Rainfall Frequency Analysis of the Johor Big Flood 2006/2007

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ABSTRACT. In the end of December 2006 and Early January 2007, Johor was hit by the worst flood ever recorded in Malaysia. Did the rainfall exceed historical records and how rare is it? This paper answers these questions. Estimation of return periods were done by using Generalized Extreme Value (GEV) distribution model and stations with more than 25 years records data. Three rain gauge station have been used to analyze the rainfall return periods. Annual Maximum Series (AMS) data was determined by using R-Code programming. The reason why using GEV as distribution model is because it having the highest rank in Kolmogrov Smirnov, Anderson Darling and Chi-Squared goodness of fit tests. The frequency analysis were carried out by using Easyfit software to identify the rainfall return periods. The location mapping of the gauge station was done by using ArcGIS 10.3. Bukit Besar and Ulu Remis is the station that experienced ARI near and over 100 years and 200 years according to the analysis. Next, the value of ARI in hourly event rainfall for all rainfall station in first wave and second wave is same. The sub-daily rainfall intensity (12-hour and less duration) during the event has ARI less than five years. We can see that, that the sub-daily rainfall intensity was not rare and may not be contributing as an extreme rainfall event. However, for more than 1-day rainfall intensity, the event rainfall experiences larger ARI where some reaches to more than 500 years for first wave and 100 years for second wave of ARI. We can see that most of the events exceeds historical events. This indicates that the extreme rainfall events are from long-duration rainfall events coincides with monsoon type of rains.

Keywords: Flood, Return Period, Frequency Analysis, rainfall

INTRODUCTION

Peninsular Malaysia is located near the Equator line at latitudes 1 ° 0'00"U to 7 ° 0'00"U and 100 ° 0'00"T to 105 ° 0'00"T. Due to its proximity to the Equator and surrounded by South China Sea in the east and the Straits of Malacca in the west, it leads to uniform year-round temperatures and high humidity.

In addition, heavy rainfall along the east coast and west coast of the Peninsular is caused by the influence of northeast monsoon (from November to March) and southwest monsoon (May to September). Southwest monsoon are generally dryer than the northeast. During the northeast monsoon, a series of heavy rainfall episodes could cause flooding.

During the period from 16 to 31 December 2006 and 12 to 17 January 2007, Peninsular Malaysia was hit by a series of heavy floods due to northeast monsoon winds that caused extraordinary flooding in the east coast states of peninsular Malaysia (Shafie, 2009). There have been major damage and destruction of homes that cost millions of dollars as a result of big floods, especially in four states namely Negeri Sembilan, Malacca, Pahang and Johor. The study will focus on flooding in Kota Tinggi as the area is among the worst affected with almost 100,000 people evacuated.

Flood is one of the most common natural disaster in Malaysia. The Johor River Basin is one of the regions in Malaysia where floods occur annually, either in small or large events. It becomes a main disaster issue in Johor River Basin. Johor River is approximately 122.7 km long with drainage area of 2636 km^2. It originates from Mt. Gemuruh and flows through the southeastern part of Johor and finally ends into the Straits of Johor (Shafie, 2009). The catchment is irregular in shape. The maximum length and width are about 80 km and 45 km respectively.

The December 2006 and January 2007 flood were the most destructive event occurred at the Johor river basin during that period. More than 100,000 people and 18 deaths recorded with a total estimated loss of 0.5 billion U.S dollars (Kia et al., 2012). The main contributing factor to these tragedies was the heavy rainfall brought on by the North-East monsoon in December and January during that year (Baharudin Yatim, 2012).

Problem Statement

During the north east monsoon season, the east coast of peninsular Malaysia may experience an unusually heavy rainfall contributing to large amount of runoff exceeding the river capacity. The rivers may not hold large quantities of water hence it will cause overflow of the river bank. Lowlands area may be flooded in a very short time. Issues regarding the December 2006 and January 2007 flood concerned are whether the rainfall exceed previous records? How rare are the rainfall events? What are the contributing factors to this extreme event? In what way the rainfall spatial distribution influences the location of the flood?

Objectives

This study aims to analyze the rainfall of the flood events in Johor during end of December 2006 and early of January 2007. The analyze includes identifying the return period of rainfall of rainfall events associated to major flood events. Three objectives have been outlined for this study:

1. To determine the return period of rainfall during the flood event in Kota Tinggi;

2. To identify any climatic patterns causing the Kota Tinggi big flood 2006/2007, and;
3. To compare historical rainfall against the event rainfall of 2006/2007 Kota Tinggi big flood.

Scope of Study

The scope of the study area is focus on Kota Tinggi and Johor River Basin. The data of the rain gauge station associated to the flooding area will be taken into consideration for the analysis purpose. The analysis will be based on daily rainfall for every rain gauge station located area in Kota Tinggi. Other than that, the method uses to analyze the data is by using continuous frequency distribution model to fit the extreme rainfall value. The analysis also includes various cumulative rainfall distribution periods of 1-hour, 2-hours, 6-hours and 12-hours for hourly rainfall and followed by daily rainfall analysis which are 1-day, 2-day, 3-day, 5-day and 7-day rainfall. Hence, the information of the rainfall distribution can help to identify the characteristic of the rainfall which could be the main cause of the Kota Tinggi big flood 2006/2007.

LITERATURE REVIEW

Flood Mechanism

Flood is one of the most common natural disaster, which is a natural phenomenon of an extreme, often irregularly. There are seasonal and intra-annual variations in river flow resulting in very high flow periods but floods occur when the excess rainfall (runoff) escapes the boundaries of the flowing water body and damages the surrounding area (M.Karamouz, et al., 2013). Flood is also described as a volume of water that enters a certain area that cannot be discharged quickly. As the result, the water level rises and flooding occurs. Flood can occur based on several factors of weather events and geomorphological factors. There are six types of flood categories (M.Karamouz, et al., 2013), they are flash floods, coastal floods, urban floods, river floods, ponding floods and inland floods.

Table 1 Flood categories

Number	Flood Categories	Explaination
1	Flash Floods	In general, flash floods generated in less than 6 hours can lead to rapid rises and falls in water levels. It is one of the most dangerous weather-related natural disasters in the world and can create hazardous situations for people and caused extensive damage to property.
2	Coastal Floods	Main coastal flood sources are tides, meteorological surges and gravity waves. Wind stress over shallow water is the most influential of surge formation processes, whilst in deep water surge elevation are approximately hydrostatic with 1hPa decrease in atmospheric pressure giving 1 cm increase in surge elevation (Flather,2000)
3	Urban Floods	Flood events may occur due to short period of high rainfall intensity (Gaitan, et al., 2015). It might occur on a larger scale due to increase in water levels in natural or built flood channels and collapse of drainage.
4	River Floods	When precipitation is heavy and could not infiltrate the soil, most of the volume runs into the drainage system, exceeding its natural discharge capacity. The excessive water that cannot be drained flows into the flood plain, following the topography, in order to the flood area that near the rivers (Carlos, 2007).
5	Ponding Floods	Commonly occurs in relatively flat areas. The runoff produced in an area is normally stored in the ground and in canals, lakes or is drained away or pumped out. When the runoff produced exceeds the storage and conveyance capacity of a system, flooding occurs. In this case, rain is the source of the flood (M.Karamouz, et al., 2013).
6	Inland Floods	It occurs when the volume of surface runoff exceeds the capacity of the drainage system. The excess flow will follow the direction of the slope of the surface to approach its outlet. The depth of the overflow depends on its size as well as on the topography of the basin. The inland flood damage is related to the flooding depth

Monsoon

As mentioned in Malaysian Meteorological Department, Ministry of Science, Technology and Innovation, Peninsular Malaysia is influenced mainly by north east monsoon and south west monsoon. For north east monsoon, it occur between mid-October and the end of the March meanwhile for south west monsoon occur between May and September (Suhaila et al, 2010). During both monsoons, it could be raining all days and this could affect the normal rainfall distribution as compared to the areas which does not experiencing the monsoons. This also could explain why the rate of change of rainfall sometimes increased or decreased drastically.

During Southwest monsoon, the Australian continent is in the winter season, and the Asian continent in the summer season. Thus, the low air temperature from the Australian continent creates high pressure and the high air temperature from the Asian continent creates low pressure. This condition causes winds to move from Australia to the northwest across the Indian Ocean, and while crossing the equator, the wind is deflected to the northeast ultimately arriving at Peninsular Malaysia and the South China Sea (Masseran, et al., 2016). During this season, the winds generally come from the southwest at a speed of 15 knots. The speed of wind during the Southwest monsoon is less than those during Northeast monsoon. The Southwest monsoon also has less rain because it is blocked by the island of Sumatra (Masseran, et al., 2016). However, areas that are not blocked by the range of Titiwangsa can receive heavy rainfall.

Northeast monsoon is the major rainy season in the Malaysia. It occurs during the summer season on the Australia continent, while the Asian continent is in winter. The low pressure of the Asian continent forms a low pressure area. As a result, the wind moves from the high pressure area of Asia to the low pressure area of Australia. In this season, the wind comes from the east or northeast of Peninsular Malaysia with a speed 10-20 knots and is then deflected towards Australia when crossing the equator (Masseran, et al., 2016). The east coast states of Peninsular Malaysia such as Kelantan, Terengganu and Pahang more affected by this monsoon which the wind speeds that can reach up to 30 knots (Masseran, et al., 2016)

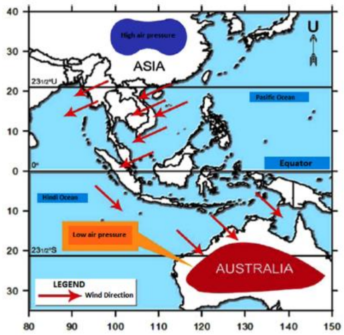


Figure 1 The process of formation of the Northeast monsoon in Malaysia

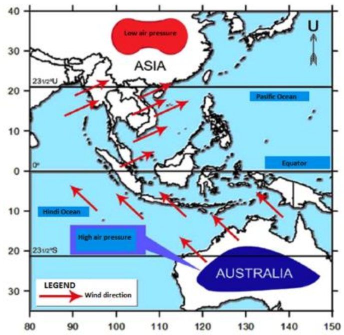


Figure 2 The process of formation of the Southwest monsoon in Malaysia

Climatic pattern

La Niña event is the example of climatic pattern. The occurrence of La Niña event tend to disrupt the global weather pattern. It is a phenomenon that describes cooler than normal ocean surface temperatures in the Eastern and Central Pacific Ocean (Glantz, 2012). The regions is close to the equator off the west coast of South America. In some parts of the world, La Niña causes increased rainfall while in other regions it causes extreme dry conditions (Glantz, 2012). The conditions that cause La Niña recur every few years and can persist for as long as two years. El Niño occur every two to seven years and La Niña events sometimes follow El Niño events (Glantz, 2012).

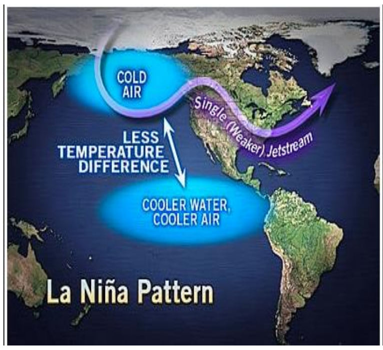


Figure 3 La Niña pattern (Glantz, 2012)

Frequency Analysis

Frequency analysis is a technique used by hydrologist to predict flow values corresponding to specific return periods or probabilities along a river (Philip B.Bedient, et al., 2008). The primary objective of frequency analysis is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distribution (Chow et al., 1988). It is a tool for determining design rainfall and design discharged for drainage works and drainage structure especially in relation to their required hydraulic capacity.

M.Karamouz, et al. (2013) chooses the best frequency distribution from the statistical distribution such as Binomial distribution, normal distribution, lognormal distribution, exponential distribution, the Gamma (Pearson type III) distribution, and the Log Pearson type III distribution. Flood frequency curves are plotted after the best fitted probability distribution were chosen. The graphs are then used to estimate the design flow values corresponding to specific return period which can be used for hydrologic planning purpose.

In order to understand how flood frequency works, it is essential to understand the concept of return period. Philip, Wayne and Boxter states that an annual maximum event has a return period or recurrence interval of T years if its magnitude is equaled or exceeded once, on the average, every T years. The reciprocal of T is the exceedance probability, 1-F of the event that is the probability the event is equaled or exceeded in any one year. It is important for hydrologist to indicate the probability of an event to assign a return period of the event. The concept of a return period implies independent events and usually found by analyzing the series of maximum annual floods or rainfall.

Annual Maximum Series

An Annual Maximum Series for a particular duration is obtained by selecting the largest value of rainfall depth for the duration in each year of the rainfall records and contains only one observation per year. According to Villarini, et al., (2011) state the common usages of AMS are extreme value and trend analysis.

Probability Distribution

In Malaysia, there is also several studies investigated on the distribution of rainfall either in hourly, daily or annually. Quantitative goodness of fit tests was done to determine the probability distribution most appropriate for describing annual maximum rainfall series in Peninsular Malaysia. Probability distribution was investigated as potential candidates to describe the annual extreme rainfall data of Peninsular Malaysia. The common distribution model used in practice in many references were Gumbel, Gamma, Generalized Extreme Value (GEV), Generalized Pareto (GPA), normal distribution, Log-Pearson type 3 (LP3) and log normal (e.g Ahmad et al, 1988; Hosking, 1990; Chowdhury et al, 1991; Vogel & McMartin, 1991; Stedinger et al, 1993).

Zalina M.D., et al (2002) stated that generalized extreme value (GEV) distribution is more suitable to be used to study the annual maximum rainfall data in Peninsular Malaysia. Meanwhile, Kolmogorov Smirnov (KS) goodness-of-fit-test is applied when evaluating the performance of the distributions and to determine the best describe of the daily rainfall process.

Return Period

The most common means used in hydrology to show the probability of an event, is to assign a return period or recurrence interval to the event. Return period is an annual maximum event that has a return period or recurrence interval of T years, if this value is equaled or exceeded once on the average every T year (Bedient et al., 1948). The reciprocal of T is called the probability of the event or the probability the event is equaled or exceeded in any one year. As example, a 50-year flood has a probability, P=1/T = 1/50 = 0.02 or 2% of being equaled or exceeded in any single year. The concept of a return period is usually found by analyzing a series of maximum annual floods, rainfall, etc. For example, if the return period for a precipitation of 5 hours of a total of 100 millimeters for a city in particular is 50 years, this means that, on the average, a precipitation of 100 millimeters over 5 hours occurs in that city every 50 years. Another example is that, if the period of return of a flow of 200 m^3/sec is 10 years, then, equal flows or greater than that volume would occur on the average for every 10 years.

In addition, return period is the most significant value that need to be taken into account, particularly when engineers designs a hydraulic structure to control flooding, as in case of spillways dams for flooding control and construction of bridges. Chow (1964), discusses a mathematical method to estimate the relationship between the annual maximum recurrence series (in years) of intervals and the recurrence intervals of annual occurrences and by plotting the results in logarithmic paper. For hydraulic construction purposes, the return period varies as a function of the importance of the hydraulic structure, that is, of the socio-economic, strategic, touristic or the desired goal of flood risk or damage reduction. Moreover, this is a function of the existence of alternative means capable of reducing damage and destruction that is the loss of human life, the cost and time of construction, the economic and political cost of the failures of the structure. Sometimes, it is necessary to oversize the hydraulic structure to minimize the damage in case of extreme events.

Generally, the return periods accepted for hydraulic works for channeling of pluvial waters in middle and big cities is between 20 to 50 years meanwhile for small cities the return periods would be between 5 to 10 years. Similarly, for important bridges, an acceptable return period would be 100 years. In some cases, for hydraulic structures, whose failure would mean a very elevated risk of loss of human lives; these return periods are revised using the method of Maximum probable precipitation (Bedient et al. 1948).

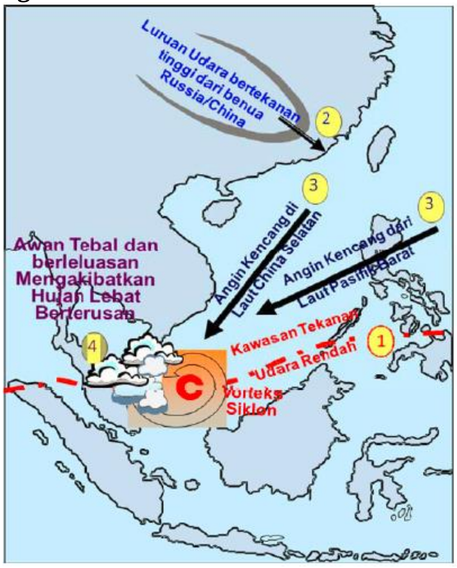
METHODOLOGY

The analysis uses the rainfall data obtained from the Department of Irrigation and Drainage (DID) Malaysia. In order to calculate the return period, three rainfall station have been selected in Kota Tinggi within Johor River Basin area. The criterions of the stations selected are those with observation period of more than 25 years. Annual maximum series for hourly (1-hour, 2-hours, 6-hours and 12-hours) and daily (1-day, 2-days, 3-days, 5-days and 7-days) period rainfalls represent the extreme values series.

The Generalized Extreme Values distribution model was used for the fittings. There are several distribution models initially tested which are Gumbel Max, Lognormal, Lognormal (3P), Normal distribution, Weibull, Weibull (3P) and Generalized Extreme Value (GEV). However, GEV fits the most for the extreme values series. Other than that, GEV also is the highest rank in the goodness of fit based on Kalmogorov Smirnow (KS), Anderson Darling (AD) and Chi-Squared (CS). By using the parameters estimated from the frequency analysis, return periods of the highest rainfall values during the flood were estimated.

RESULTS AND DISCUSSION

Contributing Storm



1) Low pressure area and cyclone vortex from November until January in Equator.
2) High pressure air brings prevailing winds from Russia and China when the condition is favourable

3) Strong winds occurred simultaneously in West Pacific Ocean and South China Sea, both crossing path near the low pressure area in Peninsular Malaysia

4) Cumulonimbus clouds was formed with widespread heavy rainfall and rough seas occur usually in the East Coast.

Figure 4 Heavy rains caused by the prevailing monsoon (Atikah Shafie, 2009)

The storms that caused floods of December 2006 and January 2007 was the unusual Northeast Monsoon that come from South China and West Pacific Ocean. Usually, the Northeast Monsoon brings heavy rain to the upper East Coast area. It is normal for the lower East Coast area to receive heavy rains during the monsoon season but during the flood events, it brought extremely high rains (Atikah Shafie, 2009).

Frequency Analysis

There are three rainfall stations used for Frequency Analysis and determining the return period. Table 2 shows the list of rainfall station with the coordinate and the years observed,

Table 2 Rainfall stations for Frequency Analysis

STATION_NO	STATION_NAME	Years Observed	LATITUDE	LONGITUDE
1541139	Johor Silica	25	1.526389	104.1847
1834001	Ulu Remis	25	1.845833	103.475
1737001	SMK Bukit Besar, Kota Tinggi	25	1.763889	103.7194

Figure 5: The location of rainfall station

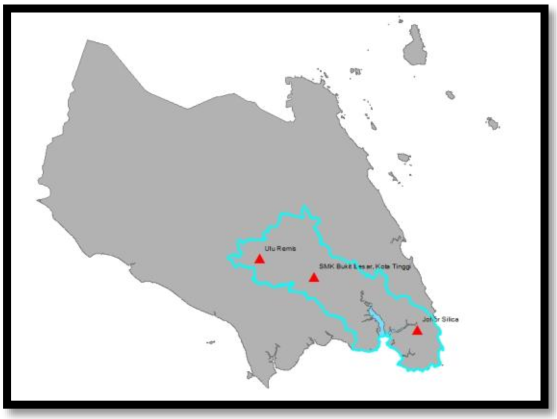


Figure 6: The location of rainfall station along the Johor River Basin

Frequency analyses of the extreme values were conducted to estimate the return period of the rainfall events. By estimating these return periods, how rare the rainfall events are during the big flood 2006/2007 against historical records can be assessed. A rainfall event having a return period of 25 years means that particular rainfall event has a possibility to occur within 25 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. The GEV distribution model is use for this fitting. The analysis uses hourly maximum series which are 1-hour, 2-hours, 6-hours and 12-hours followed by daily maximum series which are 1-day, 2-days, 3-days, 5-days and 7-days. All the maximum series were fitted to its parameters and used to estimate the return periods.

The results are delivered in Table 3 for hourly rainfall data meanwhile Table 4 for daily rainfall data. The stations are arranged starting from stations located at the downstream of the Johor River Basin to the upstream. Assessment shows that the return period or average recurrence interval (ARI) for first wave of big flood during period 16 December 2006 until 29 December 2006. For Bukit Besar and Ulu Remis rainfall station, the actual rainfall data during the event was missing. So, the analysis representing the event highest uses the Johor Silica hourly or daily data. The value of ARI in hourly event rainfall for all rainfall station is same. The sub-daily rainfall intensity (12-hour and less duration) during the event has ARI less than five years. We can see that, that the sub-daily rainfall intensity was not rare and may not be contributing as an extreme rainfall event. However, for more than 1-day rainfall intensity, the event rainfall experiences larger ARI where some reaches to more than 500 years ARI. We can see that most of the events exceeds historical events. This indicates that the extreme rainfall events are from long-duration rainfall events coincides with monsoon type of rains.

Table 3 Hourly Rainfall to determine return period during first wave flood

	1-HOUR RAINFALL			2-HOUR RAINFALL		
Station	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)
Johor Silica	33.9	1	144	51.5	1	144
Bkt. Besar	33.9	1	390	51.5	1	290
Ulu Remis	33.9	1	142.3	51.5	1	221.1

	6-HOUR RAINFALL			12-HOUR RAINFALL		
Station	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)
Johor Silica	90.2	2	176	98.5	2	198.9
Bkt. Besar	90.2	2	290	98.5	3	290
Ulu Remis	90.2	3	305.3	98.5	2	327.1

Table 4 Daily Rainfall to determine return period during first wave flood

	1-DAY RAINFALL			2-DAY RAINFALL		
Station	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)

Johor Silica	164.7	3	266.7	263.3	4	436.3
Bkt. Besar	164.7	8	297.5	263.3	27	303.5
Ulu Remis	164.7	9	327.4	263.3	16	422.8

3-DAY RAINFALL				5-DAY RAINFALL		
Station	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)
Johor Silica	348	7	468.6	472	12	561.2
Bkt. Besar	348	57	370.9	472	855	370.9
Ulu Remis	348	26	423.3	472	50	441.6

7-DAY RAINFALL			
Station	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)
Johor Silica	533.4	13	603.5
Bkt. Besar	533.4	417	406.9
Ulu Remis	533.4	57	472.3

For the next assessment, the table 5 and 6 shows the analysis the return period for second wave of big flood during period 8 January 2007 until 15 January 2007. During the second wave of flood, the actual rainfall data for Bukit Besar and Ulu Remis also error. Hence, the analysis used the data event highest of Johor Silica to determine the return period by using their parameters respectively. For hourly rainfall assessment, the return period is not categorized as extreme rainfall because the return period is very low. The event highest also not exceeding the historical highest for all three rainfall stations. For daily rainfall assessment, the return period for 3-Day, 5-Day and 7-Day is very high and exceeding historical highest. The value of ARI in hourly event rainfall for all rainfall station is same. The sub-daily rainfall intensity (12-hour and less duration) during the event has ARI less than five years. We can see that, that the sub-daily rainfall intensity was not rare and may not be contributing as an extreme rainfall event. However, for more than 1-day rainfall intensity, the event rainfall experiences larger ARI where some reaches to more than 100 years ARI. We can see that most of the events exceeds historical events. This indicates that the extreme rainfall events are from long-duration rainfall events coincides with monsoon type of rains.

Table 5 Hourly Rainfall to determine return period during second wave flood

1-HOUR RAINFALL				2-HOUR RAINFALL		
Station	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)
Johor Silica	32.5	1	144	46.1	1	144
Bkt. Besar	32.5	1	290	46.1	1	290
Ulu Remis	32.5	1	142.3	46.1	1	221.1
6-HOUR RAINFALL				**12-HOUR RAINFALL**		
Station	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)
Johor Silica	86.8	2	176	110.2	2	198.9
Bkt. Besar	86.8	3	290	110.2	3	290
Ulu Remis	86.8	3	305.3	110.2	3	327.1

Table 6 Daily Rainfall to determine return period during second wave flood

1-DAY RAINFALL	2-DAY RAINFALL

Station	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)
Johor Silica	154.1	3	266.7	296.5	6	436.3
Bkt. Besar	154.1	6	297.5	296.5	68	303.5
Ulu Remis	154.1	7	327.4	296.5	23	422.8
3-DAY RAINFALL				5-DAY RAINFALL		
Station	Event Highest (mm)	ARI (Year)	Hist. Highest (mm)	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)
Johor Silica	408.5	13	468.6	431.9	8	561.2
Bkt. Besar	408.5	186	370.9	431.9	282	370.9
Ulu Remis	408.5	45	423.3	431.9	35	472

7-DAY RAINFALL			
Station	Event Highest (mm)	ARI (Year)	Hist. Highest (mm) (1974 – 2005)
Johor Silica	451.4	7	603.5
Bkt. Besar	451.4	89	406.9
Ulu Remis	451.4	28	533.4

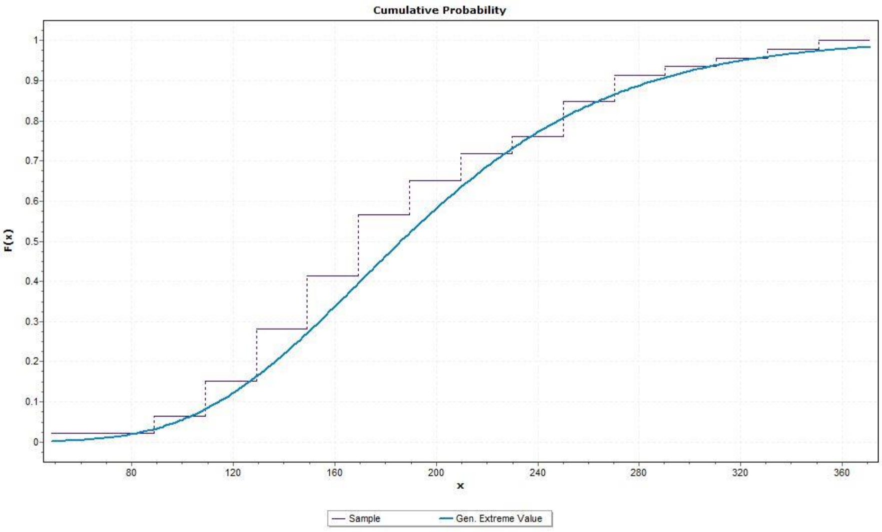


Figure 7: Cumulative Distribution Function (CDF) for 5-Days Rainfall in Bukit Besar

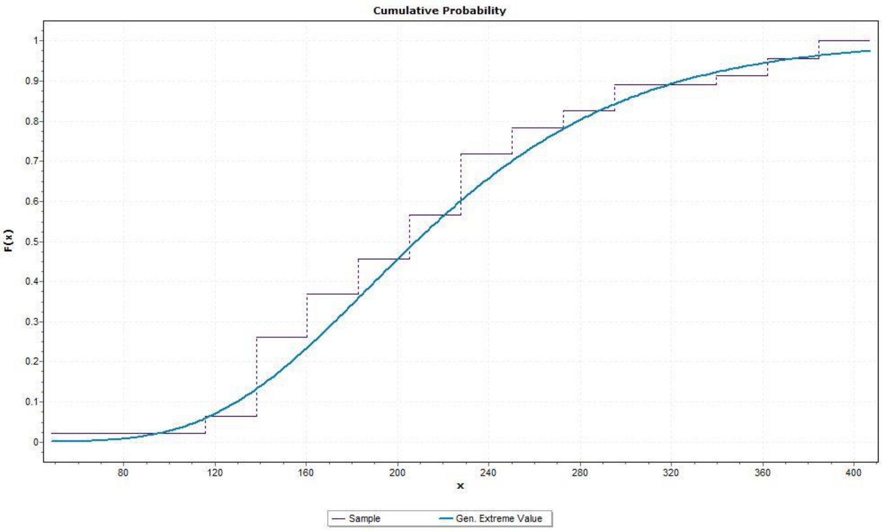


Figure 8: Cumulative Distribution Function (CDF) for 7-Days Rainfall in Bukit Besar

During the first wave of big flood, the return period for 5-days rainfall in Bukit Besar is very high which is 855 years. The event exceed historical highest. The highest rainfall data during the flood in 5-days rainfall is 472 mm. This can be seen in the cumulative distribution function (CFD) in figure 7, the probability of the event highest is near to 1. Hence, it is the reason why the average reccurence interval exceeding to 200 years. In conclusion, the 5-days rainfall events in Bukit Besar was very rare based on the return period calculation. For second wave of flood, the 7-days rainfall was recorded 431.9 mm exceeding the highest historical highest. The probability of the event also reached near to 1 and consequencing to the event being rare due to the high return period.

Next, the return period for 7-days rainfall in Bukit Besar also high which is 417 years during first wave flood. The event highest was recorded in 7-days rainfall is 533.4 mm exceeding the highest historical events. From the CDF in figure 8, the probability of the events reached near to 1. Therefore, leading to a high return period.

CONCLUSION

Analysis and assessment of the extreme rainfall of Kota Tinggi show several major key points on the factors influencing the extreme flood in December 2006 and January 2007.

There were two phases of rainfall. The first phase on 16 December 2006 to 29 December 2006 has heavy rainfalls falling at Johor River Basin. This contributes to the increase of water levels of Sungai Johor. This causes the existing natural drainage and man-made drainage could not withstand the heavy rainfall therefore causing flooding in Kota Tinggi area. The number of flood victims is high during the first wave flood in Kota Tinggi.

Meanwhile, the second phase occurred on 8 January 2007 to 15 January 2007. By comparing the return period of first wave and second wave flood, it shows that the first wave of flood has higher return period, in which Bukit Besar 5-day rainfall is equivalent to a 855 years ARI. In the previous report of Malaysian Department of Irrigation and Drainage, the number of flood victims for second wave is higher compared to the first wave of flood. This is because during the first wave of flood, the rainfall contributes to the soil being saturated and river swelling. The difference between first phase and second phase is just 10 days. Then, when the second phase of rainfall occurred, saturated soils and full capacity of rivers worsen the flood. Hence, increasing the number of flood victims during second wave flood.

Next, the value of ARI in hourly event rainfall for all rainfall station in first wave and second wave is same. The sub-daily rainfall intensity (12-hour and less duration) during the event has ARI less than five years. We can see that, that the sub-daily rainfall intensity was not rare and may not be contributing as an extreme rainfall event. However, for more than 1-day rainfall intensity, the event rainfall experiences larger ARI where some reaches to more than 500 years for first wave and 100 years for second wave of ARI. We can see that most of the events exceeds historical events. This indicates that the extreme rainfall events are from long-duration rainfall events coincides with monsoon type of rains.

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