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Hydrological Analysis on Semi-Urban and Urban Areas in Kajang

N.Azimah.Bahrum, M.A.Malek

***Abstract*— Flooding is a natural phenomenon occurred mainly due to heavy rain and improper water resources planning. It is one of the serious natural hazards that may cause damage to human lives, agriculture, environment and structures. This study focuses on the establishment of the latest trending on intensity duration frequency (IDF) curves and determination of various hydrological parameters such as curve number (CN), hydrograph peak time (t_p), time of concentration (t_c) and manning's roughness coefficient (n) for urban and semi-urban areas in Kajang, Selangor, Malaysia. 25 years of rainfall data from 1990 to 2014, obtained from the Department of Irrigation and Drainage (DID), Malaysia were used in this study. Moreover, the temporal pattern in this study is built of 15 minutes, 30 minutes, 60 minutes, 120 minutes, 180 minutes, 360 minutes, 720 minutes and 1440 minutes. Results from this study exhibited the new established IDF curves developed for Kajang at both semi-urban and urban areas for Sg. Jelok sub-catchment. Based on the calculations conducted, it is found that although the urban areas has a larger value of time of concentration, t_c at 12.98 hour and highest value of hydrograph peak time, t_p at 0.87 hour, various flooding events are still occurring in several places in the urban areas. These flooding are probably still occurring due to the current active residential constructions and on-going constructions of elevated inner city train (LRT) in addition to the old drainage system still used in the urban areas of Kajang that hinder the flow of surface runoff.**

***Index Terms*— Intensity Duration Frequency (IDF), hydrological parameters, urban, semi-urban areas, flooding.**

I. Introduction

Meteorology, physical characteristics and land use exercise significant influences to the hydrology characteristics of an area [1]. One difference in any of the characteristics between the two sub-catchments will result in a different behavior of their hydrology. Therefore, it is important to discuss the differences between semi-urban and urban areas as presented in this paper.

Large developments in urban areas of Malaysia have increased the percentage of impervious surfaces, resulting in a large amount of surface runoff. In addition, inadequate drainage facilities have also contributed to the short term floods namely flash floods occurring in urban areas [2].

These disturbing scenarios served as a statement of problem in this study. Researchers and other scholars worldwide have also taken initiatives to conduct studies specifically to reduce the negative effects of urban runoff and improving the local conditions [3], [4] and [14].

In the last decade, issues on flooding and storm water pollutions have risen in Malaysia. It was identified as major environmental impacts of urban development on storm water, discussed since the late 1970s due to widespread occurrence of flash floods, especially in Kajang. Nowadays, awareness on the importance of hydrology, as a branch of natural science has arisen. It includes assessment, development, utilization and management of water resources. This phenomenon can be proved with hard work in hydrology education, research, development and analytical techniques for global hydrological information collection [1].

There are several flood events recorded within Kajang town in the recent years especially in 2008, 2011 and 2012. Kajang experienced one of its worst flash floods in October 2008, submerging nearly two-thirds of the town. The flood level is between 0.5m to 1.5m and brought traffics to a standstill in many parts of the town. Disaster seemed certain with Langat River and its tributary Jelok River threatening to burst their banks after just an hour of rain [5].

Jelok River is one of the main tributaries of Langat River. It flows from the upstream of Kajang Prison and finally flows to Langat River at the downstream through Kajang town at the length of 9 km. The total catchment area of Jelok River is about 1765 hectares. The rapid development at the upstream of the river especially the on-going residential projects have increase the water runoff during heavy rains which caused flooding at the downstream of the river in Kajang town.

Hence, the scope of works in this study includes hydrological analysis such as double mass curves, intensity duration frequency (IDF) curves and temporal pattern were conducted at both the semi-urban and urban areas of Kajang. Comparison between semi-urban and urban areas will then be established.

I. Study Site and Methodology

The study area is located in Kajang, a town in the eastern part of Selangor, Malaysia. Due to data availability, one (1) rainfall station has been selected to represent the rainfall pattern of the area. The selected station is RTM Kajang station for Jelok River sub-catchment. In this study, Jelok River sub-catchment is further divided into two (2) smaller sub-catchments namely Kajang Prison (semi urban) and Kajang town (urban) areas. 25 years of rainfall data from 1990 to 2014 obtained from the Department of Irrigation and Drainage (DID), Malaysia were used. Fig. 1 shows the Jelok River sub- catchment.

Nur Azimah Binti Bahrum, Department of Civil Engineering, College of Engineering, Universiti Tenaga Nasional, 43000, Selangor, Malaysia.
Marlinda Binti Abdul Malek, Assoc. Prof. Ir. Dr., Department of Civil Engineering, College of Engineering, Universiti Tenaga Nasional, 43000, Selangor, Malaysia

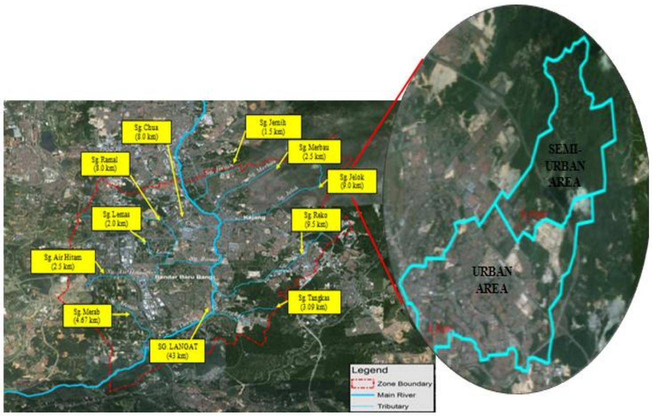


Fig. 1: Delineation of Jelok River Sub-Catchment

This study is carried out at Jelok River sub-catchment situated in Kajang, Selangor. Availability of information and data are the main factors for the success of this study. The information required for hydrological analyses are double mass curves, intensity duration frequency and temporal pattern. The hydrological parameters required are curve number, time of concentration (t_c), hydrograph peak time (t_p) and manning's roughness coefficient (n).

A. Frequency Analysis

Daily recorded rainfall data from year 1990 - 2014 at RTM Kajang Station (Station No. 2917001) are used in this study as shown in Fig.2.

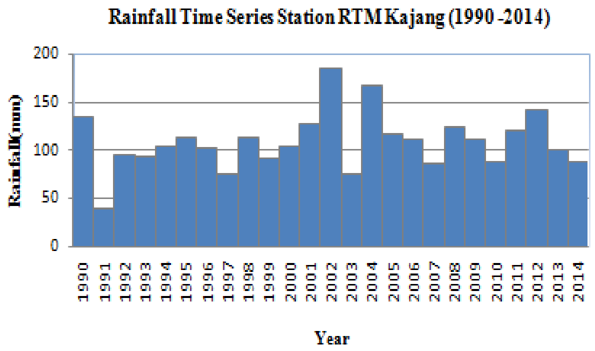


Fig. 2: Daily rainfall data at RTM Kajang Station (1990 - 2014)

The highest daily rainfall recorded at RTM Kajang Station occurred on 29th April 2002 is at185mm depth.

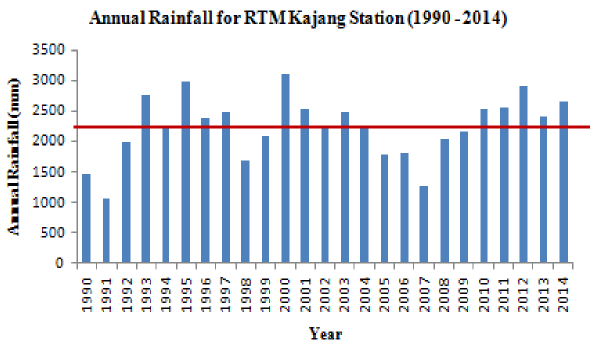


Fig. 3: Annual rainfall for RTM Kajang Station (1990 - 2014)

Fig. 3 shows the distribution of annual rainfall recorded at RTM Kajang Station (Station No. 2917001) from 1990 until 2014. The annual rainfall varies at each year, where in year 2000 the station received the highest amount of rainfall at 3098.6 mm. The least amount of rainfall received is in year 1991 with 1077.5 mm a year. The mean annual rainfall at the station is 2234.35 mm.

B. Double Mass Curve

The purpose of double mass curve is mainly to detect the rain gauge consistency. It can also be used to correct the annual precipitation recorded [6]. In addition, the mass curve is also used to check the consistency of many kinds of hydrological data. The mass curve is then used to adjust inconsistency of rainfall data. Graph of the cumulative data of one variable versus the cumulative data of a related variable is linear as long as the relation between the variables is a fixed ratio. The breaks in the mass curve of such variables are caused by changes in the relation between the variables.

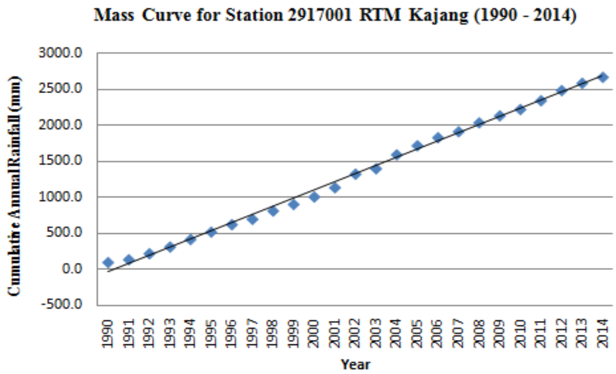


Fig. 4: Double mass curve for RTM Kajang Station (1990 – 2014)

C. Intensity Duration Frequency (IDF)

In many hydrological design projects the first step is to determine the maximum rainfall event. The most common method of determining the design storm event is using IDF curves which relate the rainfall intensity, duration, and frequency (or return period). It also provides a summary of the site's rainfall characteristics by relating storm duration and exceedance probability to rainfall intensity which is assumed to be constant over the duration (time of concentration) [1].The IDF curves of the study area were developed in this study using historical rainfall data available.

This approach depends on the information required and data availability. It is advisable to use instantaneous rainfall data and storm duration in minutes. In this study, the duration of rainfall used is 5, 10, 15, 30, 60, 180, 360, 540, 720, 1440 min for 3 days and 5 days for 2, 5, 10, 20, 50 and 100 years of reoccurrence interval. The IDF curves were developed using Gumbel's Distribution Method. This extreme value distribution was introduced by Gumbel (1941) and it is known as Gumbel's distribution. It is widely used for prediction of flood peaks, maximum rainfall and maximum wind speed. In this method, flood is defined as the largest from the 365 numbers of daily flows. Where, the annual series of flood flows constitute to a series of largest values of flows. The equations used in this method are shown in (1) to (3).

$$x_T = \bar{x} + K\sigma_{n-1} \quad (1)$$

Where

σ_{n-1} = standard deviation of the sample size of

$N = \sqrt{\frac{\Sigma x - \bar{x}^2}{N-1}}$

K = frequency factor expressed as:

$$K = \frac{Y_T - \bar{Y}_n}{S_n} \quad (2)$$

Which

$\bar{Y}_n$ = reduced mean, a function of sample size N

S_n = reduced standard deviation

Y_T = reduced variate, a function of T and given by:

$$Y_T = -\,[\text{In.In}\frac{T}{T-1}] \quad (3)$$

Fig. 5 exhibits the steps to develop IDF curves used in this study.

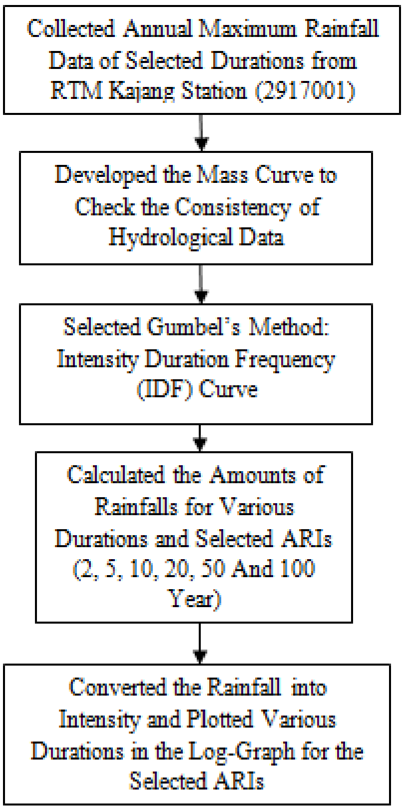


Fig. 5: Typical steps to develop IDF curve [7]

A. Design Temporal Rainfall Pattern

In this study, average variability method is used to develop the temporal rainfall pattern for Kajang as recommended by [8]. The temporal pattern basically represents the variation of rainfall intensities through the time of occurrence of a typical design storms.

This study utilizes all available data including the recent storm events in order to derive rainfall temporal pattern in this study. The design temporal patterns were derived from the observed temporal patterns of a large number of storm events at the chosen rainfall station. The design temporal patterns derived in this study cover the storm duration of 15, 30, 60,120, 180, 360, 720 and 1440 minutes. The standard time intervals recommended for the urban storm water modeling is as stated in Table I [9]. The highest rainfall bursts of selected design storm duration are chosen from the archived rainfall records available. The derivation of temporal pattern is conducted based on MSMA 2nd Edition – Chapter 2 [9].

Table I: Recommended Interval for Design Temporal Patterns [10]

Storm Duration (minutes)	**Time Interval (minutes)**
Less than 60	5
60 - 120	10
121-360	15
Greater than 360	30

Fig. 6 summaries the steps to develop Design Rainfall Temporal Pattern performed in this study.

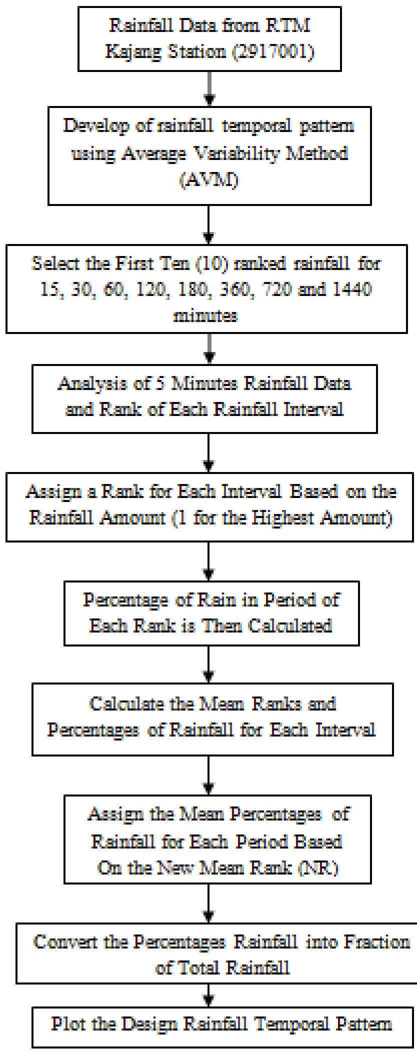


Fig. 6: Typical steps to develop IDF curve [7]

The average variability method (AVM) used, is explained in Table II. For example at 15 minutes duration, ten (10) selected most intense bursts with dates and annual maximum rainfall amount for 5 minutes rainfall interval are as shown in column D to F, where the first burst is 54mm, second and last burst are 0mm. The period will then be ranked in the next three columns G to I based on the rainfall amount from highest to lowest. For the same rainfall amount in the intervals, an average ranks are assigned. The average value (MV) for ranks of each period is obtained and is given the assigned ranks based on these average values. According to DID (2000) using these steps, the chronology on the ranks of rainfall periods such as heaviest rainfall period, second heaviest rainfall periods and etc., can then be identified.

In columns I to L, the percentages of rainfall in each period of each rank are listed in the order of magnitude, thus the average of the percentage will then be obtained. Based on Table II column I to L, the average rainfall (MV) at the heaviest rainfall period is 41% of the total burst, the second heaviest rainfall period is 34% and the third heaviest rainfall period is 25% of the total burst. The assigned average percentages of rainfall for each period based on the new rank (NR) are as listed in row NR for column G to I.

The chronological sequence of the periods is then determined. It is considered that the most intense rainfall should be assigned to the interval whose average rank is the lowest. Similarly, the second most intense rain is assigned to the period whose average rank is the second lowest and so on. The lowest average rank occurs in column H as shown in column G to I in Table II, which represents the second period of the rainfall burst. The next lowest average rank is in the third period of the burst and so on.

The fraction of total rainfall is then converted to percentages. This is shown in column G to I of Table II, where from the ten (10) most intense 15 minutes duration bursts shown would have 5 minutes periods containing 0.340, 0.410 and 0.247 of the total rainfall. Lastly, the histograms of rainfall temporal pattern (TPF for column G to I) are then plotted. This procedure is then repeated for other durations.

Table II: Analysis for 15 minutes rainfall duration for RTM Kajang station

		A	B	C	D	E	F	G	H	I	J	K	L
		Duration = 15 min Number of Intervals = 3			Rain (in mm) at 5 minute Interval			Rank of Each Rainfall Interval (Mean Rank for the Intervals with Same Rainfall Values)			Percentage of Rain for the Interval		
No.	Date	Time	Total Rain (mm)	Rank	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
1	1-Jan-97	8:15:00	54	1	54	0	0	1	2	2	100	0	0
2	4-Feb-92	21:15:00	51	2	18.1	30.7	2.2	2	1	3	35	60	4
3	20-Sep-93	15:45:00	46.3	3	32.8	13.1	0.4	1	2	3	71	28	1
4	13-May-09	15:15:00	43.2	4	17.3	15.1	10.8	1	2	3	40	35	25
5	30-Oct-02	15:30:00	38	5	9.5	15.5	13	3	1	2	25	41	34
6	25-Aug-96	15:30:00	36.9	6	11.9	16.6	8.4	2	1	3	32	45	23
7	31-Aug-10	16:15:00	36.1	7	7.7	11.4	17.1	3	2	1	21	32	47
8	10-Jan-08	16:45:00	36	8	7.5	11.5	17	3	2	1	21	32	47
9	25-Oct-12	20:00:00	33.7	9	11.4	10.9	11.4	1	3	1	34	32	34
10	3-Nov-13	20:00:00	33.4	10	10.2	12.7	10.5	3	1	2	31	38	31
						Mean Value (MV)		2	1.7	2.1	41	34	25
						New Rank (NR)		2	1	3	1	2	3
						Rainfall Pattern (in % as per the New Rank)		34	41	25			
						Design Temporal Pattern, in fraction (TPF)		0.340	0.410	0.247			

E. Curve Number (CN)

In this study, the CN number is calculated at the downstream and upstream of Jelok River sub-catchment for land use at both semi-urban and urban areas. Land use map for the study areas was created using digital topographic maps and satellite images. CN value is calculated by using weightage average as in (4) [1].

$$\text{Weighted CN} = \frac{\text{Total Product}}{\text{Total Area}} \quad (4)$$

F. Time of Concentration, t_c

Time of concentration, t_c is the time required for a particle of water to flow hydraulically from the most distance point on a watershed to the design point in question. In this study, t_c

from SCS Lag equation (1973) is used, due to the characteristics of Jelok River sub-catchment. Equation (5) [13] is used in this study.

$$t_c = \frac{100\, L^{0.8}\left[\left(\frac{1000}{CN}\right) - 9\right]^{0.7}}{1900\, S^{0.5}} \quad (5)$$

G. Hydrograph Peak Time, t_p

The hydrograph peak time, t_p is calculated based on time of concentration, t_c. Hydrograph peak time, t_p is obtained by delineating the length, area and elevation from the sub catchments of the study area, identified using Geographical Information System (GIS). The t_p value is then determined as in (6).

$$t_p = 0.067\ t_c \qquad (6)$$

I. RESULT AND DISCUSSION

The nearest rainfall station located within the study area is RTM Kajang Rainfall Station (Station No. 2917001). This rainfall station is chosen for the derivation of Rainfall Intensity Duration Curve (Fig. 7) and temporal pattern (Fig. 8) which are then used as rainfall inputs for the hydrological model. The analysis contains hydrological analysis and hydrological parameters such as curve number (CN), hydrograph peak time (t_p), time of concentration (t_c) and manning's roughness coefficient *(n)* for urban and semi-urban areas in Kajang.

A. Design Intensity Duration (IDF) Curve

In this study, hydrological analysis using Gumbel's Distribution Method was performed in order to establish the latest trending of IDF curves in Kajang as shown in Fig. 7. These new IDF curves were developed for both the semi-urban and urban areas in Kajang. Based on data exploration, within the study area it is found that, only RTM Kajang Rainfall Station (Station No. 2917001) has rainfall data available at the duration of 20 years. A minimum of 20 years data is required to establish IDF curves [1].

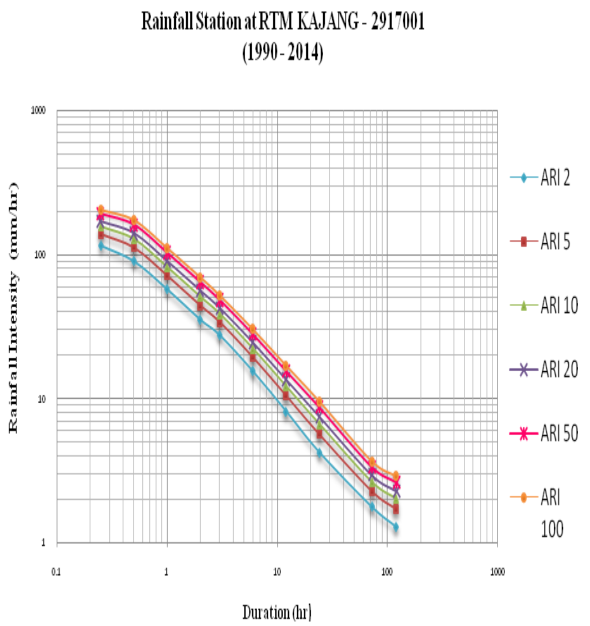


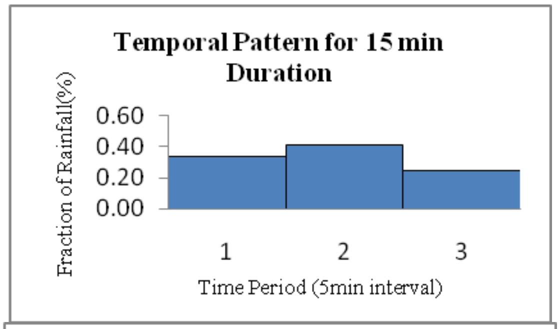
Fig. 7: IDF Curve at station 2917001 (RTM Kajang)

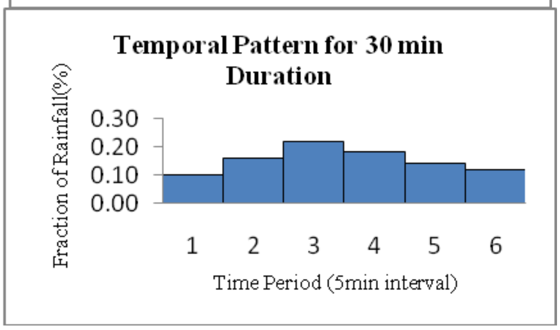
Fig. 7 shows the intensity duration frequency (mm/hr) curves developed in this study at various return period or Average Recurrence Interval (ARI) from 2 years till 100 years for RTM Kajang Rainfall Station from 1990-2014. The y-axis shows the rainfall intensity in mm/hr, and the x-axis shows the rainfall duration (hour). The nearly parallel lines on the IDF Curves represent probability, or frequency. Each plotted line in the graph represents rainfall events with the same probability of occurrence, in a range of durations with duration plotted on the x-axis, rainfall intensity (mm/hr) on the y-axis and a series of curves, one for each design return period (ARI-2, ARI-5, ARI-10, ARI-20, ARI-50 and ARI-100).

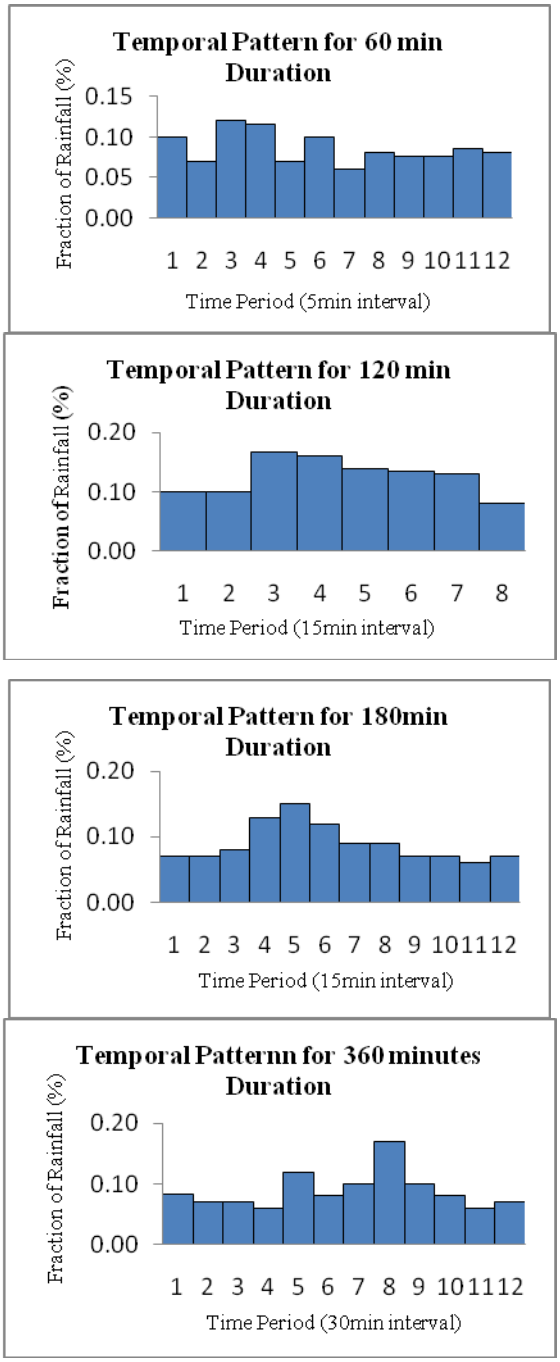
A. Design Temporal Rainfall Pattern

Analyses are conducted to develop temporal pattern for the selected rainfall station before regional temporal pattern is developed in this study. Selection of the ten most intense rainfalls for each 15, 30, 60,120,180, 360, 720 and 1440 minutes duration are required to develop the temporal pattern based on data from 1990 to 2014 for Kajang, Selangor.

For instance, the 1 day temporal pattern can be determined by taking the most intense 24 hours rainfall burst within that storm. Fig.8 shows the temporal patterns for different durations developed. A comparison is made between temporal pattern developed in this study and the one adopted from normalized design rainfall temporal pattern in Selangor [7]. It is found that the temporal patterns obtained are quite different for all durations







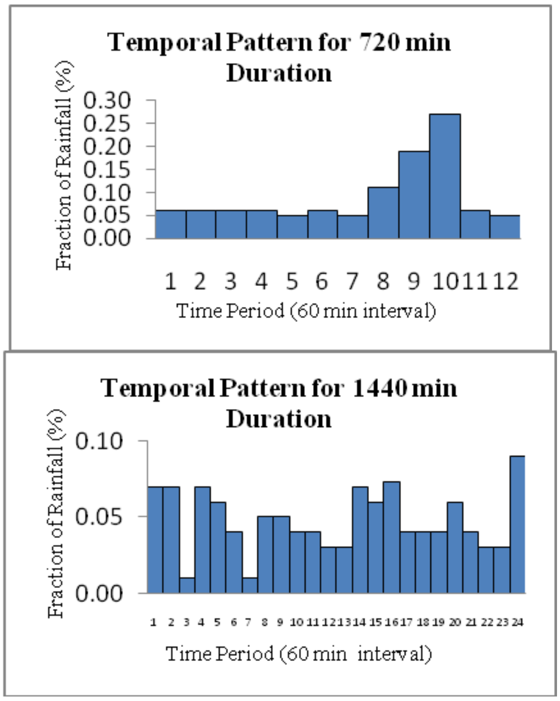


Fig. 8: Rainfall hyetograph for different durations RTM Kajang rainfall station (1990 – 2014)

A. Curve number (CN)

Approximately 85% of the Jelok River sub-catchment area is within the municipality of Kajang which has been developed with housing, shops and factories. Fig. 9 shows the percentage of various land use activities in Jelok River sub-catchment.

CN is a coefficient that reduces the total precipitation to runoff, potential after losses such as evaporation, absorption transpiration and surface storage. The semi- urban (SJ 1 and SJ 2) areas in Kajang have a total area of 709.34 ha. Based on Fig. 10, the forest area is the largest land use (53%) in this semi-urban area of Kajang. In this forest area, Jelok River Forest Reserve is located at the upstream of the catchment.

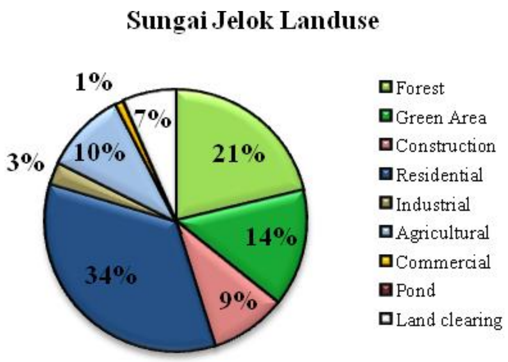


Fig. 9: Percentage of Land Use activities in Jelok River sub-catchment

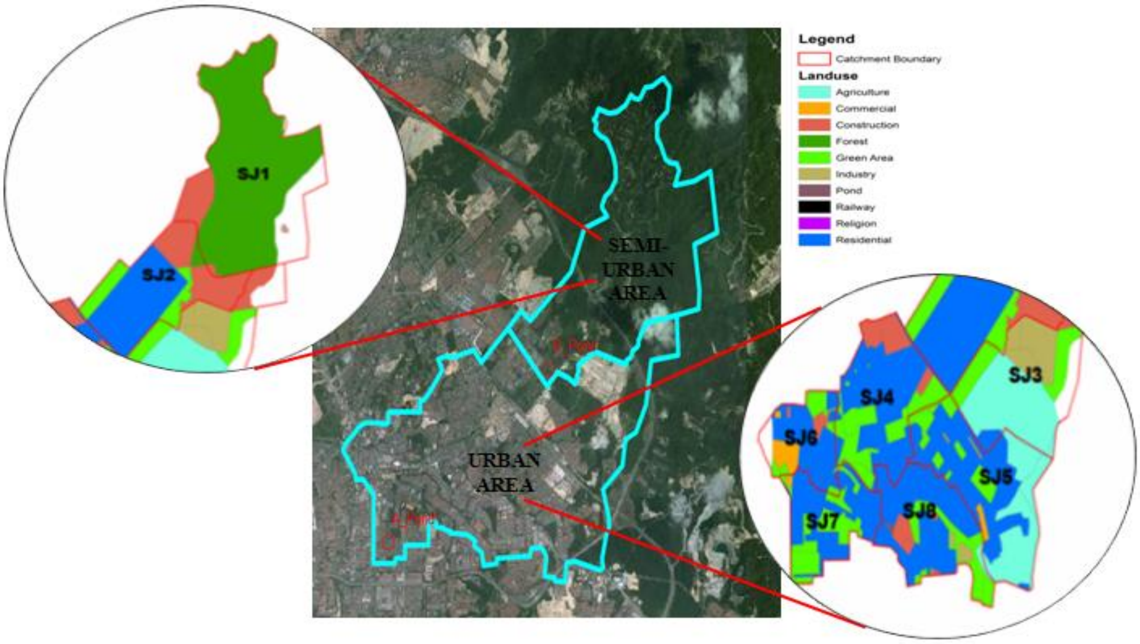


Fig. 10: Location on various Land Use Activities in Jelok River Sub- Catchment

Based on the Fig. 11, residential area is the largest land use (53%) in semi- urban (SJ 1 and SJ 2) areas in Kajang.

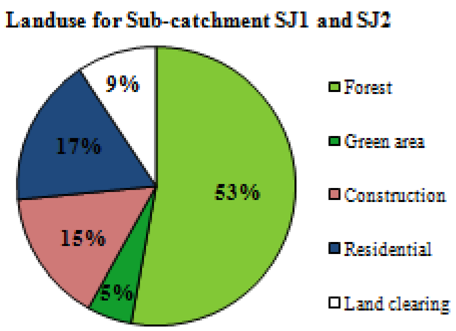


Fig. 11: Percentage of Land Use Activities in Semi-Urban Areas of Kajang

Based on the Fig. 12, residential area is the largest land use (46%) in urban areas of Kajang. Kajang town is located in this urban area.

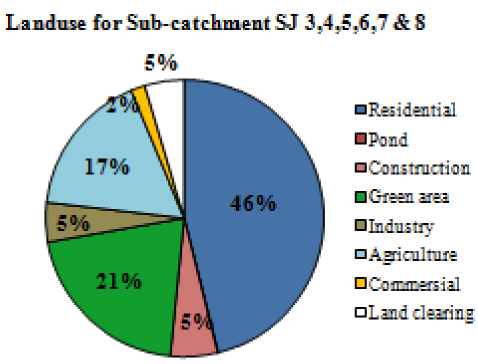


Fig. 12: Percentage of Land Use Activities in Urban Areas of Kajang.

The CN values for all the types of land uses and hydrologic soil group in Jelok River sub-catchment are adopted from Technical Release 55 [13]. For the semi-urban areas, it is found that the lowest CN value is 65 for forest. The construction area has the highest CN value at 88. Therefore, the weighted CN value for the semi-urban areas is 74.

For the urban areas, it is found that the lowest CN value at 80 is for residential area. The pond area has the highest CN value at 96. Therefore the weighted CN value for urban areas is 83. Based on the calculations conducted, there are differences in the CN values for semi-urban and urban areas due to its variety land use activities.

A. Time of Concentration (t_c)

In order to determine the time of concentration, $t_{c,}$, length of river, L (ft) and the distance weighted channel slope, S (%) are to be calculated. The highest t_c value obtained is at the urban areas at 12.98 hour. This is because the urban areas are bigger in size as compared to semi-urban areas. The lowest t_c value is in the semi-urban areas at 6.43 hr.

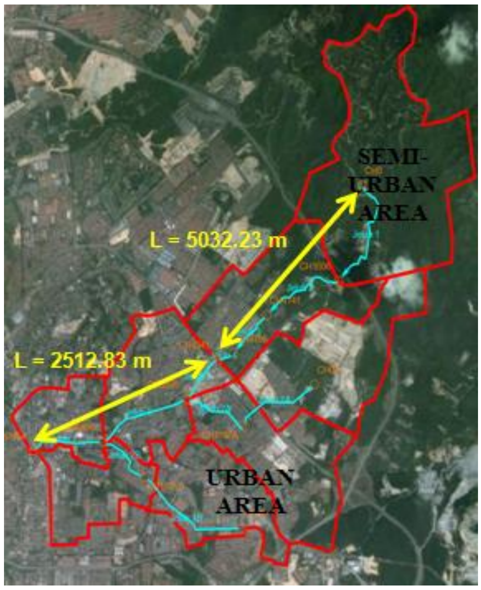


Fig. 13: Sub-catchment of semi-urban and urban areas of Jelok River

The hydrograph peak time (t_p) is calculated based on time of concentration (t_c). Results for both t_c and t_p obtained are presented in Table III.

Table III. Hydrograph Peak Time, t_p for for Jelok River Sub-Catchment

Sub Catchment	Time of Concentration, t_c (hr)	Hydrograph Peak Time, t_p (hr)
Semi- urban	6.43	0.43
Urban	12.98	0.87

These values were obtained using SCS Lag Equation (1973). Based on hydrology theory, the longer the Time of Concentration, t_c and the higher the Hydrograph Peak Time, t_p will allow enough time for the surface runoff to flow across the sub-catchment, where gushes of water(in a very short time span) accumulating to overflow resulting in floods can be avoided. As seen in Table III, although the urban area has a larger value of t_c at 12.98 hour and highest t_p value at 0.87 hour, various flooding events are still occurring in several places in the urban areas. These flooding are probably still occurring due to the current active residential construction activities and on-going constructions of elevated inner city train (LRT) in addition to the old drainage system still used in the urban areas of Kajang that hinder the flow of surface runoff.

B. Manning's Roughness Coefficient (n)

In this study, manning's roughness coefficient in river channel and floodplain area used for semi-urban areas is between 0.03 and 0.05 [14]. Fig. 14 illustrates the drainage system within Jelok River sub-catchment that flows from the upstream, where it is mostly hills and forest to the downstream where Kajang Prison is located. The entire channel in semi-urban areas is classified as natural or earth with manning's, n value is 0.03. Value of manning, n for overbank areas is also used as 0.03. The river channels and floodplain or overbank areas are based on actual drainage system and existing conditions on site.

In this study, it is found that most channels in the urban areas are built up with concrete as shown in Fig. 14. The concrete is divided into two (2) categories, namely finished and unfinished. The value of manning, n for both types of channel is 0.015 and 0.017 respectively. While, the value of manning, n for the channels' overbank used is 0.03, categories as pasture of short grass. Based on theory of hydrology, in general, higher stages of river water should result at lower manning's, n values. This shows in the Jelok River sub-catchment for both semi-urban and urban areas where the risen of river water has resulted in the various flooding events in Kajang.

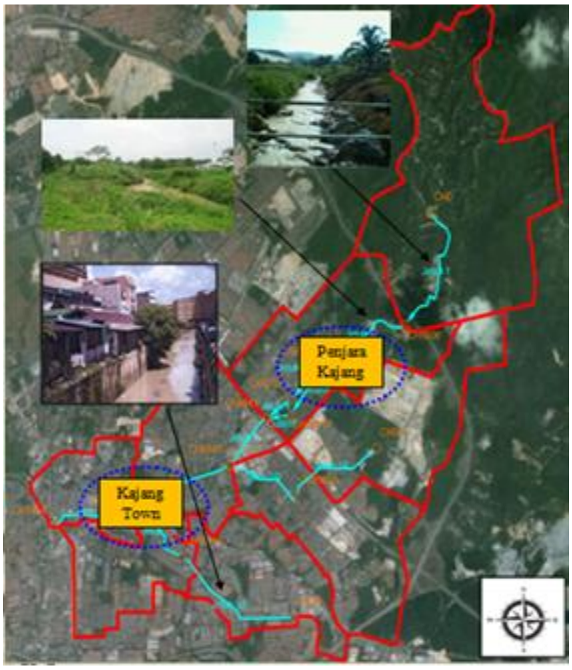


Fig. 14: Drainage Layout of Jelok River Sub-catchment

I. CONCLUSION AND RECOMMENDATION

This study has developed a set of hydrological analysis on semi-urban and urban areas for Kajang. In this study, hydrological analysis is performed to establish the latest trend of IDF curves for Jelok River sub- catchment. Based on calculations conducted, it is found that there are no obvious differences in the hydrological parameters except for time of concentration, t_c and hydrograph peak time, t_p where the values for urban areas are found to be higher. This paper presents a comparison on hydrological analyses between semi-urban and urban areas. Thus, recommendation is made for future studies that utilize bigger catchment for study areas which could cover vast geographical, hydrological and land use activities. All hydrological calculations performed in this study are based on MSMA 2^{nd} edition 2012 specifically designed for Malaysia's conditions and environment.

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Nur Azimah Binti Bahrum, Date of birth is 7th December 1990.Age 26 years. Education: Bachelor of Civil Engineering (Hons.), Department of Civil Engineering, College of Engineering, Universiti Tenaga Nasional (UNITEN), Selangor, Malaysia (2012 – 2016). Diploma in Civil Engineering at Polytechnic Sultan Idris Shah, Selangor (2009-2011), Work experience: at Public Works Department (JKR) Gombak (2010) and ZHL Engineer Sdn. Bhd. Consulting Engineers (2015) as practical trainer. Achievements: Dean's List Award for 2 semesters at Universiti Tenaga Nasional and Dean's List Award for Diploma at Polytechnic of Sultan Idris Shah.

Marlinda Binti Abdul Malek, Assoc. Prof. Ir. Dr. FIEM. Academic Qualification: PhD in Civil Engineering (Water Resources Eng.), Universiti Teknologi Malaysia, 2008.M.Sc in Civil Engineering, University of East London, United Kingdom, 1998, Working Experience: Associate Professor in Civil Engineering Department, UNITEN (2001- to date), Senior Engineer in Consulting Engineering Company (1991-2001). Publications: Extreme Learning Machines: A New Approach for Prediction of Reference Evapotranspiration, Suitability of ANN Applied as a Hydrological Model Coupled with Statistical Downscaling Model: A Case Study in the Northern Area of Peninsular Malaysia and others. Research/Projects: Hydrological Study of Surface Water & Groundwater in Klang River Basin: The Use of ANN in Development of Rainfall Model from Incomplete Hydrological Data in Malaysia and others.