STUDY ON MALAYSIAN URBAN RAINFALL-RUNOFF CHARACTERISTICS: CASE STUDY OF SUNGAI KAYU ARA, DAMANSARA, SELANGOR

by

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LIST OF SYMBOLS

C_s = Storage coefficient
I = Potential Infiltration depth
T_p = Time-to-peak
T_c = Time of concentration
T_{recess} = The time measured from the peak discharge to the end of direct runoff
T_b = Time base
A_{tri} = Illusive triangular area (m^3) under discharge hydrograph
A_T = Total trapezoidal area (m^3) under discharge hydrograph
Q = Instantaneous discharge (m^3/s)
t = Time interval (10 min)
R = Direct runoff depth (mm)
p = Average precipitation depth between two isohyets (mm)
A_{eff} = Effective rainfall area (m^2) with minimum precipitation at 3 mm
A = Inter-isohyet area (m^2)
A_{isoh} = Total isohyetal area (m^2)
P = Mean areal rainfall (mm)
W_s = Fraction of sub-area 1 (suburban/rural area)
P_s = Mean areal rainfall at sub-area 1 (suburban/rural area)
W_u = Fraction of sub-area 2 (developed area)
P_u = Mean areal rainfall at sub-area 2 (developed area)
J = Distance of centroid of net storm from the start of time step (min)
H = Rainfall distributed in hyetograph ordinate (mm/10 min)
C_v = Coefficient of variation
r^2 = Coefficient of determination
F_u = Rainfall concentration at developed area
F_s = Rainfall concentration at suburban/rural area
C = Runoff coefficient
L = Lower 95 % confidence limit
U = Upper 95 % confidence limit
ϕ = Constant loss rate
C_{skew} = Skew coefficient
γ = Semivariance of averaged square difference between rainfall data
h = Lag distance

LIST OF SYMBOLS (Cont'd)

α = Direction of vector h
N = Number of observation
z = Random variable
x = Location of point data
A' = Catchment area in km^2
R_v = Storm runoff coefficient proposed by Schueler (1987)
I' = Degree of imperviousness (%)

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Leong, W.C. and Abustan, I. (2006) *Development of Urban Runoff Characteristics of Sg. Kayu Ara Catchment, and to Validate Rainfall-Runoff Chart in the Malaysian Stormwater Management Manual (DID, 2000).* In: Malaysian Hydrological Society. National Conference on Water for Sustainable Development towards a Developed Nation by 2020, July 2006, Port Dickson. Kuala Lumpur: Humid Tropic Centre, Malaysian Department of Irrigation and Drainage.

Leong, W.C. and Abustan, I. (2006). *Development of Malaysian Urban Rainfall-Runoff Characteristics*. In: ACEPRO, Universiti Sains Malaysia. Postgraduate Seminar 2006, August & October 2006, Nibong Tebal. Seberang Perai Selatan: School of Civil Engineering, Universiti Sains Malaysia.

KAJIAN CIRI-CIRI HUJAN-AIR LARIAN BANDAR DI MALAYSIA: KAJIAN KES SUNGAI KAYU ARA, DAMANSARA, SELANGOR

ABSTRAK

Pengetahuan dalam agihan hujan yang berubah mengikut ruang dan masa serta respon hujan-air larian amat diperlukan dalam aplikasi kejuruteraan untuk kawasan pembangunan beriklim tropika lembap. Kajian ini lebih berfokus kepada respon air larian disebabkan kuantiti hujan yang berubah dalam kawasan tadahan bandar. Rekod hujan taburan harian dan data sela 10 minit untuk hujan serta air larian mulai tahun 1996 hingga 2004 telah dianalisa. Keputusan menunjukkan bahawa kuantiti hujan adalah lebih tinggi di kawasan bandar berbanding kawasan sub-bandar atau pedalaman. Sebahagian besar hujan tahunan didapati disumbangkan oleh ribut sewaktu musim perantaraan monsun. Berikutan itu, hubungan antara air larian dan hujan telah diterbit dan ditentusahkan dengan menggunakan model statistikal (SPSS®). Untuk mengenal pasti tahap perwakilan respon hujan-air larian tersebut, kesan tumpuan hujan antara kawasan yang telah dibangunkan dan kawasan sub-bandar/pedalaman ditentukan. Analisis kadar kehilangan tetap menunjukkan bahawa air larian kumulatif boleh berlaku melalui keamatan hujan yang tetap. Korelasi antara pemalar air larian dengan keamatan hujan telah dikaji. Ini bertujuan untuk menilai Carta Rekabentuk 14.3 dalam Manual Saliran Mesra Alam Malaysia (MSMA) yang digunakan untuk menganggar puncak kadar alir. Peratusan taburan nilai kajian atas jenis penggunaan tanah yang diklasifikasikan dalam carta rekabentuk tersebut didapati berhubung-kait dengan tahap litupan atas tanah yang dianggarkan melalui informasi topografi digital. Ini menyatakan bahawa, untuk takat tertentu, carta dengan pemalar air larian melawan keamatan hujan yang diguna pakai daripada *Australian Rainfall and Runoff 1977* masih sesuai untuk diaplikasi dalam keadaan perbandaran di Malaysia. Untuk memastikan bahawa kriteria rekabentuk saliran bandar yang lebih tinggi diperlukan untuk masa akan datang, respon kawasan tadahan terhadap urbanisasi

telah ditentukan. Merujuk kepada faktor seperti agihan hujan mengikut ruang dan masa, puncak kadar alir yang meningkat dan waktu ke puncak berkenaan akibat urbanisasi selama tujuh (7) hingga lapan (8) tahun telah berjaya dikenal pasti.

STUDY ON MALAYSIAN URBAN RAINFALL-RUNOFF CHARACTERISTICS: CASE STUDY OF SUNGAI KAYU ARA, DAMANSARA, SELANGOR

ABSTRACT

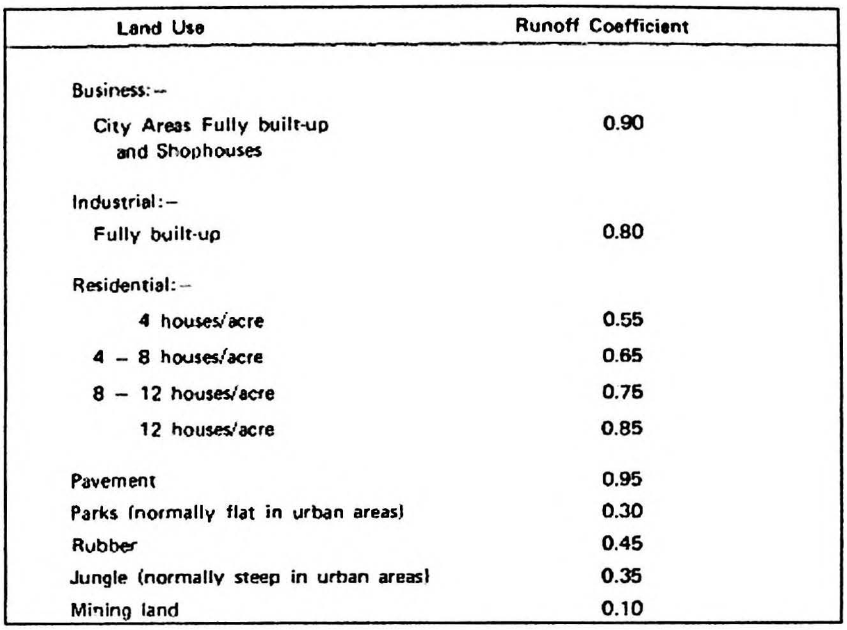
Knowledge on the rainfall spatial and temporal distribution, as well as the rainfall-runoff response, is vital in engineering practices for developing area in the humid tropics. Nevertheless, this study will primarily discuss the runoff response due to varying rainfall within small urban catchment in Malaysia. Daily totals rainfall and 10-min intervals rainfall and runoff data from year 1996 to 2004 had been analysed. The result shows that greater rainfall volume fell on developed area, compared to suburban/rural area. This is proven that most of proportion of annual rainfall extent is contributed by strong convective storm during the inter-monsoon season. The relationship between direct runoff and mean areal rainfall was developed and validated using statistical model (SPSS®). To verify the representativeness of rainfall-runoff response, rainfall concentration between the developed area and suburban/rural area was determined. Analyses of constant loss rates indicate that the generation of cumulative direct runoff can be attributed to the constant rainfall intensities. The correlation between the derived runoff coefficients and rainfall intensities was made. This was to assess the Design Chart 14.3 for peak flow estimation in the Malaysian Urban Stormwater Management Manual (MSMA). The distribution percentage of observed data among classified land uses in the relevant design chart is found to have corresponded quite well with the degree of land use covers, estimated from digital topographic information. This implies that, the runoff coefficient versus intensity chart adopted from the Australian Rainfall and Runoff 1977 is still in the suitable range for use in Malaysian urban condition. To ensure a future need for higher design requirement in urban stormwater control facilities, the catchment response subjected to development was determined. Factors such as rainfall volume and its temporal and spatial distribution of rainfall were taken into account for this purpose. The increasing peak flow with corresponding time-to-peak resulted from seven (7) to eight (8) years' urbanization had been successfully identified.

CHAPTER 1
INTRODUCTION

1.1 Research Background

An extreme rainfall event with long duration and high frequency is common in Malaysian urban cities, especially in the West Coast area. This phenomenon is formed mostly through convective process (Embi and Dom, 2004), followed by monsoon seasons. The occurrence of three devastating flash floods in three continuous years (i.e. 26 April 2001, 11 June 2002 and 10 June 2003) within urban cities and town areas (DID, 2004) has created the awareness of designing better urban stormwater management system for the future. According to a study by Desa et al. (2005) in urbanized Kerayong catchment near Kuala Lumpur, the highest 5-min point intensity in the greatest storm event in year 2003 was 222 mm/hr and the rain lasted for 114 minutes. Since the high volume of stormwater rapidly disposed from urban area will cause inundation in the downstream area, control at source concept is hence, introduced in the Malaysian Urban Stormwater Management Manual (DID, 2000).

To overcome these flash flood problems, the Hydrological Procedure No.16 (HP 16): Flood Estimation for Urban Areas in Peninsular Malaysia had actually been published since the year 1980. Among the important issues discussed is the modified Rational Method which is suitable in designing urban drain system for large catchment whenever its rainfall spatial and temporal variations are significant. This is the reason why the standard Rational Method is only recommended to be used for urban catchment which is smaller than 25 km^2 (IEA, 1987). Realizing the fact that standard runoff coefficient is incapable to account for the storage effect in large catchment, therefore in the HP 16, the storage coefficient (C_s) is developed. It is served as the multiplier to runoff coefficient in the computation of peak flow rate using standard Rational formula (Fricke et al., 1980).



Land Use	Runoff Coefficient
Business:–	
City Areas Fully built-up and Shophouses	0.90
Industrial:–	
Fully built-up	0.80
Residential:–	
4 houses/acre	0.55
4 – 8 houses/acre	0.65
8 – 12 houses/acre	0.75
12 houses/acre	0.85
Pavement	0.95
Parks (normally flat in urban areas)	0.30
Rubber	0.45
Jungle (normally steep in urban areas)	0.35
Mining land	0.10

Table 1.1: Runoff coefficient for Malaysian urban areas (Fricke et al., 1980)

The runoff coefficients, as shown in Table 1.1 are proposed in the HP 16 for Malaysian urban area based on different types of land use. Series of sources had been referred to determine the most suitable runoff coefficient in Malaysian urban catchment. This includes the design values recommended by the American Society of Civil Engineers (ASCE), The Ministry of Environment Singapore, Proctor and Redfern International Ltd. as well (Fricke et al., 1980). Nevertheless, runoff coefficient may change due to the impact of urbanization over the years.

Findings by Salleh (1998) show that the urbanization rate in year 1990 at Peninsular Malaysia had reached 54 per cent. There is as high as 14 per cent increment compared to the year 1980. Besides the increasing numbers of impervious area by 0.56, 0.82 and 0.83 % per year at Damansara, Penchala and Klang respectively (Ruzardi et al., 1999), rainfall intensity particularly over these urban zones also shown an increasing trend. It is most probably due to the more significant urban heat island effect (Embi and Dom, 2004). Therefore a new approach in determining the runoff coefficient has been vindicated. In line with this, the Malaysian Urban Stormwater Management Manual (MSMA) was introduced by the Department of Irrigation and Drainage Malaysia (DID) in year 2000. The MSMA had superceded the foregoing guidelines in HP 16 with sets of runoff coefficient that change with varying intensity according to different land uses. The design chart as shown in Figure 1.1 was adopted from the Australian Rainfall and Runoff 1977 and is stipulated in Chapter 14 in the MSMA.

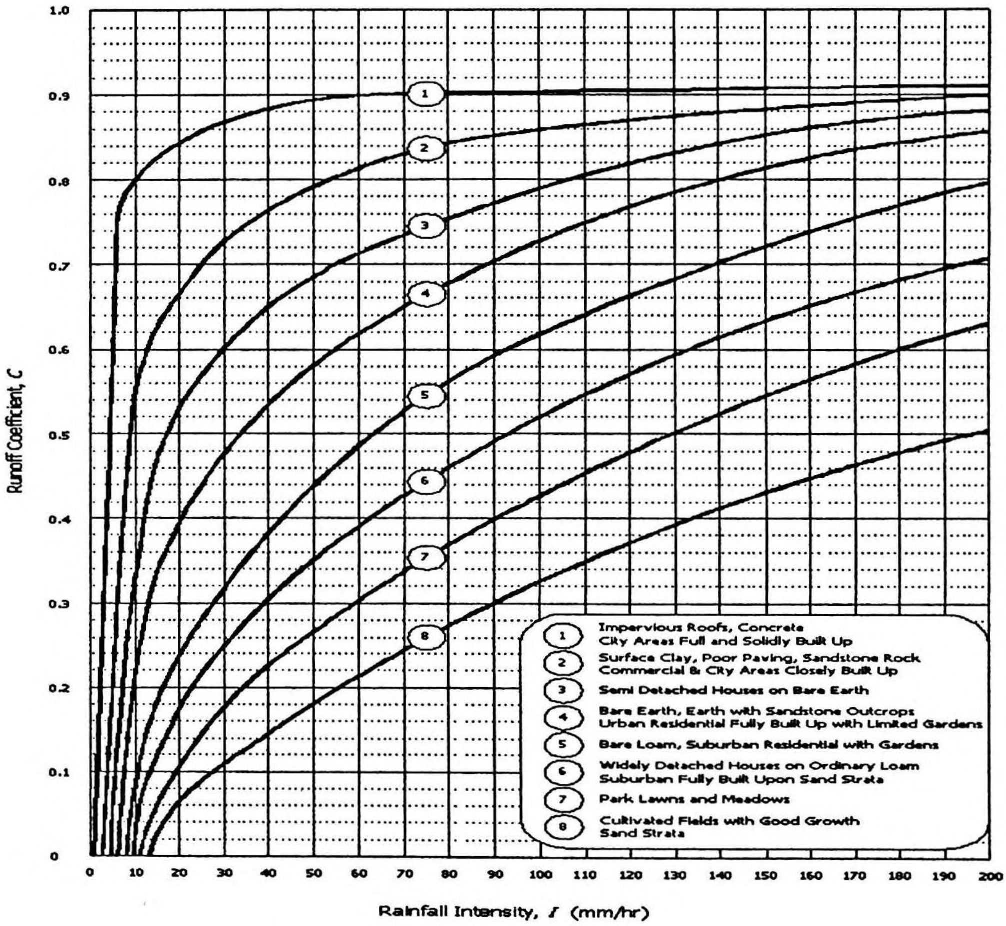


Figure 1.1: Runoff coefficients for urban catchments (DID, 2000)

The MSMA guidelines, particularly in the aspect of peak flow estimation, are mostly based on the standard codes of practice in the Australian Rainfall and Runoff (1977). The design curves in Figure 1.1 for various land uses were formed based on rainfall and runoff records in Australian cities of different regions. In contrast to Australia with 60 per cent of total area belonging to temperate climate (http://www.worldtravelguide.net, 2007), the intensity and frequency of rainfall in Peninsular Malaysia is relatively higher. Occurrence of long duration rainfall with high intensity due to monsoon seasons (i.e. December to March, June to September) in transition with convective rainfall season may have raised the soil moisture content, in most of the time (Desa and Niemczynowicz, 1996). In order to justify the applicability of such design curves in Malaysia, an urban rainfall-runoff study which complies with local humid tropical condition is urgently needed.

1.2 Objectives

The study is only part of the Intensification Research of Priority Area (IRPA) project endorsed by the Ministry of Science, Technology and The Environment Malaysia (MOSTI) under The 8th Malaysian Plan. MOSTI has appointed a researcher from the Universiti Sains Malaysia to conduct this study based on the data source provided by the DID Malaysia. Therefore, the research findings would be served as an intellectual property between the Universiti Sains Malaysia and the DID Malaysia. Further, completed study could be used as a guideline to water-related agencies in designing the best proper urban drainage facilities. The study findings can also be transferred to other countries in the South-East Asia which have difficulties in managing urban runoff. Here are the four (4) main objectives to be reached in this study:

1. to study the spatial and temporal distribution of rainfall within urban catchment,

2. to develop the rainfall-runoff relationship for urban catchment,
3. to assess the MSMA Design Chart using derived hydrological parameters, and
4. to determine the catchment response over years.

1.3 Scope of Study

Desk study was the preliminary step to be carried out for better understanding in the study process. Research design had been worked out to spell out all the study requirements and the steps. The hydrological data and digital topographic data were acquired from the DID Hydrology Unit and the JUPEM , Malaysia. Besides, the material and software model for analysis were set up before the following four (4) sections of researching works were commenced.

1.3.1 Chapter 2 – Literature Review

In this section, a variety of literature material is needed in order to determine whether there is any similar research had been conducted. The significance of rainfall distribution, rainfall-runoff response, as well as the change in runoff response due to urbanization are focused into detail. Different types of approach for instance, the testing of data consistency, estimation of mean areal rainfall and direct runoff, and loss rate analysis are evaluated. This is important to choose a proper approach with strong backup of literature sources.

1.3.2 Chapter 3 – Methodology

This section will discuss on how the baseline data was utilized for various quantitative analyses. The analysis of rainfall distribution pattern, rainfall-runoff response and loss rate are described with regard to the information obtained in Chapter 2. This chapter explains the step-by-step analysis model and statistical approach. Besides, the method of analysis criterions such as the selection of effective rainfall-runoff events and formation of catchment properties are clearly stated. Example of the application of analysis model is also provided for a better illustration.

1.3.3 Chapter 4 – Results and Discussion

Among those being discussed in this chapter are the differences in rainfall distribution between urban and suburban/rural zone, the development of urban rainfall-runoff relationship as well. In addition, the validation of analysed hydrological parameters is used to assess the MSMA Design Chart 14.3. The degree of runoff changes in terms of peak discharge and time-to-peak within seven (7) to eight (8) years of urbanization is the final part of the study.

1.3.4 Chapter 5 – Conclusion

The first part in this chapter will initially outline the brief work frame of the study in brief. It concludes the results of study through the most comprehensive form. The aspect being concluded is related to the four (4) main anticipated objectives as discussed in the preceding section. The following part will suggest some of the constructive ideas to make the future rainfall-runoff study to be more efficient.

CHAPTER 2
LITERATURE REVIEW

2.1 Rainfall Characteristics

Generally, Peninsular Malaysia receives the highest precipitation during the transition period between the northeast (i.e. December to March) and southeast monsoons (i.e. June to September). The most intense rainfall usually occurs in the month of April, then followed by October and November (DID, 2000). However, January (northeast monsoon) is the driest month whereby it only covers 4.57 per cent of the long term mean annual rainfall (Desa and Niemczynowicz, 1996).

To compare the two (2) monsoon seasons, the southwest monsoon draws less precipitation, especially in the month of July (Goh, 1974). Wind flows below 15 knots in the southwest monsoon while for the northeast monsoon is within 10 to 20 knots. However, wind system during inter-monsoon season tends to result in lower pressure zone with moist air from the higher pressure zone will reach and form the thick cloud (http://www.kjc.gov.my, 2006). In view of the Malaysian rainfall characteristics, it is shaped by maritime exposure. The monsoon season is caused by the differences of land-sea temperature, resulting from the extensive sun's heating of averagely six (6) hours per day (http://www.kjc.gov.my, 2006).

The monsoon seasons do not impose much significant impact on the West Coast of Peninsular Malaysia, if compare to the East Coast. However, during the inter-monsoon season, the convective rain is frequently occurred, which is associated with thunderstorm, lightning, and strong wind. Chang (1993) found that the number of thunderstorm days in Malaysia exceeds 60 per year whereas Nieuwolt (1982) reported over 80 days in tropical climate. This indicates that inter-monsoon season does contribute most of the annual precipitation. The convective process occurs when the moist air arises due to the heat that stored by land mass and then being cool in a very short time before the condensation process begins. In general, convectional rain which occurs mostly at afternoon or early evening is in short duration. It sometimes may last for within one (1) to two (2) hours (Nieuwolt and McGregor, 1998). Rainfall intensity of such event may vary significantly from one event to another. In comparison, monsoon rain is equally distributed and widely spread rather than inter- monsoon rain as discussed by Ong and Liam (1986).

In comparison to rainfall of convective type, precipitation due to orographic effect whereby there is more rainfall at windward slope and mountainous area is less significant at urban area in the West Coast of Peninsular Malaysia. Moreover, its intensity is typically low or moderate. Barstad et al. (2007) found that orographic effect is associated with two (2) mechanisms, namely airflow dynamics and cloud microphysics. Airflow dynamics controls the lifting to form cloud while cloud microphysics controls the evolution of water droplets and hydrometeors (Bras et al., 2007). The occurrence of orographic rainfall is subject to the elevation of barrier, rate of rise and moist air moving direction, too.

Intense urbanization may lead to significant changes on microclimate (Changnon, 1984). Local atmospheric zone with climate different from the surroundings may range from a size of garden to even square miles of area (http://en.wikipedia.org, 2007). Difference in road surface properties and low wind velocity in fully developed urban area may cause a higher temperature, compared to rural area (Takahashi et al., 2004). A major city is warmer than rural area because of dense and high-rise buildings that are hard to release the heat storage by blocking the wind flow. This urban heat island intensity results in up to 10 K temperature difference between the urbanized area and its surrounding rural zones (Santamouris et al., 2001).

With the help of condensation nuclei, for example the particles emitted from vehicle, rainfall due to convective effect is easily formed (Toebes and Goh, 1975). The rainfall within city area will become relatively frequent than that in the surrounding suburban or rural area. To prove this phenomenon, study by Landsberg (1956) had stated that the increase of rainfall in cities is mainly due to the extra 10 per cent or higher occurrence of thunderstorm events. However, another source claims that rainfall extent over the entire area subjects to urbanization will decrease over years as the consequence of decreasing evapotranspiration capacity (Savenije, 1996). This is true if the relevant developing area is located in continental region whereby the climate is belongs to semiarid type.

Rainfall event is considered if precipitation in a particular area that drops to the ground is at least in the range of 0.5 mm to 3 mm (Chin, 2000). Many previous studies had shown that rainfall depth is decreasing from the storm center. In Malaysia, in areas where thunderstorm is frequent, large variation of rainfall depth will occur even in a short distance (Dale, 1959). Therefore, the adequacy of raingauge is important if the rainfall depth over a particular catchment is to be investigated in detail. Further, the intensity of frequent rainfall in Malaysia is known to be much higher than that of the temperate country (DID, 2000). The antecedent moisture content should therefore be considered during the analysis of runoff response. A study by Abustan (1997) at Centtennial Park catchment in Australia showed that the rapid drying effect is significant at impervious area. An urban catchment is only considered to become wet if there is rainfall exceeding 5 mm within 24 hours (Abustan, 1997). However, in Malaysian equatorial climate, corresponding rainfall volume may be higher and the drying time would be then shorter.

2.1.1 Lost Data and Data Consistency

Missing data orand inadequacy of data are among the major problems encountered in hydrological studies. Precipitation record from a particular raingauge is not 100 per cent complete throughout the year. It may have some missing gap in between a short period or totally without any record in relatively long period. Moreover, some records are not reliable as all the data exhibits same value for a long period. These may due to the failure of instrument or human error while collecting or downloading the data. To remedy the problem, a number of methods were developed to figure out the missing portion of data. These consist of the station average method, the normal ration method, the quadrant method and the isohyetal method as suggested by McCuen (1989).

The station average method is the easiest to apply as it does not account for the density of raingauge network. In addition, this method had been proven to be not accurate if the difference between annual precipitation reading of the raingauge of interest and total annual precipitation of other raingauge varies more than 10 per cent (McCuen, 1989). If this occurs, normal ration method is preferred. Similar to the normal ration method, the quadrant method is based on the weighted mean. However, there is a minor difference of weighted mean used by these two methods. The normal ration method is based on annual precipitation of related neighbouring raingauge, however quadrant method utilizes the distance between neighbouring raingauge (McCuen, 1989). The disadvantage of using quadrant method is too much time consumed for determining missing rainfall data, and yet its predicted value is not necessary will be accurate.

The double mass curve, which is mainly for the purpose of detecting raingauge consistency, can be used to correct the annual precipitation record. The computation process is brief. Correction is determined merely through the slope adjustment of cumulative precipitation of interested raingauge for consecutive years versus cumulative precipitation of neighbouring raingauge (McCuen, 1989). Therefore, the trend of precipitation variation over years or namely changes of gauge consistency is easily noticed from the abrupt change of slope in double mass curve (Wilson, 1984). The slope adjustment may drive every subsequent of annual precipitation records to be the true representatives of the storm morphology of the area where the raingauges are sited.

Some data recorded by raingauges may be not representing the actual rainfall once they are statistically inconsistent with other nearby gauges (Damant et al., 1983). Therefore, it is vital to exclude such gauges or patch its data with the aid of covariance biplot. The covariance biplot provides graphical interpretation between the data of different gauges and shows the possible outliers (Pegram and Zucchini, 1992). This biplot, however, does not incorporate any physical properties of the gauges, such as spatial location and elevation (Pegram, 1993). It is because these factors may impose significant impact on rainfall and should be taken into consideration when interpreting the biplot.

2.1.2 Mean Areal Rainfall

There are three (3) common ways to estimate mean areal precipitation, namely the station average method, Theissen polygon method and isohyetal method. Every method has its own advantage and constraint. For example, the station-average method is only recommended for a very small catchment of up to one (1) km radius (Vaes et al., 2004) with evenly installed with raingauges. It is a simple method by just merely averaging all recorded precipitation to obtain the mean areal precipitation (Linsley et al., 1992). The Theisen polygon, indeed, is also a convenient way. A perpendicular bisector is to be drawn between two nearby raingauge points before converging to a point, together with two other bisectors, and form a polygon for each representative point (Linsley et al., 1992). This method provides weights proportional to the size of polygon area, pivoted by each raingauge. In fact, this method is widely used because of its practicability and less time consuming with relatively high accurate estimates (Damant et al., 1983).

The isohyetal method has now become more widely used, especially after surface mapping software and digitization of surveying data using GIS technology are available. It takes into account the orographic effect and storm morphology into weights calculation in the analysis (Gupta, 1989). This estimation will be more accurate and reliable, compared to other methods. This method is versatile because it will incorporate records of all raingauge without discarding any of them, as what may occur in the Theissen method.

Study by Pegram (1993) indicated that by excluding any raingauge will lower the accuracy of estimates due to the forfeited weight that had been relocated to other raingauges. Nevertheless, when the density of raingauge is low, then it will be difficult to draw the isohyets. Manual drawing is subjective and hence, surface mapping model such as Surfer, is vital in this case. With the aids of model, estimation of annual precipitation, monthly precipitation, weekly precipitation or even daily precipitation for any raingauge point of interest has become easier. Therefore, isohyetal method is also very useful in recovering data loss both in long term and short term at any raingauge.

Nowadays, isohyetal line plotted using surface mapping software is mostly based on numerical fitting technique such as the Kriging technique, reciprocal distance and multiquadratic equation (Balascio, 2001). Kriging type is the most intensive geostatistical technique to determine high estimate of areal precipitation, especially in areas with complicated topography where the rainfall variation is significant (USEPA, 2003). In other words, it enhances the isohyetal mean method (Bras and Rodrigez-Iturbe, 1985) through the application of computer plotting model. Study by Sarangi et al. (2006) reported that the geostatistical interpolation method (i.e. Kriging type) is a more reliable technique than deterministic method (i.e. inverse distance weighting) for generating the spatial variability of hydrologic response.

In Kriging technique, analysis of spatial structure through variogram is performed (Sarangi et al., 2006). Averaged squared difference between the data as a function of separation distance is estimated by the following (Deutsch and Journel, 1992).

$$\gamma(h,\alpha) = \frac{1}{2N(h,\alpha)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 \qquad (2.1)$$

where: $\gamma(h,\alpha)$ is a semivariance as a function of both the magnitude of the lag distance or separation vector h and its direction α; $N(h)$ is the number of observation pairs separated by h used in each summation; $z(x_i)$ is the random variable at location, x_i. Thus, selection of method is important because a 10 per cent bias in rainfall may cause a 35 per cent variation in estimated runoff (Mein and Nandakumar, 1997).

2.2 Runoff Characteristics

In general term, surface runoff starts when there is not sufficient time for soil to soak up the rainfall volume during a storm. This condition will be exacerbated during heavy downpour. Flash flood occurs when rainfall intensity exceeds soil infiltration rate and typically at catchment smaller than 259 km^2 (Davis, 1998). Besides loss of lives and properties, flash flood also causes non-point source pollution to the receiving water bodies. In urban area, more than 60 % of the Malaysian inland waters are polluted due to non-point source during excessive direct runoff (Mokhtar, 1998).

River discharge at any point is made up of direct runoff and subsurface runoff which comprises interflow and groundwater flow. The direct runoff contributes more to flood flows because it produces large concentration of flow in a shorter period, if compared to subsurface runoff. Ponce (1989) suggested that interflow moves within unsaturated soil layers under ground surface while groundwater flows vertically deep into alluvial deposits and water bearing formation below water table. In hydrological studies, a baseflow which is defined as the water discharged from groundwater storage is an important indicator to separate between direct runoff and indirect runoff (McCuen, 1989). In the humid tropics, when there is no rainfall, a river baseflow will only constitute of groundwater flow (Ponce, 1989). This is because perennial type of river is common in that region. It will be advantageous to use remotely-sensed data and GIS for runoff estimation when the catchment is large and in-situ data are not available (Melesse et al., 2003).

2.2.1 Rainfall Abstraction

Rainfall abstraction is the component of rainfall that does not turn to direct runoff. This hydrological abstraction generally comprises the following: interception, infiltration, depression storage, evaporation and evapotranspiration. After the initial abstraction is fulfilled, any excess rainfall will become direct runoff (Melesse et al., 2003). However, in urban catchment, interception, evapotranspiration and evaporation do not serve as important factors for study on runoff and river discharge (DID, 2000). This is mainly because of its less significant impact.

Infiltration is the dominant process of hydrological abstraction (Chin, 2000), and yet a complicated process whereby its rate is normally to be empirically judged. Infiltration depends upon factors such as tillage, soil structure, antecedent moisture content, soil exchangeable sodium, infiltrating water quality and the soil air status (Grismer et al., 1994). There is a variety of model used to explain the infiltration process at instantaneous rate, namely Horton model (Horton, 1939), Green-Ampt Model (Green and Ampt, 1911), and NRCS Curve-Number Model (USCS, 1972). On the other hand, to determine the average infiltration rate, the constant loss rate method that makes use of infiltration index (Cook, 1946) is recommended. During infiltration, abstracted water will move either laterally as interflow into the receiving waters, or vertically until it percolates into the aquifers to give way to groundwater recharge (Réthâti, 1983).

At the early stage, initial abstraction is caused by infiltration. It is commonly known as the rainfall that is absorbed by the soil prior to the start of direct runoff; while some assume that it is the extent of water that penetrates before the infiltration reaches a constant rate. Earlier studies by Viessman (1968) had found that the initial abstraction for small urban catchment is about 0.1 inch (2.54 mm). Thus, it is believed that for rural catchment, this figure will be higher because of more pervious area than urban catchment. The approaches to determine initial abstraction are very subjective. It may be determined using the specifically fixed volume or just by examine the rainfall extent before the occurrence of direct runoff (McCuen, 1989).

Until today, there is no definite way to compute the initial abstraction. In common practices, the initial abstraction is just construed as a part of rainfall losses computed through various models. Despite that, in many hydrological studies, especially in the humid tropics, initial abstraction is usually estimated through the linear regression model (Wilson, 1984). The initial abstraction can then be predicted through the x- intercept of the runoff versus rainfall chart (Harremöes and Ambjerg-Nielsen, 1996). However, if there is less rainfall event which yields runoff depth which is small enough until nears zero, the initial abstraction predicted from the foregoing equation may not be representing the actual value.

Depression storage is the precipitation accumulated on the land surface, such as puddles, ditches, and others (DID, 2000). In most of the time, when urbanization commences, the infiltration rate is reduced; the depression storage will also decrease. The water stored in such way will then either evaporate or infiltrate into deeper ground. Common consensus had been achieved that depression storage will increase if the catchment slope is lower. According to Tholin and Keifer (1960), depression storage for paved area ranged from 1.3 to 2.5 mm. The estimated depression storage is found to be similar to the initial abstraction in small urban catchment discovered by Viessman (1968). Therefore, in order to trigger the direct runoff within urban catchment, a minimum value of 2.5 mm (≈ 3.0 mm) rainfall depth is needed.

There are five (5) models of rainfall excess proposed by the Institution of Engineers, Australia as well as the Department of Irrigation and Drainage, Malaysia. They are illustrated in Figure 2.1 and described as below.

a) Constant fraction of loss rate in each time interval. It follows the runoff coefficient concept

b) Constant loss rate, where the rainfall excess is the residual left after the loss

c) Initial loss and continuing constant loss, where no runoff is assumed to occur except when the initial loss of rainfall is fulfilled.

d) Infiltration curve, where loss rate is decreasing with time

e) Standard rainfall-runoff relation generated by the U.S. Soil Conservation Service

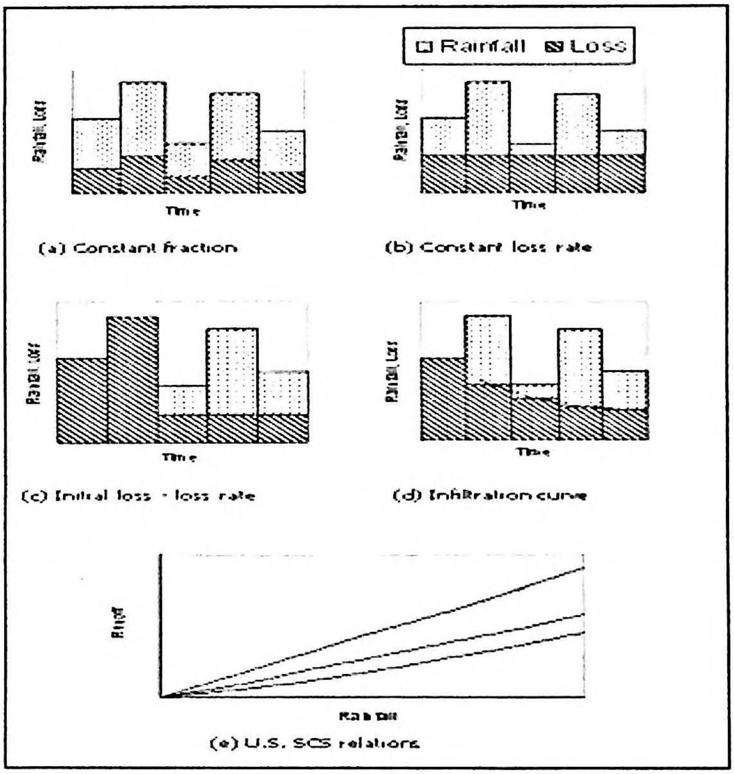


Figure 2.1: Loss models (DID, 2000)

Among the many infiltration models, the constant loss rate method is the most convenient and practicable way (Gupta, 1989). The infiltration index (ϕ index) which tends to underestimate high initial infiltration rate and overestimate the low latter infiltration rate (Ponce, 1989) attributes to the use of this approach in the humid tropics. This is owing to its rainfall frequency and moisture content which are always higher than the temperate or arid region. In addition to the statement above, constant loss rate model, initial loss and continuous loss model are recommended when the Horton overland flow is dominant and runoff is likely to occur over the entire catchment (IEA, 1987). This means that the constant loss rate method is also suitable to be applied on urban catchment with low infiltration rate (Horton, 1933).

Studies had been carried out by Pilgrim (1966) to quantify the infiltration rate on temperate catchments in United States, Australia and New Zealand. The constant loss rate approach was used. The finding had been compared with the study result obtained by Taylor and Toh (1980) over Malaysian local catchments. There might have some subjective judgement due to ways of study by different parties, as the whole, it is believed that the accuracy of techniques used would not differ much. In Figure 2.1, it is clearly shown that the ϕ index recorded in Malaysian catchment, is higher than that of the three (3) foregoing countries. 74 per cent of data observed in local catchment exhibits loss rate exceeding 0.25 in. /hr (6.35 mm/hr); compared to United States at 14 per cent, Australia and New Zealand with 10 per cent and 13 per cent respectively. One possible reason is that the local study areas were not as well developed as those western countries, during when the data was collected of at least 30 years ago.

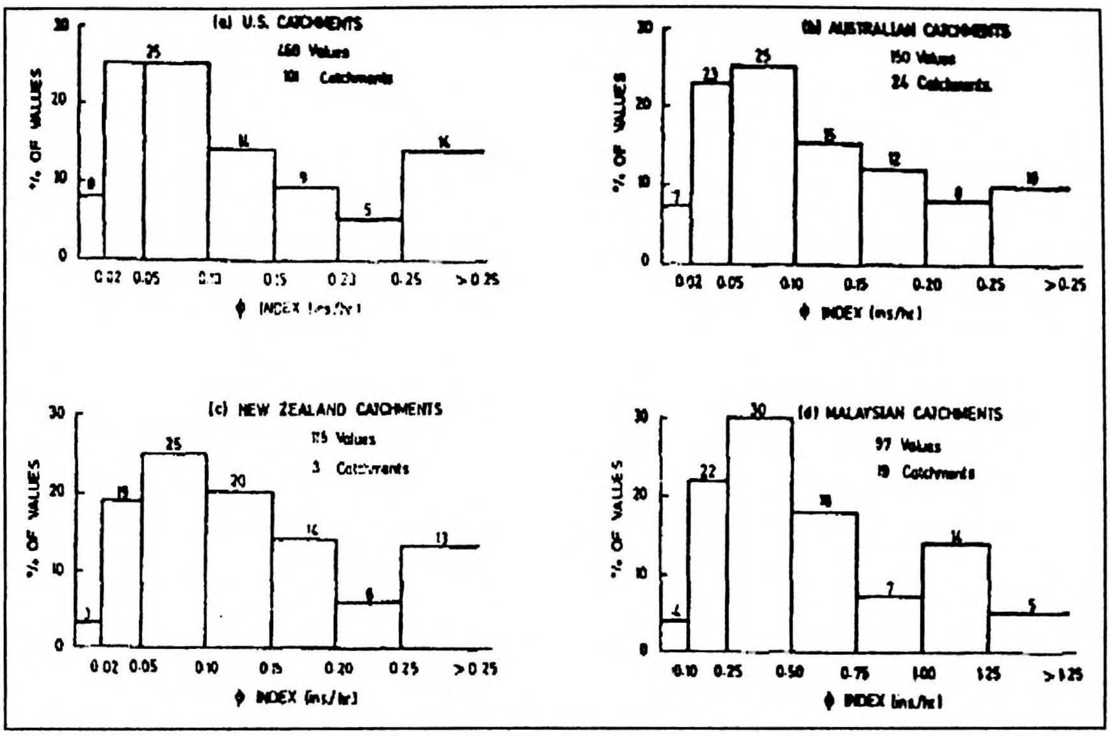


Figure 2.2: Comparison of loss rates between Malaysia and foreign countries (Taylor and Toh, 1980)

Based on the basic infiltration rate (also known as ultimate infiltration rate) of three (3) major soil; clay, loam and sand, the type of soil that may resemble the constant loss rate of catchment can be determined. However, this is merely a general indicator, as to the degree where the imperviousness of entire catchment lies. Range of the basic infiltration rate for various soils, as shown in Table 2.1, had been identified through the field test conducted by Brouwer et al. (1988). For well developed catchment, most of the soil had been compacted during construction period. Analysis by Akram and Kemper (1979) indicated that the changes of pore size distribution in sandy loam after compaction by heavy machinery will reduce its infiltration rate from 15 mm/hr to 3 mm/hr. In other words, this implies that the constant loss rate estimated from the studied catchment most probably is rarely signify the true infiltration rate of its original soil and allowance has to be made for better estimation.

Table 2.1: Basic infiltration rate for different soil types (http://www.fao.org/docrep/S8684E/s8684e0a.htm, 2006)

Soil Type	Basic Infiltration Rate (mm/hr)
Sand	Less than 30
Sandy Loam	20 – 30
Loam	10 – 20
Clay Loam	5 – 10
Clay	1 – 5

2.2.2 Direct Runoff

There are three (3) major techniques for baseflow separation, namely the straight line separation, constant slope separation, and concave separation (McCuen, 1989) as shown in Figure 2.3. Hewlett and Hibbert (1967) had generated an empirical equation for constant slope separation: Constant slope = 0.00055 A $(m^3/s)/hr$ in which A is the catchment area in km^2. For concave separation, separation line is constructed between the point prior to the rise of discharge and the recession point where both of them meet at the time-to-peak (McCuen, 1989). However, there is no conclusive rule on how to separate baseflow accurately. This is due to the fact that, all the methods were devised based on the observed data from different types of catchment throughout the world. Runoff response is hence, varied from one to another catchment. No matter which method to be used, baseflow must be separated in such a way that it will ease the computation of direct runoff.

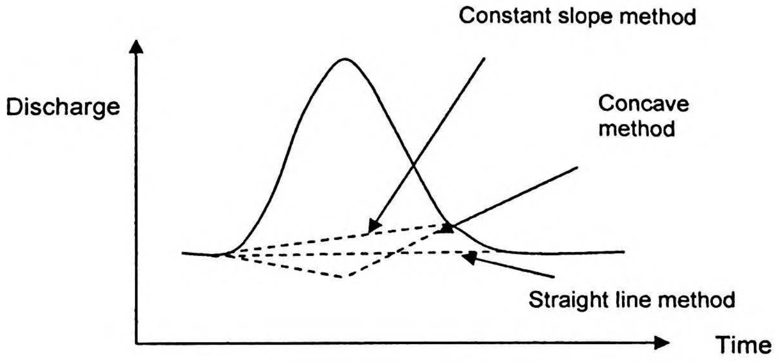


Figure 2.3: Common types of baseflow separation

For different catchment hydrologic response, appropriate way of baseflow separation should be selected for the convenience of a study. For urban catchment, most of the areas are paved and this has raised the degree of imperviousness. Consequently, rainfall water that infiltrates into the soil to form interflow or groundwater recharge will become scarce, if compare to rural area. Forest and hilly areas are cut and flatten for urbanization, regardless of the fact that upland slope area is where the groundwater recharge is taking its own course (Ponce, 1989). Thus, it will decrease the groundwater storage and the low flow level drops gradually. This infers that the subsurface flow will only start to contribute to direct runoff once the depleted groundwater storage has been fulfilled. The effect of groundwater to river discharge is negligible in urban catchment (Abustan and Ball, 2000), especially during low rainfall event.

Unlike the straight line separation, both the constant slope and concave separation are based on the assumption that the recharged groundwater will start to contribute to the direct runoff before the total runoff hydrograph equals the baseflow rate. In the view of low groundwater recharge rate in urban catchment, the constant slope and concave baseflow separation may under-estimate the direct runoff in urban catchment study. With reference to Figure 2.3, in the straight line baseflow separation, a line that divides direct runoff and indirect runoff is drawn from the point of discharge point prior to the rise until the recession limb of runoff hydrograph at a constant rate (Chow et al., 1988). However, in reality, this is rarely possible to do so in most of the times. Though the recession of hydrograph has ceased, but it will not fall as the same level as before the rainfall event owing to the interference by subsurface flow. To overcome this uncertainty, Gupta (1989) had proposed that the starting point and ending point of baseflow separation can be arbitrarily selected by logical engineering judgement.

2.2.3 Stage-Discharge Data

Water level record at certain time interval, for instance, 1-min, 5-min, 10-min and 15-min intervals are usually needed in the analysis of streamflow data. Provided with such records, flow rate can be estimated using the rating curve. Selection of rating curve in transforming the water level to discharge unit is more recommended than the application of Manning's Equation which is more time-consuming. Nevertheless, a river cross section may change in urban catchment when the river is either canalized or widened. This includes a river that is susceptible to souring and silting effect (Wilson, 1984). Thus, it is suggested to acquire the latest stage-discharge curve developed for particular study area from the related water authority.

In the event of extreme rainfall, rating curve sometimes is incapable to measure the discharge rate above its upper limit. Thus, extension of rating curve is needed. This rare event usually leaves some useful evidence, such as the highest water level ever happens can be recorded based on lines of debris at the river bank. In line with this, there are three common ways to extend the rating curve. This includes the conversion of rating curve equation into logarithmic form, Steven's method and slope-area method (Wilson, 1984). During extreme rainfall, there may be an abrupt increase of high flow resulted from the cross-sectional changes and this is beyond estimation using the first method. For the latter two methods, both provides erroneous estimation when the flood scour and subsequent low water decomposition occurs (Wilson, 1984). Every method has drawbacks and hence precaution should be taken during the practical application.

2.3 Hydrological Response

There was a rainfall-runoff study done by Chong et al. (2000) for Taman Mayang catchment (i.e. 2.316 km^2) in Damansara, Selangor. However, the results were inconclusive due to the lack of hydrological data. Similar studies had been carried out by Taylor and Toh (1980) and the results were published in the design flood hydrograph guideline proposed by the DID Malaysia. Based on 97 records observed throughout the year 1964 until 1973, one linear regression formula was derived. Moreover, one empirical formula was proposed by Chow (1964) ;

Direct runoff, $Q = 0.33P$ (2.2)....... for rainfall depth less than 3 inches (76.2 mm)

Direct Runoff, $Q = \dfrac{P^2}{(P+I)}$ (2.3)...... for rainfall depth more than 3 inches (76.2 mm)

where, P = Total rainfall subtracted from initial loss
I = Potential infiltration at 6 inches (152.4 mm)

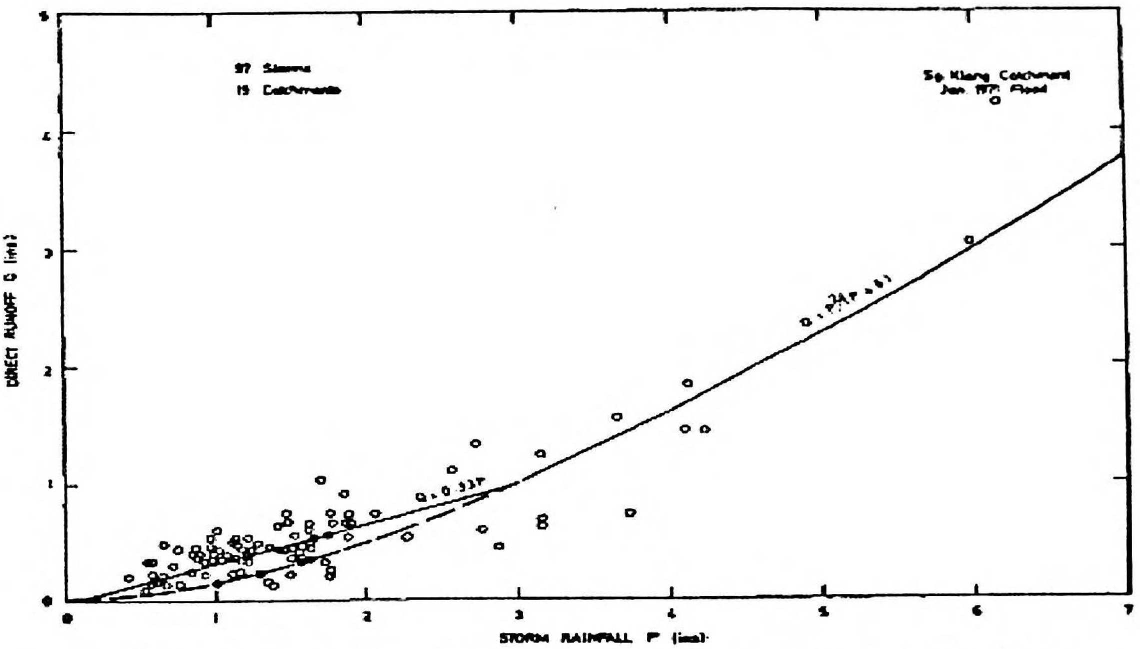


Figure 2.4: Rainfall-runoff relationship at local catchments (Taylor and Toh, 1980)

All the data as plotted in Figure 2.4 was observed from 19 catchments in Peninsular Malaysia (Taylor and Toh, 1980). It is noticeable that the direct runoff depth increased drastically after three (3) inches (i.e. 76.2 mm) of rainfall. This might be due to that the soil had become saturated and not capable to infiltrate excess rain water. Another possible reason is that the high proportion of direct runoff depth per unit rainfall resulted from the subtraction of initial loss. Further, the fitting of the two regression formulas were done with visual inspection (Taylor and Toh, 1980) without validating their prediction accuracy using statistical approach. Therefore, further statistical analysis is vital before the developed rainfall-runoff relationship is applied.

Selection of catchment with appropriate size is an important factor because it resembles the rainfall-runoff response in different manner. According to Ponce (1989), there are three (3) types of such hydrological response as follows. Rainfall on small catchment which is normally less than 25 km^2 (IEA, 1987) is uniformly distributed with time and space with significant overland flow. When catchment size increases, rainfall will vary with storm duration which is uniformly distributed in space while the dominating flow is of overland and stream channel type. Large catchment that typically exceeds 100 km^2 (Smith et al., 2006) covered by both time and space varying rainfall with significant channel storage effect. When the catchment size is larger, the time travel of rain water from the drain to confluence point will become higher until it approaches the time of concentration (Fricke et al., 1980). This implies that for the same extent of land use changes, the peak discharge will not be significantly affected in the considerably larger catchment.

The channel storage effect is less significant for small and medium catchment. Therefore, the Rational Method is suitable to be used for peak flow estimation, especially for the design of urban drainage facilities (Walesh, 1989). The application of the Rational formula is subject to runoff coefficient which can be interpreted in several ways., The runoff coefficient denotes the ratio between runoff and rainfall; or the ratio of their peak rates; or the ratio of the runoff to rainfall frequency curves according to Institution of Engineers, Australia (1987). This coefficient is governed by the effects of hydrological abstraction and rainfall intensity (DID, 2000). The more areas within a catchment are paved, the higher runoff coefficient will increase. Basically, rainfall with low intensity will not produce runoff, unless when the intensity exceeds the minimum or even rate of infiltration (Mays, 2001), especially after the initial abstraction is achieved.

Schueler (1987) conducted a study to correlate imperviousness and runoff coefficient using data from 40 catchments under the National Urban Runoff Program (NURP) and four (4) catchments in Washington, D.C. The trend of runoff coefficient versus imperviousness is shown in Figure 2.5 and linear regression analysis was performed. The analysis showed that the coefficient of determination (r^2) for (2.4) was