HYDROLOGY ANALYSIS FOR THE JOHOR RIVER USING SYNTHETIC UNIT HYDROGRAPH GAMA I

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Abstract

A series of floods occurred in several places in Malaysia during December 2006 – January 2007, including the southern state of Malaysia; Johor Bahru. The rain recorded in the city of Johor Bahru was 286 mm. To understand this phenomenon and to investigate the design flood of this region, a hydrology analysis procedure was taken into account. The hydrology analysis procedure includes collecting rainfall data, analyzing rainfall data including areal rainfall and rainfall frequency, developing synthetic unit hydrograph using SUH GAMA I. It is noticed that the length of rainfall data collected, i.e. 60 years, is sufficiently long for analysis. From the hydrology analysis done in this study, it can be concluded that the rain fell during 2006-2007 flood events had nearly 100 years period of rainfall. And the prediction for 100 years period of flood is 16,962 m^3/s.

Abstrak

Serangkaian kejadian banjir terjadi di beberapa tempat di Malaysia selama Desember 2006 – Januari 2007, termasuk di negara bagian sebelah selatan Malaysia; Johor Bahru. Hujan yang tercatat di kota Johor Bahru setinggi 286 mm. Untuk memahami fenomena ini dan menyelidiki banjir rancangan untuk daerah ini, suatu prosedur analisis hidrologi telah dilakukan. Prosedur analisis hidrologi meliputi pengumpulan data hujan, analisis data hujan yang mencakup hujan rerata DAS dan analisis frekuensi hujan, pengembangan unit hidrograf sintetik GAMA I. Dari analisis tersebut diketahui bahwa panjang data tercatat, yaitu 60 tahun, cukup panjang untuk analisis. Dari analisis hidrologi yang dilakukan dalam studi ini, dapat disimpulkan bahwa hujan yang jatuh selama kejadian banjir tahun 2006-2007 tersebut memiliki kala ulang hampir 100 tahun. Dan prediksi untuk kala ulang 100 tahun banjir sebesar 16.962 m^3/det.

1. INTRODUCTION

The Johor River is the main river in the Malaysian state of Johor. The river flows in a roughly north-south direction and empties into the Strait of Johor. The Johor River played a very important role to the Johor Sultanate, as several spots along its banks have once served as the centres of capital for the sultanate.

The 2006-2007 Malaysian floods are a series of floods that hit Malaysia. The floods were caused by above average rainfall, which was attributed to Typhoon Utor which had hit the Philippines and Vietnam a few days earlier. By the third week of January 2007, Johor was hit by a larger flood. Singapore and certain parts of Indonesia were flooded due to the same typhoon. Throughout the week of December 18, 2006 a series of floods hit Johor, Malacca, Pahang and Negeri Sembilan. During this period, these southern Malaysian states, along with Singapore, experienced abnormal rainfall which resulted in massive floods. The rainfall recorded in the city of Johor Bahru on December 19 amounts to 289 mm when the annual rainfall of the city alone is 2400 mm. In Singapore the 24-

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hour rainfall recorded on December 20 was 366 mm, the third highest recorded rainfall in 75 years.

Figure 1. Floods in Kota Tinggi January 2007

Recent flooding of the Johor river has caused vast destruction in Kota Tinggi. According to a Malaysian official, the flooding may be due to the land reclamation efforts made by Singapore. The reclamation project has reportedly narrowed the mouth of the Johor river, slowing the flow of water into the Johor Straits. About 100,000 people have been evacuated from their homes because of flooding during December and January.

As Kota Tinggi has been devastated by the flood, the analysis of hydrology becomes important to determine the design flood. In fact, the local government had decided to do some actions to encounter the flood effects.

1.1. Rainfall-Runoff Transformation

The transformation of rainfall to runoff occurs in both spatial and time domains. The accumulated rainfall depth at any point on the land surface is transformed into surface runoff depth and soil moisture storage, which is controlled by the heterogeneity of soil properties and antecedent moisture content. In the spatial domain the transformation is called concentrating action or convergence (Sivapalan et al, 2001) where the rainfall depth is initially transformed into well distributed surface runoff depth. The spatial movement of water is due to gravity, topography and the existence of a stream network. The initially well distributed spatial fields of runoff generation depths become concentrated or converged into a spatial flow field that is restricted to the narrow boundaries of the stream network. In the time domain the transformation is called smoothing or filtering action (Sivapalan et al, 2001). The water that is added to soil moisture moves through the subsurface soil of the hillslope, driven by gravity. The water movement is initially in the vertical direction and is influenced by soil layers, resulting in water flowing eventually towards the bottom of the hillslopes. The filtering action of hillslopes partitions the water movement over and through hillslopes by various pathways (surface runoff, subsurface runoff, and deep groundwater flow) with a variety of timescales.

The transformation of a rainfall field to the movement of water over the variety of space and time scales and in the various hydrologic subsystems, for example hillslopes and network, is nonlinear. This means the change of depths and spatial patterns of rainfall affect the distributions of flow pathways and the associated travel distances and travel times, causing the changes in volume and space-time distributions of streamflow.

1.2. Flood Frequency and Design Flood

The flood frequency curve, typically estimated from observed flood records and widely used in flood estimation practice, is the culmination of complex interactions between climatic inputs (rainfall intensities, evaporation demand) and those landscape properties that have a bearing on the rainfall to runoff to flood peak transformation, presented within a stochastic framework (Sivapalan et al., 1990; Sivapalan et al., 2005, Kusumastuti et al., 2007; 2008a; 2008b). For a given storm event, apart from its dependence on rainfall intensity and volume, the flood peak is a function of storm duration and the response time of the dominant flood producing process (Robinson et al., 1997; Gupta and Waymire, 1998).

The determination of design flood could be conducted with many kind of methods. One of the methods had been developed in Java Island using Synthetic Unit Hydrograph (SUH) GAMA I, where the design flood determined by SUH GAMA I method based on catchment physical parameter in order to obtain the main parameters of unit hydrograph. The use of SUH GAMA I is not only applied to catchments in Java, but also to other places such as Lampung (Kusumastuti, 2008) and South Sulawesi (Mancar and Sri Harto, 2007) showing a result that catchment area, source factor, source frequency and main stream length are dominant parameters.

2. METHODOLOGY

Hydrology analysis is meant to obtain the flood frequency estimates, which is presented as flood hydrographs with return periods of, for example, 2, 5, 10, 20, 50, and 100 years. Hydrology analysis consists of rainfall data collection, rainfall data analysis, unit hydrographs analysis, and flood hydrograph analysis.

2.1. Data Collection

Hydrology data available on the study area consits of rainfall and water level data. Since there is no rating curve of the rivers in this catchment, which can be used to convert water level to corresponding discharge, the flood frequency analysis will be based on the rainfall data. Rainfall data is collected from 6 (six) private stations and 4 meteorological stations (to date rainfall data from meteorological stations is in monthly form, while the frequency analysis requires daily step). From those ten rainfall stations, the data from three rainfall stations are used for further analysis based on the length of the data, completeness, etc. The three rainfall stations are : Ldg. Telok Sengat at Kota Tinggi, Johor [R 1540135], Ldg. Sg. Papan at Kota Tinggi, Johor [R 1541137], dan Ldg. Nam Heng [R 1639132] at Kota Tinggi, Johor with the length of rainfall data is 60 years.
Annual maxima series, which is the most commonly used technique for flood frequency analysis, selects the largest flood peak for each year of the data series and is the approach used in this work. Therefore there are 60 maximum daily rainfall from 60 years length of data (annual maxima series) for each rainfall stations.

2.2. Rainfall Data Analysis

For the trasformation from rainfall data to flood discharge, it needs to determine : [1] areal rainfall, [2] rainfall frequency, and [3] hourly rainfall distribution.

1. Areal Rainfall

The areal rainfall can be calculated using average algebra, Thiessen polygon, and Isohyet. For this work, the areal rainfall is calculated using average Algebra and the result is presented in Table 1.

Table 1. Areal rainfall for Johor Baru Basin

Year	**Average rainfall (mm)**	**Year**	**Average rainfall (mm)**
1948	145.9	1978	214.2
1949	103.7	1979	158.5
1950	130.6	1980	106.7
1951	187.0	1981	87.0
1952	132.0	1982	139.0
1953	116.8	1983	135.8
1954	251.2	1984	95.0
1955	138.0	1985	87.2
1956	196.3	1986	128.0
1957	94.4	1987	123.3
1958	112.5	1988	134.7
1959	142.9	1989	185.3
1960	126.3	1990	103.8
1961	84.8	1991	109.0
1962	106.3	1992	152.5
1963	85.9	1993	72.7
1964	136.9	1994	98.0
1965	73.0	1995	142.8
1966	85.7	1996	146.7
1967	164.4	1997	79.2
1968	127.1	1998	189.0
1969	183.0	1999	204.5
1970	79.1	2000	127.5
1971	129.2	2001	306.5
1972	87.8	2002	114.8
1973	146.7	2003	214.5
1974	78.8	2004	143.5
1975	80.7	2005	115.5
1976	181.5	2006	286.0
1977	109.5	2007	185.0

2. Rainfall Frequency

There are several frequency distributions which can be used for hydrology analysis :

[1] Normal distribution,
[2] Log-Normal distribution,
[3] Log-Pearson Tipe III distribution,
[4] Gumbel distribution.

To determine which distribution to be used is based on the statistical properties of the data, as presented in Table 2.

Table 2. Statistical Properties Analysis of Rainfall Data

Parameter	**Remark**	**Formula**	**Value**
n	Number of data	data	60
∑Xi	Cumulative maximum areal rainfall 60 years	∑Xi	8204.1
Xr	average	Xr = ∑**X**i/n	136.7
$\sum(Xi - Xr)^2$			150023.6
$\sum(Xi - Xr)^3$			9435983.335
$\sum(Xi - Xr)^4$			1769201790
S	Deviation standard	$S = \{\sum(Xi - Xr)^2/(n-1)\}^{0,5}$	50.426
Cv	Variation coefficient	Cv = S/Xr	0.3688
Cs	Skewness coefficient	$Cs = n \sum(Xi - Xr)^3/\{(n-1)(n-2) S^3\}$	1.2903
Ck	Coefficient of kurtosis	$Ck = n * \sum(Xi - Xr)^4 / \{(n-1)(n-2)(n-3) S^4\}$	4.7977

Variable coefficient of skewness (Cs), coefficient of variance (Cv) and coefficient of kurtosis (Ck) are used to determine which distribution is suitable for the rainfall data.

Table 3. Statistical distribution

Distribution	**Value**	**Result**	**Remark**
Normal	Cs = 0	1.2903	No
Log Normal	Cs/Cv = 3, Cs Positif	0.2689	No
Gumbel	Cs = 1,1396 Ck = 5,4	1.2903 4.7977	No
Log Pearson III	-	-	Yes

As it is presented in Table 3, the distribution which agrees with the statistical properties of the rainfall data in Johor Baru basin is Log Pearson Type III. Plotting data on the probabilistic sheet is carried out by sorting the data from the smallest to the largest and its probability is defined as :

$$P = \frac{m}{(n+1)}$$

dimana :	P	=	probability of data
	m	=	rank
	n	=	number of data

The theoritic line on the probability paper Log Normal can be calculated as follow :

$$X_T = Xr + K \cdot S$$

where :	X_T	=	rainfall depth for a return period
	Xr	=	average rainfall depth
	K	=	frequency factor
	S	=	standar deviation

To draw the theoritic line, several values of X_T are calculated to obtain a smooth curve (see Table 4). Those values are plotted on the probability paper of log Normal distribution to get a curve. As a result, daily maximum rainfall design or rainfall frequency can be obtained as presented in Table 5.

3. Hourly Rainfall Distribution

For the transformation of rainfall to flood hydrograph using unit hydrograph method, the rainfall data will be distributed into hourly rainfall. For this catchment, daily rainfall is concentrated during 4 hours with 90% of the rainfall falls within 24 hours distributed 10%, 40%, 40% and 10%. Assuming the rainfall frequency for various return period is distributed hourly with the same percentages, the hourly rainfall for Johor Baru Basin is presented in the Table 8.

2.3. Synthetic Unit Hydrograph GAMA I

This method was developed by Sri Harto (1993, 2000) based on characteristics of 30 catchments in Java islands. Several main variables of this synthetic unit hydrograph are time to peak (*TR*), peak discharge (Q_p), base time (*TB*), and recession curve determined by storage coefficient (*K*) which follows the equations :

$$Q_t = Q_p e^{-t/K}$$

where :

Q_t	: discharge at time t (m^3/s)
Q_p	: peak discharge (m^3/s
T	: time from peak discharge (hour)
K	: storage coefficient (hour)

Time to peak (*TR*) :

$$TR = 0.43(L/100\,SF)^3 + 1.0665SIM + 1.2775 \quad (1)$$

Peak Discharge (*QP*) :

$$QP = 0.1836A^{0.5886}TR^{-0.4008}JN^{0.2381} \quad (2)$$

Base Time (*TB*) :

$$TB = 27.4132 TR^{0.1457} S^{0.00986} SN^{0.7344} RUA^{0.2574} \quad (3)$$

Recession coefficient (*K*) :

$$K = 0.5617 A^{0.1798} S^{-0.1446} SF^{-1.0897} D^{0.0452} \quad (4)$$

Baseflow (***QB***) :

$$QB = 0.4715 A^{0.6444} D^{0.9430} \quad (5)$$

where :

A : catchment area (km^2)
L : length of main channel (km)
S : slope
SF : source factor, comparison between total length of first order river and total length of all order
SN : source frequency, comparison between the number of first order river and the number of all order
WF : width factor, comparison between catchment width at 0.75 L and 0.25 L from hydrometry station.
JN : number of river junction
SIM : symmetry factor, *WF* multiply by *RUA*
RUA : catchment area at the upper part
D : drainage density, number of total length of all order river per unit of catchment area.

3. RESULTS AND DISCUSSION

As mentioned in the Methodology above, the suitable distribution for the rainfall data is Log Pearson Type III. Using the distribution, the return period of design rainfall is calculated and the result is presented in Table 5.

Tabel 4. Computation for Drawing Theoritic Line of Log Pearson Tipe III

T (Tahun)	Kurtosis K Cs = 1,2903	Xt (mm)	1/T (%)
1.0101	-1.2525	73.541	99.0
1.0526	-1.206	75.886	95.0
1.1111	-1.064	83.047	90.0
1.25	-0.838	94.443	80.0
2	-0.210	126.111	50.0
5	0.719	172.956	20.0
10	1.339	204.220	10.0
25	2.147	244.965	4.0
50	2.667	271.186	2.0
100	3.211	298.618	1.0
200	3.914	334.067	0.5

Table 5. Rainfall Frequency of Johor Baru Basin

Kala Ulang (Tahun)	P_T (mm)
2	126.11
5	172.96
10	204.22
25	244.96
50	271.19
100	298.62

It is noted that the rain fell on Kota Tinggi in December 2006, i.e. 289 mm, nearly had 100 years return period of rainfall.

3.1. Flood Frequency

Using the rainfall frequency calculated above, the flood frequency will be computed using a Synthetic Unit Hydrograph GAMA1. For this purpose the hourly rainfall distributed was calculated and the result is presented at Table 6.

Tabel 6. Hourly Rainfall Intensity of Johor Baru Basin

Return Period (Years)	Rainfall Design (mm)	90 % Rainfall Design (mm)	Rainfall Intensity (mm/hr)			
			Hour-1 10%	Hour-2 40%	Hour-3 40%	Hour-4 10%
2	126.11	113.499	11.350	45.400	45.400	11.350
5	172.96	155.664	15.566	62.266	62.266	15.566
10	204.22	183.798	18.380	73.519	73.519	18.380
25	244.96	220.464	22.046	88.186	88.186	22.046
50	271.19	244.071	24.407	97.628	97.628	24.407
100	298.62	268.758	26.876	107.503	107.503	26.876

Estimation of the parameters based on observable physical characteristics of the catchments

- Catchment area : 1964.154 km2
- Length of main channel : 108 km
- River slope : 0,016 %
- Number of first order stream : 5283
- Number of all order stream : 9759
- Total length of first order stream : 1023.5 km
- Total length of all stream order : 1698 km
- Width of catchment at 0.25 L from the outlet : 38.73 km
- Width of catchment at 0.75 L from the outlet : 86.1 km
- Catchment area at upstream of the centre weight : 900 km2

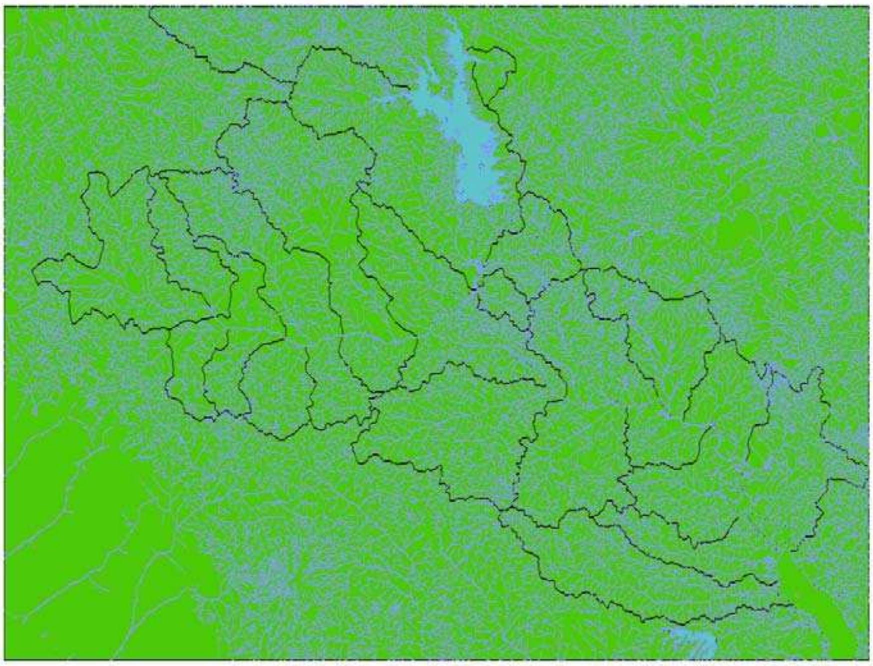

Figure 1. River network of Johor Baru Basin

Based on the computation using Synthetic Unit Hydrograph GAMA1, the flood frequency for Johor Baru Basin is as follows:

Table 9. Flood frequency for Johor Baru Basin

Return Period (years)	**Q_T (m^3/s)**
2	6084
5	9850
10	11619
25	13926
50	15410
100	16962

With the rainfall having nearly 100 years of return period, the flood occured during 2006-2007 flood event was close to 16000 m^3/s of discharge.

4. CONCLUSIONS

1. The length of rainfall data collected is 60 years and sufficiently long for hydrology analysis.
2. The analysis on return period of rainfall showed that the rain fell during 2006-2007 flood event had nearly 100 years period of rainfall.
3. The prediction for 100 years period of flood is 16.962 m^3/s.

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