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FLOOD POTENTIAL ESTIMATION OF TWO SMALL VEGETATED WATERSHEDS

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Abstract: Real-time (observed) rainfall-runoff data from two small watersheds was use to estimate the flood potential of the area. The first watershed (W-1) is located in a hilly area near Serdang, Selangor. The second watershed (W-2) is a flat land of peat soil located in Pontian, Johor. A SCS (Soil Conservation Service) curve number (CN) technique, which is, considered as one of the GIS-based empirical approach was used in the study to predict daily-event storm runoff. The predicted runoff obtained from SCS-CN technique was compared with those of the observed values and from conventional Rational method. The results show that the SCS-CN technique was over-predicted for cases in W-1 watershed. Conversely, the SCS-CN was under-predicted for W-2 watershed.

Keywords: *Soil Conservation Service-Curve Number; GIS; Flood Event; Rational Method.*

Abstrak: Data cerapan hujan dan aliran sungai daripada dua kawasan tadahan kecil telah digunakan untuk menganggar kecenderungan berlaku banjir di kawasan tersebut. Tadahan pertama (W-1) terletak di kawasan berbukit di Serdang, Selangor. Tadahan kedua terletak di kawasan tanah rata bertanah gambut di Pontian, Johor. Kaedah `Soil Conservation Service'- 'Curve Number' (SCS-CN) yang boleh dianggap berasaskan pendekatan G.I.S. empirikal telah di gunakan untuk menganggar air larian permukaan bagi peristiwa hujan harian. Nilai anggaran yang didapati daripada kaedah SCS-CN dibandingkan dengan nilai cerapan sebenar dan juga nilai yang didapati daripada kaedah Rasional. Keputusan mendapati kaedah SCS-CN terlebih anggar untuk tadahan W-1, sebaliknya terkurang anggar untuk tadahan W-2.

Katakunci: *SCS-CN; GIS; Peristiwa Banjir; Kaedah Rasional.*

1. Introduction

1.1 General

The estimates of peak runoff or `flood' at real-time basis from a watershed or catchment area are required for water resources and river basin management purposes. The runoff production can generally be estimated through the knowledge of rainfall-runoff relationship of the catchment. The rainfall and runoff relationship is complex and depends on many factors. The amount of runoff from a given area is dependent on many inter-related factors; the watershed characteristics such as slope, shape, size, soil cover and rainfall characteristics such as amount, intensity and duration. All these have a direct effect on the peak flow or `flood' event and the volume of runoff produced by a defined watershed area. On both vegetated hilly and flat areas, knowledge on the relationship between rainfall and peak runoff is critical. This is because the rainfall and runoff are found to be the active forces in causing much water-related problems, such as erosion and slope stability, river sedimentation as well as flash flood. In countries where the amount and intensity of rainfall are high, water erosion is always a major problem (Soong et al., 1980). As most vegetated watershed are undergoing development process (agricultural, tourism and housing), records on the observed rainfall-runoff relationship for a particular area would be an important database for future reference. The estimate of peak runoff production by generated rainfall is thus needed before a better development concept of the watershed can be systematically carried out.

1.2 Catchment System and Flood Occurrence

The hydrograph of a streamflow from a catchment is the overall continuing response of that catchment to the previous history of rainfall and evaporation over the catchment. It is simplified as in flow diagram in Figure 1**.** Flood is defined as the discharge that may be expected from the most severe combination of meteorological and hydrologic conditions that are considered reasonably characteristic of the geographical region involved, excluding extremely rare combination (Linsley and Franzni, 1979).

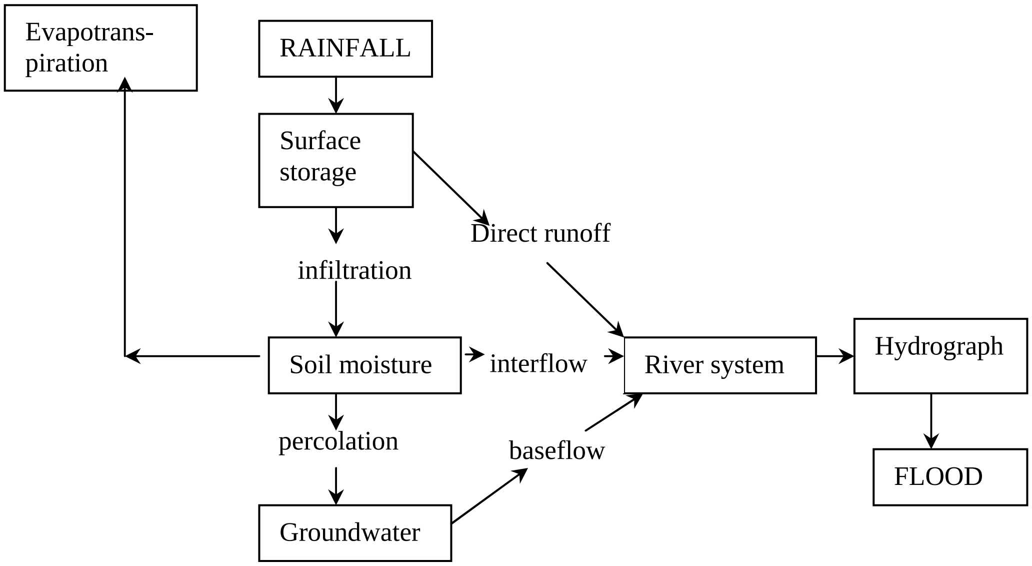

Figure 1: The catchment system in relation to flood occurrence

Flood design on the other hand is refer to the maximum probable peak discharge, Q_p, produced maximum design capacity for any hydraulic structures meant for flood mitigation purposes. These structures would include culverts, bridges, retention ponds as well as the river system. In the past, the design of a flood for a specific location has been carried out using an empirical approach watershed. The peak flow analysis by using simple rational method is generally considered to be one of the best available and simple peak runoff estimation for small watersheds (Sheafer et al., 1982). In general flood design can be represented by a general flood formulas:

$$Qp = cA_d^n \qquad (1)$$

where c and n are the coefficient factors and A_d is the drainage area.

1.3 The Use of GIS in Flood Estimation

The use of Geographic Information System (GIS) in hydrologic studies has become popular among hydrologists that it provides the primary source of data for decision-making (Bruce and Feldman, 1992; Ross and Tara, 1994). This is simply because hydrologic analysis requires geographical data that has to be linked between them before a meaningful output is expected. For instance, using simple empirical rational approach (Sheafer et al., 1982) peak flood occurrence within a given geographical set-up could be estimated after having known lump topographical setup and stream networks of the watershed. When a spatial and temporal flood analysis is required, rational (lumped) approach alone could not be practical anymore, as spatial design criteria would not be possible to obtain. Having known a detail spatial geographical set-up of the watershed and using GIS- lumped hydrologic model approach, a real-time flood estimation (spatial and temporal) could be employed (Bruce and Feldman, 1992). Forecasting floods occurrence in a watershed at real-time basis, spatially and temporally is of paramount importance these days. This is particularly true for an urbanizing watershed system where a dynamic land-use change is observed. The changes in land use pattern would definitely affect the spatial distribution of potential flood in the study area. In GIS approach, the spatial flood distribution of the area would be governed by topograpical index of the watershed system.

A SCS-CN surface flood runoff prediction approach requires geographical detail of the watershed. This would allow us to make an accurate peak flow prediction based on physical characteristics of the watershed. For a small agricultural watershed between 5-2000 acres, SCS procedures TP-149 (Viessman and Lewis, 1996) is recommended. The input parameters are the drainage area, watershed slope, rainfall distribution type, watershed composite CN and rainfall depth.

This paper reports the findings of a short-term study on the relation between rainfall and peak runoff (flood potential) in two small-vegetated watersheds using GIS approach. It is intended to estimate the runoff production generated from the various rainfall conditions at real-time basis. Evaluations were made using observed data with GIS-CN approach. These results may be used as a reference to some similar watershed characteristics in other parts of the country.

2. Materials and Methods

2.1 The Study Watershed

The selected watersheds were located in two different locations in Peninsular Malaysia. The first location (and so called watershed W-1) was in Serdang, Selangor, close to Putrajaya new township. It lies on 3^o N and 101^o 44 'E. The area of the watershed was about 262 ha. It is about 2.38 km long and its maximum width is about 2.13 km. The highest point was about 90 m above mean sea level and the altitude of the downstream end was approximately 27 m. The second watershed (and so called watershed W-2) is in Pontian, Johor. It lies on $103^o16'15''$E, $01^o42'35''$N, about 80 kilometers from Johor Bahru. The area of the watershed is about 184 ha. It was about 2 km long and 1 km wide. The area is basically flat and covered by peat soil.

Figure 2 shows the rough location of the study sites. The topographical features of both watersheds are shown in Figures 3 (a) and (b). The general climatic conditions of the watershed is characterized by humid topics with average annual rainfalls of 2073 mmyear^{-1} for W1 and 2600 mm for W2.

2.2 The Watershed Cover and Drainage Pattern

The soil of W-1 consists of five major soil series, namely Malacca, Muchong, Serdang, Bungor and Alluvium-Colluvium series with randomly distributed over the catchment (Paramananthan et al., 1979). The textural classes of the soil mainly fall under the category of clay, clay-loam, sandy-clay and sandy loam. The watershed was fully vegetated. Several crops were grown on the catchment. More than two third of this area was covered by tree crops while the lower plain was covered with grass. The watershed has two main streams before joining the main outlet. The total length of the stream was 6.5 km with the main one was 3.4 km. The stream density was about 0.03 kmha^{-1}. The overall slope of the main stream was 2.5 %.

The W-2 was fully covered by a single soil type, i.e. peat. It was originally a peat swamp areas and has undergone drainage processes for more than 20 years and now fully vegetated. Two major crops are palm oil and rubber trees. The watershed has a single man-made stream (Madirono Drain) with a total length of 2.0 km which make a stream density of 0.01 kmha^{-1}.

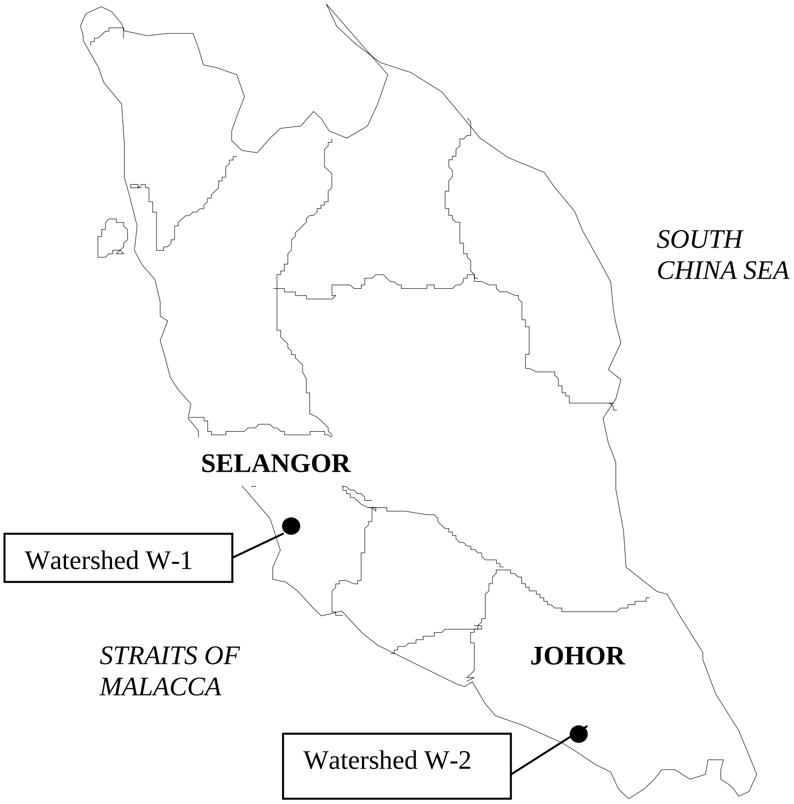

Figure 2: The study site locations

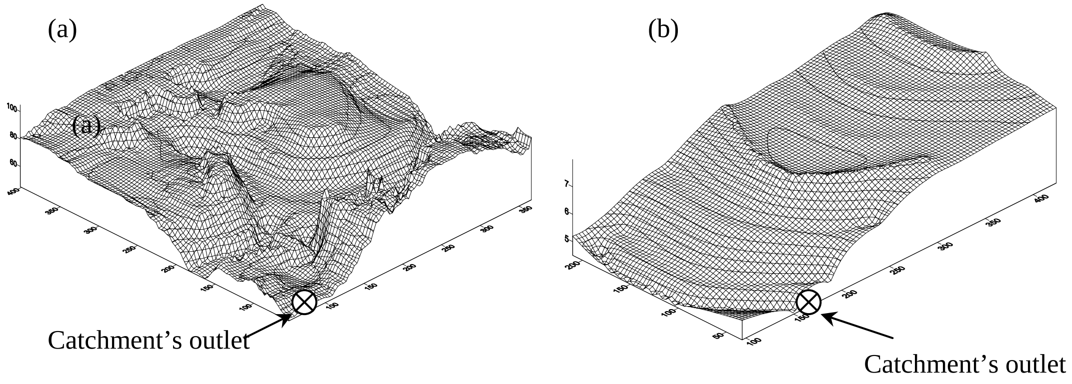

Figure 3: General Landform of Watershed (a) W-1 and (b)W-2, showing the catchment's outlet.

2.3 Observed Data Collection

The rainfall data for both sites was recorded at the weather meteorological stations inside the experimental area. The runoff volume was measured at a defined watershed outlet as shown in Figures 3 (a) and (b). For W-1, a cut-throat flume sized 0.76m in width equipped with an automatic water level recorder was used to measure the runoff volume**.** For W-2, a 120^0 V-notch weir equipped with automatic water level recorder was used to measure the runoff volume. The detailed operational procedures of these flow-measuring devices were referred to Kraatz and Mahajan (1972).

2.4 Hydrograph Analysis

Hydrograph analysis represents a fundamental tool in the study of the rainfall-runoff relationship. In hydrograph analysis, it is important to separate the flood runoff and base flow. The discharge ratio method (Wilson, 1974) was used in this study.

2.5 SCS-CN GIS Approach

The SCS procedure consists of selecting a storm and computing the direct flood runoff by the use of curves founded on the field studies of the amount of measured runoff from numerous lands cover combinations. A runoff curve number (CN) is extracted from a CN table published in most of hydrology textbooks (eg. Viessman and Lewis, 1996). Once a rainfall amount has been determined, the direct flood runoff resulting from this particular rainfall is estimated using appropriate CN.

2.6 Error of Estimate, e

Estimated flood flow obtained from SCS-CN approach was evaluated against observed data using simple error of estimate proposed by Capeace et al (1988). Percent error of estimate can be described as:

$$e = 100 \left(\frac{q_p' - q_p}{q_p} \right) \tag{2}$$

Where e is the percent error of estimate, q_p' is the estimated peak flood runoff and q_p is the observed peak flood runoff. An equal line (1:1 line) was drawn on q_p's versus q_p's plot to visualize the estimating performance. Peak flow is over estimated when a point falls above the equal value (1:1 line) and under estimated when a point fall below the equal line.

3. Results and Discussion

3.1 General Rrainfall-Runoff Relationship

Twenty-eight and 35 storm rainfall-runoff records obtained from W-1 and W-2 respectively were analyzed, hydrographically. From the result, two things are indicated, firstly the runoff volume changes in response to the change in the rainfall and secondly, the antecedent rain has a large influence on the runoff volume. It clearly exhibits the effect of the antecedent rain on the runoff volume. For example there was no rainfall for 10 consecutive days, a rainfall of 2.5 mm has produced no runoff. In another occasion, the rainfall of 33 mm has yielded only 17.6 mm or 0.39 m^3s^{-1} runoff, because there was practically no rain for more than 10 days preceding that rain. On the other hand, under a wet soil condition (indicated by the number of non-rainy-days prior to rainfall) the rainfall of only 31.5 mm induced 30.2 mm or 0.51 m^3s^{-1} runoff, that is, 1.3 times than the former. On similar study for semi-arid agricultural catchment in China by Zhu et al. (1997) found that the production of runoff could be estimated using the depth of rainfall data alone. They reported that rainfall depths less than 10, 10-20, 20-30, 30-40, 40-70 and more than 70 mm produced runoff of 9.5, 16.8, 13.8, 18.4, 22.1

and 28.2% of the rainfalls, respectively. Rainfalls that do not produce runoff are then being called non-runoff generation rainfall. In this study, as indicated, it is clear that rainfall of less than 5.6 mm produced no runoff. This is particularly true where the water loss due to crop interception is relatively high for small amount of rainfall (Herwitz, 1985). For rainfall of less than 5 mm, the interception loss could reach as high as 100%.

The direct correlation between the total amount of rainfall and the volume of runoff of W-1 watershed is shown in Figure 4. The relationship is found to be non-linear. The scatteredness of the points is to be expected since the volume of runoff varies with other factors in addition to rainfall amount, such as antecedent soil moisture, the surface cover and the rainfall intensity. Correlation analysis shows that the amount of rainfall and runoff followed a second degree polynomial relationships. A regression line equation was produced, that is:

$$Q = 0.0374P^2 - 0.3494P + 0.8941 \tag{3}$$

where Q and P is the runoff and rainfall amount respectively. A coefficient of determination, r^2 of 0.837 indicated a good polynomial relation between rainfall and runoff for this watershed. This implies that about 84% approximation of variation in the values of runoff was found to be caused by the variation in the amount of rainfall and followed an exponential relationship.

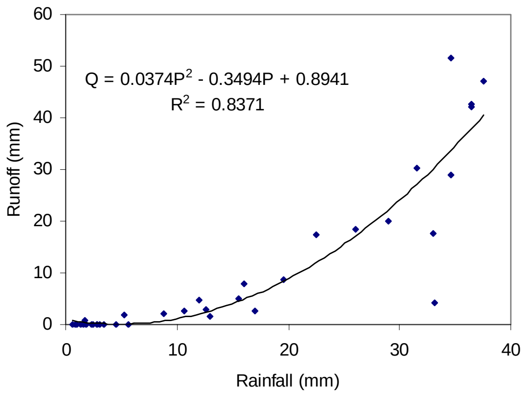

Figure 5: Rainfall-runoff relation of watershed W-1

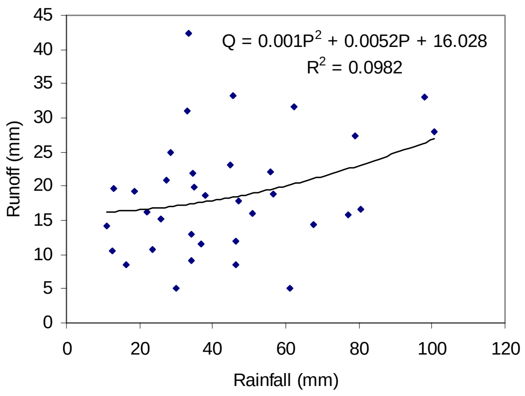

Figure 5: Rainfall-runoff relation of watershed W-2

The rainfall-runoff relationship for W-2 is shown Figure 5. Similar to W-1, the relationship is found to be non-linear. Correlation analysis shows that the amount of rainfall and runoff followed a weak polynomial relationship. A regression equation was produced:

$$Q = 0.001P^2 – 0.0052P + 0.16.02 \quad (4)$$

where Q and P are the runoff and rainfall amount, respectively. A coefficient of determination, r^2 of 0.0982 indicated a weak polynomial relation between rainfall and runoff for this watershed. This implies that only about 10% approximation of variation in the values of runoff was found to be caused by the variation in the amount of rainfall and followed an exponential relationship.

Many researchers have analyzed the rainfall-runoff relationships based on annual records. They mainly assumed that the correlation is linear. Fogel (1969) for example, used a multiple regression technique to solve a linear form of regression equation. He assumed that regression line:

$$Q = B_0 + B_1P + B_2T + B_3S + e \quad (5)$$

where Q is runoff, P is rainfall, T is time distribution factor, S is space factor and B is i values ($i=1,2$ *and* 3), i.e. coefficients to be estimated and e is error of estimation. Arai et al.(1975) also assumed that rainfall-runoff relation was a linear system. Their studies on an urbanizing area found that the slope of rainfall-runoff regression line was in the form:

$$Q(t) = R(t) - q_{inf}e^{-at} + q_{inf}, \quad (6)$$

where $Q(t)$ and $R(t)$ is the runoff rate and rainfall intensity at time t respectively, and q_{inf} is the average infiltration rate and a is a constant value. In a more simplified form, an empirical equation developed by the USDA-ARS (Fricke and Lewis, 1994) is being considered by the Irrigation and Drainage Department of Malaysia. The equation is in the form:

$$Q = P_e^{\,2}/(P_e+I) \quad (7)$$

where Q is the direct runoff, P_e is the total rainfall minus initial loss and I is the potential infiltration of the soil.

3.2 Observed Flood Hydrograph Characteristics

The observed storm hydrographs of more than 20 rainfalls of the watershed were analyzed. Eight components of the storm hydrograph namely rainfall depths, rainfall duration, runoff depth, runoff duration, rainfall intensity, time to peak,

peak flow and recession time were quantified. The correlation between these component themselves appeared to be very complex. No obvious linear relationships can be observed, but basically the runoff volume showed a quick response to the changes in the rainfall intensity and the antecedent rainfall. In this study, the antecedent rainfall was indicated by the number of dry days, prior to that particular rainfall event. This can be exhibited from the observed storm hydrographs of the study watersheds. These phenomena are expected because of the antecedent soil moisture (implied from the number of dry days) of the watershed runoff.

Table 1: Matrix correlations between hydrograph parameters for W-1

Parameter		I	T_P	Q_P
I	Pearson Correlation	1.000	0.12	0.67**
	Sig. (2-tailed)	.	0.60	0.001
	Sum of Squares and Cross-products	1385.72	20.81	31.15
	Covariance	69.28	1.04	1.55
	N	21	21	21
T_P	Pearson Correlation	0.12	1.00	0.50*
	Sig. (2-tailed)	0.61	.	0.02
	Sum of Squares and Cross-products	20.81	21.92	2.94
	Covariance	1.04	1.10	0.15
	N	21	21	21
Q_P	Pearson Correlation	067**	050*	1.00
	Sig. (2-tailed)	0001	002	.
	Sum of Squares and Cross-products	31.15	2.94	1.55
	Covariance	1.56	0.15	7.768E-02
	N	21	21	21

** Correlation is significant at the 0.01 level, $p<0.01$

* Correlation is significant at the 0.05 level, $p<0.05$

Three storm hydrograph parameters were chosen to evaluate their statistical correlations. These are Rainfall intensity (I), time to peak (T_p) and Peak flow (Q_p). Tables 1 and 2 tabulate the statistical outputs of the matrix correlation between these parameters. For W-1 (Table 1), a strong correlation between Q_p and I was obtained with coefficient of determination, r^2 =0.671. There was also a good correlation between T_p and Q_p but with a lower significance level. A non-significant correlation between I and T_p was observed. A similar result was obtained from W-2 (Table 2) hydrograph analysis. Q_p was significantly related to I at 1% level. Q_p was also significantly related to T_p at 5% level. Unlike W-1, in W-2, T_p was significantly related to I at 5% level. This has to be expected because W-2 is a more flat areas compared to W-1. The water table condition in W-2 is expected to be higher that in W-1, thus the T_p response to I is much quicker.

Table 2: Matrix Correlations between hydrograph parameter for W-2

Parameter		I	Q_P	T_P
I	Pearson Correlation	1.000	0.23**	-0.17*
	Sig. (1-tailed)	.	0.01	0.04
	Sum of Squares and Cross-products	9302.01	314.69	-345.31
	Covariance	87.76	2.97	-3.26
	N	107	107	107
Q_P	Pearson Correlation	0.23**	1.000	-0.20*
	Sig. (1-tailed)	0.008	.	0.02
	Sum of Squares and Cross-products	314.69	193.86	-58.39
	Covariance	2.97	1.83	-0.55
	N	107	107	107
T_P	Pearson Correlation	-0.17*	-0.20*	1.000
	Sig. (1-tailed)	0.04	0.02	.
	Sum of Squares and Cross-products	-345.30	-58.39	431.75
	Covariance	-3.26	-0.55	4.07
	N	107	107	107

** Correlation is significant at the 0.01 level (1-tailed), $p<0.01$

* Correlation is significant at the 0.05 level (1-tailed), $p<0.05$

3.4 The estimated runoff coefficient, C

The peak flow analysis by using simple rational method is generally considered to be one of the best available and simple peak runoff estimation for small watersheds (Sheafer et al., 1982). The peak flow can be estimated as:

$$Q = CIA \qquad (8)$$

where Q is the peak runoff, C is the runoff coefficient and I is the rainfall intensity for duration equal to the time of concentration, T_c, and A is the catchment size. Since the values of Q, A and I are measurable, the formula can be used to estimate C of the catchment, a value that is frequently used by practicing engineers. The time of concentration, T_c can be estimated using empirical formula developed from the respective local condition (e.g. Bransby Williams formula which was developed from small watershed in Australia). The formula is in the form:

$$T_c = (58L)/(A^{0.1}S^{0.2}) \qquad (9)$$

where L is the total length of the stream in km, A is the total area in km^2 and S is the stream slope in mkm^{-1}.

Table 3: Estimated time of concentrations, T_c for W-1 and W-2

Watershed	L (km)	A (km^2)	S (mkm^{-1})	T_c (min)
W-1	3.4	2.62	63/3.4	99
W-2	1.8	1.84	0.3/1.8	140

Table 4: Estimated C value for Watershed W-1: T_c = 1.10 to 1.20 hours

Rainfall event	Observed rainfall duration (hrs)	Observed rainfall intensity (mmhr^{-1})	Observed peak runoff (m^{3}s^{-1})	Estimated runoff coefficient, C
Oct, 17	1.00	15.50	0.1187	0.0105
Oct, 25	1.20	8.83	0.0807	0.0125
Dec, 28	1.00	33.00	0.3863	0.0161
			Average	0.0130

Table 5: Estimated C values for Watershed W-2: T_c= 2 and 3 hours

Rainfall event	Observed rainfall duration (hrs)	Observed rainfall intensity (mmhr^{-1})	Observed peak runoff (m^{3}s^{-1})	Estimated runoff coefficient, C
Nov, 24	2	16.75	0.66	0.0771
Nov, 6	3	11	0.88	0.1565
Oct, 26	2	17.25	0.34	0.0386
Aug, 22	3	9.5	1.60	0.3295
			Average	0.1504

Knowing A, L and S, the value of T_c for both watersheds are computed and presented in Table 3. Having values of T_c and peak discharge from a particular storm rainfall, the runoff coefficient of the study catchment can be estimated. Using rational method, the estimated C values for several rainstorms for both W-1 and W-2 are presented in Tables 4 and 5, respectively. The results show that the C value was low around 0.01 for W-1. These values are extremely low compared to that used in the standard design. For example, for steep catchment area covered with rubber trees and jungle, C value of 0.20 and 0.15 were recommended by Fricke and Lewis (1994). A C value recommended by the American Society of Civil Engineer (ASCE) (Sheafer et al., 1982) for lawns area with heavy soil having 2 to 7% slope is between 0.18 and 0.22. It is noteworthy that the values of C derived from the observed runoff data often show much less dependence on the variations in catchment characteristics such as slope, soil, or vegetation type and conditions than those assumed arbitrarily or handbook values of C (Pilgrim, 1987). Table 5 presents the C values for W-2 obtained from four rainfall events. It is noticed that the C value for W-2 is much higher than W-1. It has to be expected because the W-2 contains more wet and porous soil (peat soil) and high water tables, thus, the stream flood are more responsive to rainfall.

3.5 Flood flow Estimation Using SCS-GIS Approach

Having known geographical features of the watershed system, runoff *CN* for the watershed was determined. For a watershed having several different land cover, a composite *CN* number is thus needed before flood runoff generated by a specific rainfall can be determined. As indicated in the *CN* table the most important geographical criterion of the watershed is the soil type. For W1, the soil cover consists of five major soil types. The types of soil are Malacca Series (25%), Munchong series (45%), Serdang series (10%), Bungor series (5%) and Alluvium-Collovium series (15%). The soil textural classes for the Malacca, Munchong, Serdang and Bungor series are heavy clay, clay-loam, sandy clay loam and sandy loam respectively. The Alluvium-Collovium soil series belong to a fluctuated water table soil. For the simplicity of this study, according to the established curve number hydrologic criteria, Malacca (25%) and Munchong series (45%) can be grouped into D group of soil. The rest of the areas belong to group C of soil. Referring to standard *CN* table and land cover map, the estimated composite *CN* number is tabulated in Table 6. The estimated composite *CN* for watershed W-1 and W-2 was 82 and 45, respectively.

Having known the composite *CN* for the study watershed, the potential peak flood flow for individual storm is estimated. For this purpose a standard graphical approach was established (Viessman and Lewis, 1996) and shown in Figure 6.

Table 6: Estimated *CN* number and percentage of coverage

Crops cover under same category	%age coverage	Soil group**	*CN*	Composite *CN*
Watershed W-1				
Oil palm, rubber, coconut and cocoa	70	D	84	59+23 = 82
Pasture and grass	30	C	77	45
Watershed W-2				
Oil palm, rubber	100	A	45	

** Soil group: A=low runoff potential, B=moderate infiltration rate, C=slow infiltration rate, D=High runoff potential

Similarly, Q peak flow can be calculated using a discharge-rainfall-storage relationship as below:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{10}$$

For initial extraction, $I_a = 0.2S$, where Q is flow, P is rainfall and S is watershed storage. The storage capacity of the watershed can range from 0% (very saturated condition) to 100% (very dry condition).

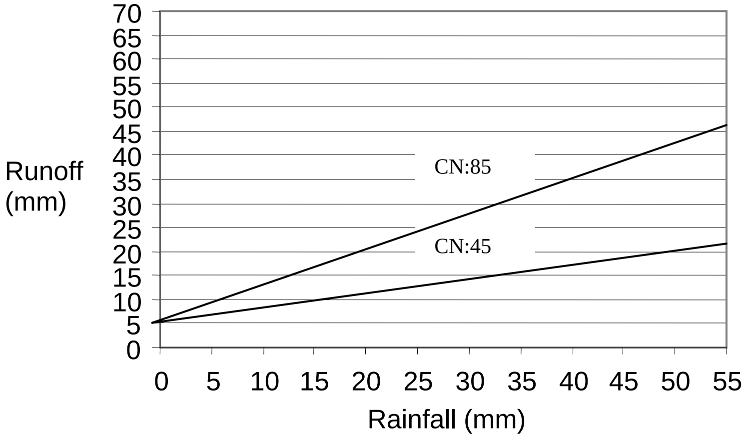

Figure 6: Interpolated Rainfall-Runoff relation for *CN*=85 and 45

The peak flood flow from individual rainfall using CN-SCS approach was then estimated. When compared to the observed peak flow for the selected rainstorm hydrograph (presented in Figures 7 and 8), the CN-SCS approach was found to be over predicted for W-1 and under predict for W-2. In other words, generalization could not be made when using CN-SCS method to estimate flood flows of various landform conditions. This is rather expected because though SCS-CN approached is claimed to be more geographically distributed, the approach is still lumped in nature.

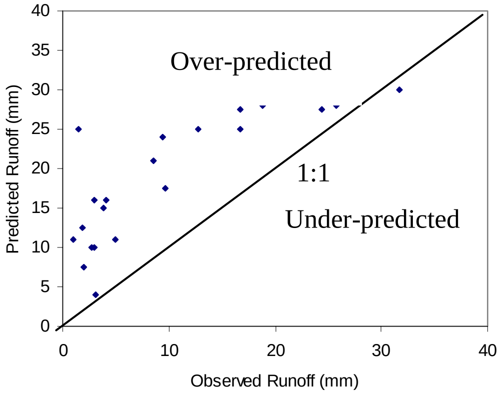

Figure 7: Observed versus predicted runoff for W-1

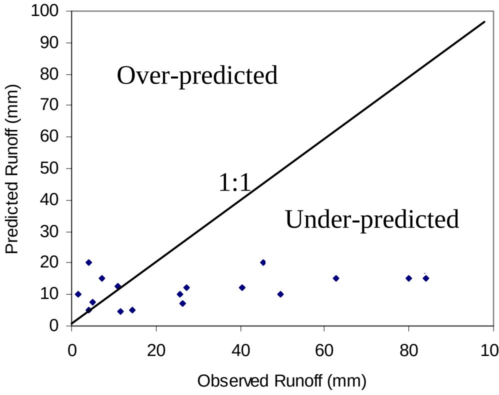

Figure 8: Observed versus predicted runoff for W-2

4. Concluding Remarks

Flood flow prediction for a clearly defined watershed can be performed using a simple Geographic Information System-SCS (GIS-SCS) approach. GIS provides detail georaphical information of the watershed that is generally required in real-time flood forecasting. The most basic GIS-based flood estimation approach is SCS-CN approach. In this approach, basic landform feature such as land cover and vegetation cover are required and the potential flood flow can be estimated after having rainfall depth as an input parameter. The weakness of this method, however, it require an accurate soil hydrologic data for the particular watershed before an accurate flood estimation could be made.

Acknowledgment

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