peninsular of Malaysia is located near the equatorial with its latitude between roughly 1º0'0''N to 7º0'0''N and 100º0'0''E to 105º0'0''E (Figure 1a). Being near the equatorial and surrounded by seas (South China Sea on the East and Malacca Strait on the West), the Malaysian Peninsular is exposed to climate with uniform temperature and high humidity. Due to the location, the rainfall distribution of the East- and West-coast of the Peninsular Malaysia is influenced by the monsoon seasons which are the North-east monsoon occurring between November to March and South-west monsoon occurring between May to September respectively (Figure 1a). During these monsoons, winds carrying moisture from the seas dump plenty of rainfalls at the East-coast and West-coast of the peninsular [1, 12].

From historical overview several major flood events experienced in the last few decades at the east-coast of Peninsular Malaysia dates as far back as 1886 where it was reported one severe flood had caused extensive damages to Kelantan. Next was the flood in 1926 and 1967 where disastrous floods surged again at the east-coast across Kelantan, Terengganu and Perak. A few years later in 1971 another catastrophic event were reported with Pahang severely affected [2].

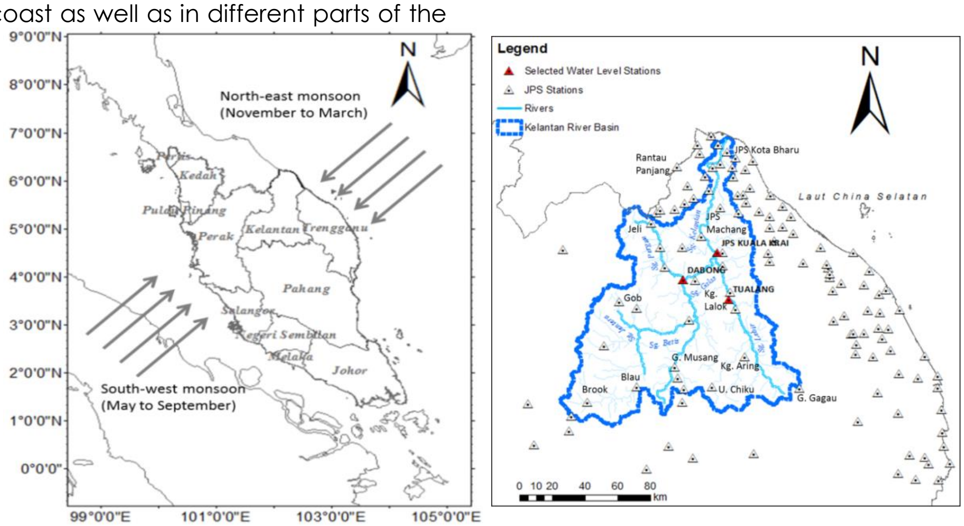
Huge floods are also been observed to occur more frequently nowadays. In November 2005, a flood in Kota Bharu was described as the worst natural flood in history at that time. Due to geographical characteristics, unplanned urbanization and proximity to the South China Sea, city like Kota Bharu has become extremely vulnerable to monsoon flood every year. Afterwards, in the year 2006, 2007 and 2008 heavy monsoons rainfall again have triggered major floods along the east-coast as well as in different parts of the country. The hardest hit areas are again along the east-coast of Peninsular Malaysia in the states of Kelantan, Terengganu and Pahang [3, 4].

Records on heavy rainfall amount and events were also reported to have an increasing trend [12, 13, 14]. The total amount of rainfall, frequency and average precipitation of wet days have shown increasing trend for several stations during the northeast monsoon.

The most recent extreme flood event occurring at the north-east coast was the flood called by locals as the Kelantan Big Yellow Flood 2014. Kelantan is located in the East-coast of the peninsular exposing it to high rainfalls during the North-east monsoon season. In December 2014, Kelantan was hit by the worst flood ever recorded in history where flood levels reaches up to 5 to 10 meters. Buildings were inundated up to the 3rd and 4th floor. Many people could not evacuate from their homes and people sheltering in evacuation centers such as school were left helpless due to lack of supplies and necessities.

Most of major historical flood events occurred were related to the north-east monsoon season which carries abundant of rainfall to the east-coast [3, 4, 5]. It is important to relate current flood events to historical rainfall records to provide facts on the rarity and the extreme level of the rainfall causing the floods.

Based on the 2014 Kelantan flood, several questions arise: Do the rainfall events exceed historical rains, how rare are they and what causes these extreme events. Question also arises in terms of the spatial distribution. In what way the rainfall spatial distribution influence the locations of the flood. The rarity of the events can be quantified using return periods estimated using frequency analysis and comparison to historical maxima.



(a) (b)

Figure 1 Geographical location (b) DID stations selected for analysis

2.0 METHODOLOGY

The analysis uses the rainfall data obtained from the Department of Irrigation and Drainage (DID) Malaysia. In order to assess the spatial distribution of the rainfall, 117 rainfall stations consisting of stations in Kelantan (52), Terengganu (56), Pahang (6) and Perak (3) were used. The stations chosen are stations containing rainfall data during December 2014. The spatial distributions were produced using the deterministic interpolation methods of Inverse Distance Weighting (IDW).

The extreme rainfall frequency analysis was conducted using 16 rainfall stations in Kelantan. The criterions of the stations selected are: 1) those with observation period of more than 25 years; and 2) contain no missing years or errors. Annual maximum series for 1-day, 3-day, 5-day and 7-day period rainfalls represent the extreme values series. The Generalized Extreme Values distribution model was used for the fittings. Several distribution models initially tested however it was found that GEV fits most of the extreme values series. Using the parameters estimated from the frequency analysis, return periods of the highest rainfall values during the flood were estimated.

Assessment on the influence of the spatial rainfall distribution patterns towards the river levels were conducted using three DID stations (Dabong, Tualang and Kuala Krai). Figure 1b and Table 1 shows the locations of the water level stations.

3.0 RESULTS AND DISCUSSION

3.1 Factors of Heavy Rainfall in December 2014

There could be several reasons contributing to the December 2014 flood in Kelantan. One of it is due to rain. The rain recorded prior to the flood was extremely high and prolonged. Factors influencing the heavy rainfalls in December 2014 were assessed based on reports by National Oceanic and Atmospheric (NOAA) [6], the Tokyo Climate Centre, [7-9] and Malaysian Meteorological Department [16].

The North-east monsoon usually brings heavy rainfall to the East-coast of the Peninsular Malaysia every year contributing to flood. Flood occurrence in the region is very common leading to people not expecting such extreme event in 2014. In December 2014, multiple factors contributed to influence the extreme amount of rainfall. Combination of the annual monsoon season and the global climatic patterns contributes to the rain enhancement.

Monsoon is influenced by the movement of winds due to the pressure difference of the land and the ocean. This pressure differences is influenced by the air temperature [10]. The North-east Monsoon commonly known in Malaysia is also called as Winter Monsoon in Asia. During winter in the Northern hemisphere, the land is colder than the sea, therefore the density and pressure of the air over the land will be higher resulting to winds flowing from land to sea. This phenomenon occurs over the Siberian High during winter where high pressure system develops over the cold Asian Continent. The reverse however occur at the Southern hemisphere were the Australian continent is experiencing summer and low pressure system. The movements of the winds were influenced by the pressure differences and the Coriolis effects forming the North-east monsoon [11] (Figure 2).

Particularly on early December 2014 the land mass in Siberia experienced a very low temperature below average [7-9]. This contributes to a high pressure at the northern hemisphere. Intense cold dry air blows out from the continent and absorb water vapour as it crosses the Pacific Ocean and the South China Sea bringing winds carrying large amount of moistures to the East-coast of Peninsular Malaysia. The effect of orographic at places near mountainous regions experienced enhanced rainfall due to this.

The low temperature in Siberia coincides with reports published by the Malaysian meteorological department (MMD). During the northeast monsoon in 2014, a report by MMD had shown that there were 4 cold surges recorded during the 2014 monsoon season. This was slightly less than the average surge per season which is five. However, intense rainfall was recorded during one of the cold surges on 15 to 25 December 2014 [16]. During the cold surge period, the daily rainfall averaged over each day during the surge is 218 mm in Kelantan and 176 mm in Pahang. These rainfall amounts are very high as compared to the average daily rainfall amounts during the cold surges.

Besides the influence of monsoon, influence of the Madden Julian Oscillation (MJO) in December 2014 was also present. MJO is a climate pattern occurring every 30 to 60 days at tropical regions. The effect of MJO is that it enhanced or depressed rainfall. In the early of December 2014, the enhanced rainfall phase of the OMJ was developing at a belt along peninsular Malaysia [6].

The El-Nino Southern Oscillation (ENSO) effects were also considered by MMD on their 2014/2015 Northeast monsoon analysis report [16]. They had found that, ENSO influence was mild as demonstrated by NOAA's recorded Oceanic Nino Index (ONI) index values. ONI is used by NOAA to detect the warm/cold episode occurrence which can lead to an El-Nino/La Nina event.

Due to the discussed climatic patterns and existing monsoon season, the rainfall at the east-coast of Peninsular Malaysia was enhanced, thus contributing to the extreme rainfall events.

Table 1 Rainfall stations for Frequency Analysis

No	Station Name	Years Observed	Coordinate	
			Latitude (°N)	Longitude (°E)
1	Brook	30	04° 40' 35"	101° 29' 05"
2	Blau	29	04° 36' 00''	101° 24' 00''
3	Gunung Gagau	30	04° 45' 25''	102° 39' 20''
4	Gua Musang	40	04° 52' 45''	101° 58' 10''
5	Kg. Aring	37	04° 56' 15''	102° 21' 10''
6	Gob	30	05° 15' 05"	101° 39' 45''
7	Dabong	40	05° 22' 40"	102° 00' 55''
8	Kg. Lalok	40	05° 18' 30''	102° 16' 30''
9	Ulu Sekor	29	05° 33' 50''	102° 00' 30''
10	K. Krai	41	05° 32' 00"	102° 10' 00"
11	Kg. Jeli	37	05° 42' 05''	101° 50' 20''
12	Kg. Durian Daun	33	05° 46' 50''	101° 58' 05''
13	Jps Machang	34	05° 47' 15''	102° 13' 10''
14	Bendang Nyior	31	05° 50' 40''	102° 04' 25''
15	Rantau Panjang	41	06° 01' 25''	101° 58' 45''
16	S. JPS. Kota Bharu	27	06° 06' 30''	102° 15' 25''

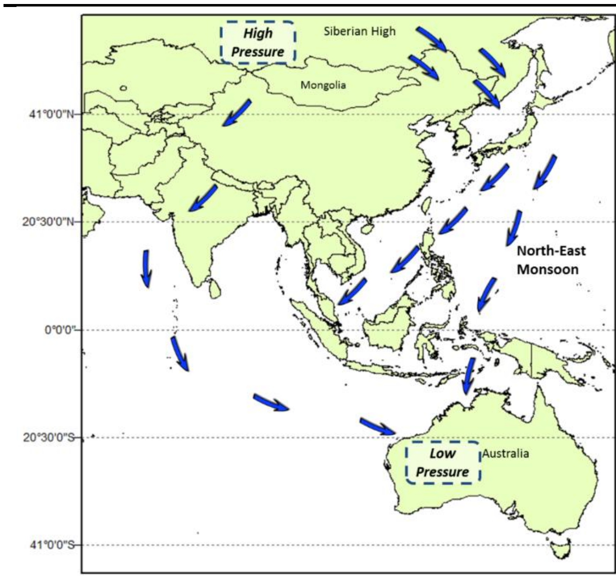


Figure 2 The North-east Monsoon

3.2 Spatial Rainfall Distribution

A general view on the rainfall distribution prior to the flood are made based on the rainfall distribution plots (isohyets) published by the Department of Irrigation and Drainage (DID) Malaysia (Figure 3). Heavy rainfalls fell in the east-coast from 15 to 29 December 2014. The rainfalls which may contribute to the flood occur in two phases. Phase one begins from 15 December to 19 December 2014 with daily rainfall reaching up to 100 mm to 300 mm. During this time most of the rainfall was concentrated to the east-coast of Peninsular Malaysia, especially the coastlines of Kelantan, Terengganu and Pahang. Phase 2 begins from 20 to 24 of December 2014 were higher intensities of rainfall were recorded. The daily rainfall during this phase reaches up to 500 mm and were more concentrated in the middle of the peninsular especially areas centre of Kelantan, Terengganu and Perak.

A detail assessment of the rainfall distribution in Kelantan River Basin was made using spatial rainfall distribution constructed from data observed in stations within the basin and its surrounding borders (Figure 4). The analysis was conducted using rainfall data from 16 to 26 December 2014. Heavy rains (more than 200 mm per day) were observed to fall during this period. By assessing the cumulated rainfalls by stages, we can assess the patterns of the spatial rainfall distribution across the river basin.

High rainfall distribution began at the upstream eastern side of the Kelantan river basin on 16 December 2014. 255 mm rainfall was recorded in Gunung Gagau station. High rainfall was also recorded in the western side of the basin which is around the Ulu Sekor and Kampung Jeli stations with the recorded rainfalls of 163.4 mm and 199.1 mm. The rainfalls on both locations could influence the Kelantan River water levels in Kuala Krai as the rains contributed to the volume of flow in Sungai Galas and Sungai Lebir. Kuala Krai is located at the intersections of three rivers of Sungai Kelantan, Sungai Galas and Sungai Lebir (Figure 1b). The high rainfall recorded in 16 December 2014 aligned with the water level records of all three water level stations of Dabong, Tualang and Kuala Krai on 17 December 2014. Records show the water level increasing near to the warning level and exceed it at the same day (Figure 5).

On the next two days (16 to 18 December 2014) and five days (16-20 Disember 2014), analyses show the cumulated rainfall were highest at the downstream of Sungai Kelantan, where the cumulated rainfall depths of 742 mm (3-day cumulated rainfall) and 876.9 mm (5-day cumulated rainfall) were calculated at the JPS Machang station.

In line with the isohyets of the peninsular Malaysia published by DID, during the second phase (20 -24 December 2014) which show very high rainfall in the middle of Kelantan and Terengganu, the 7-day total rainfall (16-22 December 2014) in Gunung Gagau reaches to 1237.5 mm. This rainfall value exceeds very far from the historical record. Similar observation can be seen for the cumulated 9-day rainfall (16-24 December 2014) where Gunung Gagau station records a total of 1866.9 mm rainfall and 10-day rainfall of 2099.1 mm, half of its annual rainfall. The mean annual rainfall (1970-2013) recorded from stations within the Kelantan River Basin is presented in Figure 6. Records taken from the Water level stations also showed very high levels far exceeding the warnings levels (Figure 5). Tualang station even showed errors and became dysfunctional on the 24th of December 2014. During this second phase, Kuala Krai, Dabong and other areas experienced the extreme flood. Post-visit to the affected areas showed water levels had reached up to 5 to 10 meters as buildings such as school were inundated up to the third floor in Kuala Krai.

Based on the spatial distribution of the rainfall depths constructed within the period from 16 to 26 December some conclusions can be made. High quantity of rainfall fell at the downstream area of the Kelantan river basin at first contributing to the increase in water level of Sungai Galas, Sungai Lebir and Sungai Kelantan. Situation became worst when heavy rainfall started to fall at the up-stream of the Kelantan River Basin especially areas near Gunung Gagau after 24 December 2014.

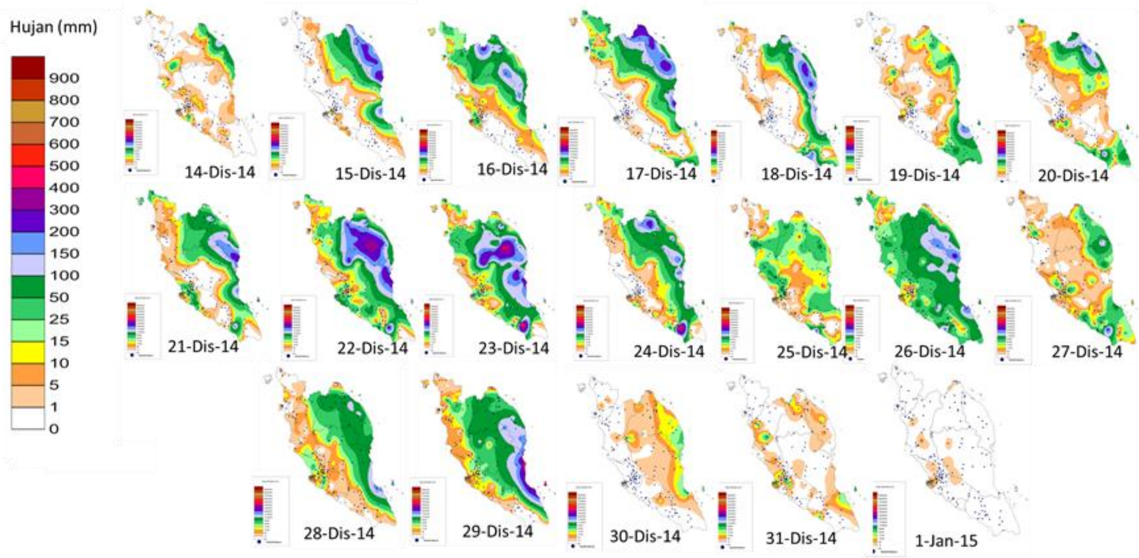


Figure 3 Rainfall isohyets of the Peninsular Malaysia 14-Dis-2014 to 1-Jan-2015 (DID, Malaysia)

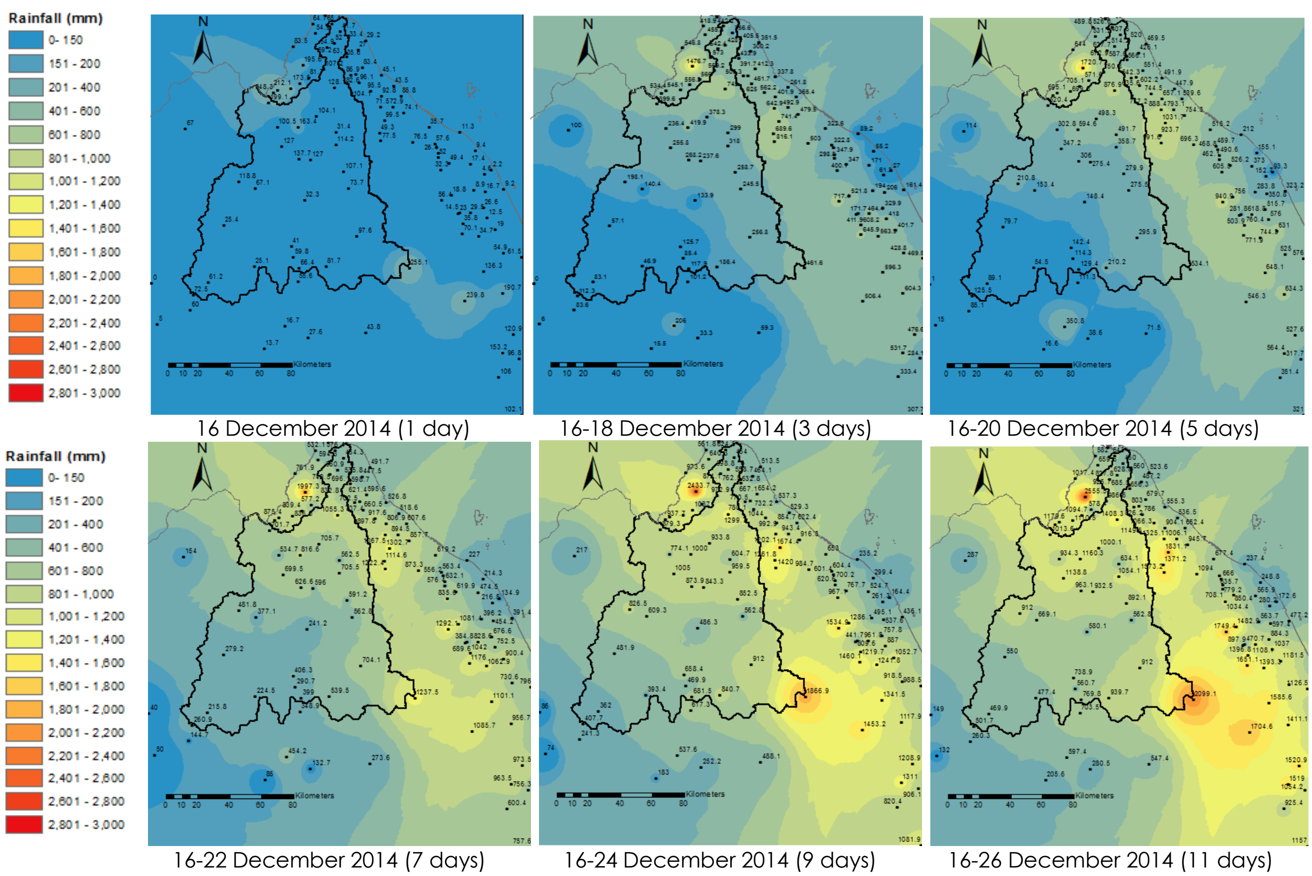


Figure 4 Spatial distribution of the cumulated rainfall depths

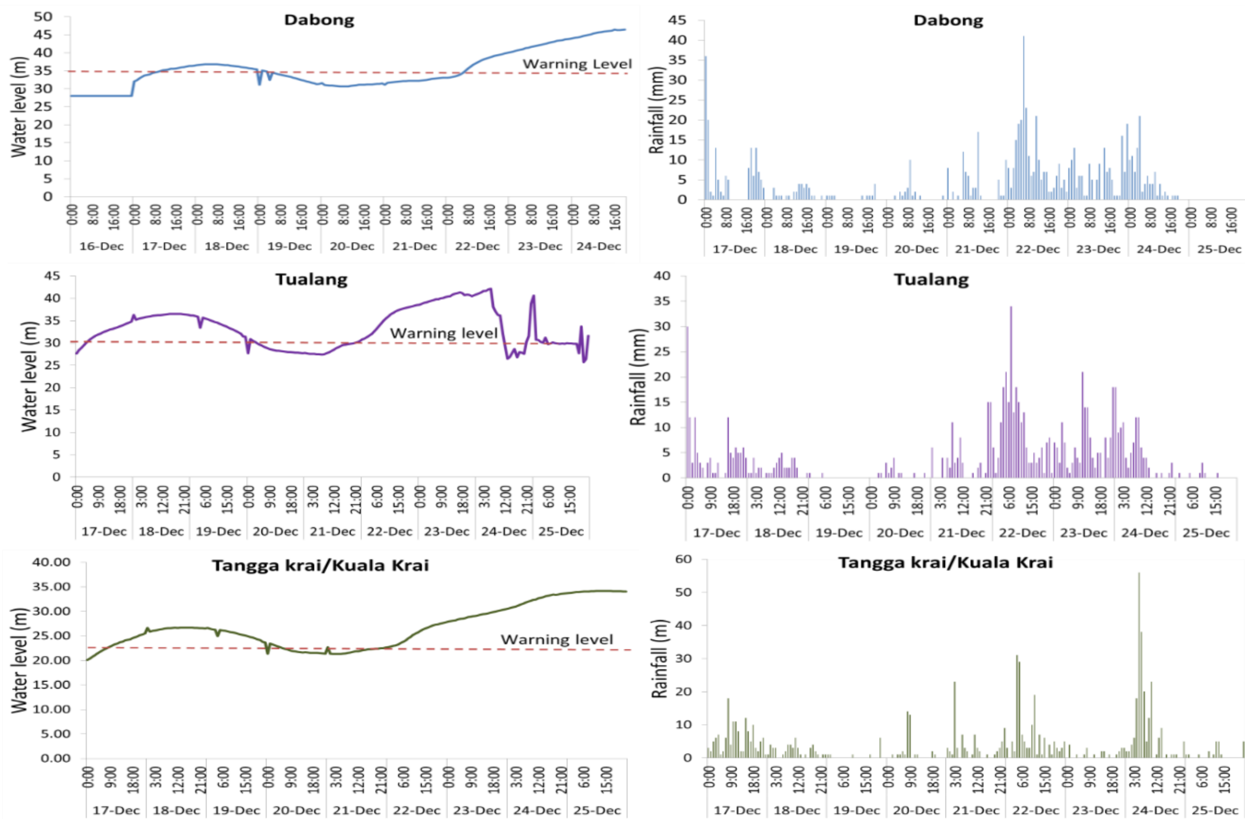


Figure 5 Water levels and hydrograph of stations Dabong, Tualang and Kuala Krai

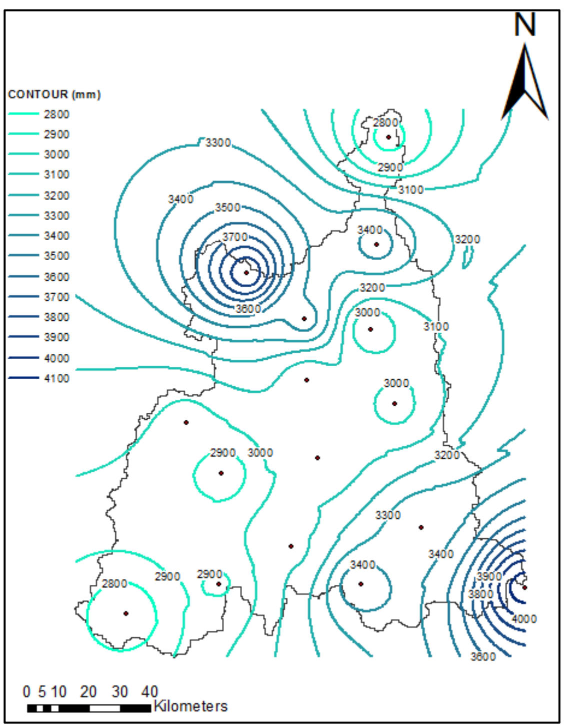


Figure 6 Mean Annual Rainfall of Kelantan

3.3 Frequency Analysis

Frequency analyses of the extreme values were conducted to estimate the return period of the rainfall events. By estimating these return periods, how extraordinary the rainfall events are during the December 2014 Kelantan flood against historical records can be assessed. A rainfall event having a return period of 10 years means that particular rainfall event has a possibility to occur within 10 years. The higher the return period values, the rarer the rainfall event is. The analysis uses the annual maximum rainfall series of more than 25 years of data (up to December 2011). The GEV distribution model for the 1-day, 3-day, 5-day and 7-day extreme rainfalls were fitted to its parameters and used to estimate the return periods. Using this models return period of the highest rainfall recorded at each station between the periods of 16 to 26 December 2014 was determined.

The results are delivered in Table 2. The stations in Table 2 are arranged starting from stations located at the downstream of the river basin to the upstream. Assessment shows that the return period or average recurrence interval (ARI) of majority of stations located at the upstream of the Kelantan river basin experienced high ARI rainfall events (ARIs near or over 100 years) compared to stations at the downstream of the river basin (ARIs near or less than 50 year), especially for rainfall periods longer than 2-days. Stations which have its recorded rainfalls experiencing ARIs more than 200 years are stations Gob (2-day rainfall), Gunung Gagau (3-, 5- and 7-day rainfall), and Brook (5- and 7-day rainfall). 9 stations also recorded rainfalls exceeding their historical values. They are JPS Machang, Kg. Durian Daun, Ulusekor, Gob, Kg. Aring, Gua Musang, Blau, Gunung Gagau, and Brook.

Table 2 ARIs for the highest rainfall recorded from16 to 26 December 2014

	1-DAY RAINFALL			3-DAY RAINFALL		
Station	Event Highest (mm)	ARI (Year)	Hist. Highest (mm)	Event Highest (mm)	ARI (Year)	Hist. Highest (mm)
Kota bharu	203	5	485.5	356.6	6	1059
R. Panjang	416.7	28	792.2	546.8	12	1126.8
Bendangnyior	438.1	49	484.9	566	8	660.2
*Jps Machang	540.5	27	454.6	742	33	721.6
Kg. Durian daun	269.1	8	372.5	545.1	9	631.5
Kg. Jeli	199.1	4	287.5	399.6	6	493.6
Ulusekor	174.4	4	306	419.9	9	586.4
K. Krai	211	4	416.5	390	5	681.7
Dabong	242.3	34	276.5	489.6	45	509
Kg. Lalok	233.5	12	396.4	494.8	21	784.7
*Gob	266.7	109	221	581.6	370	258.5
Kg. Aring	281.4	34	309.5	616.1	146	521
*Gua Musang	216.3	98	189.7	480.2	291	357
*Blau	146	19	162.1	316	127	307
*G. Gagau	495.1	50	533.5	1198.5	>200	803.5
*Brook	128.6	13	133	255.3	37	191.4
	5-DAY RAINFALL			7-DAY RAINFALL		
Station	Event Highest (mm)	ARI (Year)	Hist. Highest (mm)	Event Highest (mm)	ARI (Year)	Hist. Highest (mm)
Kota bharu	407.5	6	1119.6	434.3	5	1177.5
R. Panjang	648.8	11	1220.5	761.9	14	1278.5
Bendangnyior	571.6	5	763	577.2	4	834
*Jps Machang	876.9	40	818.2	1055.3	105	912.6
*Kg. Durian daun	699.8	10	667	836.6	12	730.5
Kg. Jeli	520.4	4	614	701.7	5	880
*Ulusekor	594.6	14	658.7	816.6	32	770
K. Krai	506	6	796.8	564	6	919.3
Dabong	594	46	654.3	683.2	44	733.3
Kg. Lalok	618.7	24	1044.7	716.6	26	1152
*Gob	667.1	443	322	713.3	496	430.5
*Kg. Aring	655.2	74	644	814.4	110	719
*Gua Musang	534.7	147	413.5	612	228	417.5
*Blau	385.6	325	355	429.1	177	443.5
*G. Gagau	1383.1	>200	873.6	1598.9	>200	976.5
*Brook	354.8	>200	235.1	386.6	>200	294

** Stations having their historical records exceeded*

4.0 CONCLUSION

Analysis and assessment of the extreme rainfall of Kelantan show several major key points on the factors influencing the extreme flood in December 2014.

One; there were two phases of rainfall. The first phase on 15 to 19 December has heavy rainfalls falling at both the eastern and western side downstream of the Kelantan river basin. This contributes to the increase of water levels of Sungai Galas, Sungai Lebir and Sungai Kelantan. During this period floods occurred at areas of Kota Bharu, Tualang, Kusial and Kuala Krai from 17 to 19 December 2014. The second phase of rainfall was from 20 to 24 December. During this time higher intensities of rainfall were recorded especially at the upstream of the River Basin in Gunung Gagau. Flood situations become more severe due to the full capacity of soils, rivers and drainage. Areas worst hit was Kuala Krai, Dabong and Manik Urai on 22 to 30 December 2014.

Second key-point is that a lot of record breaking rainfall events occurred during the flood period. Many stations at the upstream of the river basin experienced rainfall events with ARIs near and over 100 years and several stations experienced event rainfalls with ARIs more than 500 years. They are stations Gob, Gunung Gagau and Brook.

The third point is on the reason of these extreme rainfall events. The monsoon rainfall experienced during December 2014 was enhanced due to the Madden Julian Oscillation climate pattern and very low temperature below average in the Siberia during December 2014. This produces intense and enhanced rainfall at the East-coast of Peninsular Malaysia during December 2014.

Literatures have shown that there exist and increasing trend of the rainfall intensity and number of wet days during the northeast monsoon. The December 2014 event is one proof of an extreme rainfall event unexpectedly occurring contributing to record breaking rainfall amounts. Global warming and climate change were proven by many of its occurrence and will influence these extreme rainfall events [15]. Even though the influence of ENSO was mild during the 2014/2015 Northeast monsoon season, effects of large temperature anomalies can influence the rainfall amounts. Further research on relationship between the extreme rainfall events and floods in Malaysia are very important and should be discussed continuously.

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