# IDENTIFICATION RUNOFF SOURCE AREA IN TROPICAL WATERSHED

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## Abstract

Models are needed to describe how nonpoint source area of a watershed affect the rainfall-runoff process in tropical region, yet little spatially distributed data exist to develop such models. Hence, a coupled GIS-event base storm runoff model in a variable source area is developed. The model use grid-formatted map data supported by the Geographical Information System (GIS) and generates distributed results for runoff depth, discharge and coefficient of saturated area fraction. The GIS grid-based distributed CN-VSA method was evaluated for two (W1= 2.29 $Km^2$, W2 = 0.88 $Km^2$) small watersheds located in tropical region in Malaysia. The average Nash-Sutcliffe (1970) efficiency for predicting saturated area fraction and runoff within and outlet of the watershed (W1) using verification between observed and model simulated data for fifteen storm events were ($R^2$=0.99) and ($R^2$ =0.86), respectively. Coefficients indicated a good efficiency for model prediction. Since, the model proposed was found to be suitable for prediction of saturated area fraction ($A_f$) and sources area of runoff, the proposed model was applied for unmonitored sub-watersheds W11, W12, W13 (of watershed W1) and watershed W2, respectively

Key Word: Distributed curve number, Event storm runoff, Tropical watershed

## 1. Introduction

Numerous hydrological processes models have already been published in the literatures. These include the recognition of Variable Source Area (VSA) fraction as an important hydrological process and primary sources of runoff that has implications on water quality risk assessment. Recognition of the VSA fraction is important in watershed planning because restricting potentially polluting activities from runoff source areas is fundamental to controlling NPS pollution. The VSA has geospatial characteristics because potential runoff production varies with watershed characteristics. Hence, GIS as a geospatial tool able to provide integration VSA fraction with runoff generation.

Saghafian and Khosroshahi (2005) proposed and tested a unit response approach for priority determination of flood source areas of the Damavand watershed in Iran. They defined two flood indexes to prioritize sub-watersheds on the basis of the quantity of their contribution to the flood peak at the main outlet of watershed. In this method, the changes in flood peak values of the generated hydrographs are compared with the base case in which all sub-watersheds were present in the simulation. Such comparison can pave the way to quantitatively identifying the single contribution of each sub-watershed unit on the flood peak at the main outlet.

## 2. Methodology

### 2.1. Study Site

Two watersheds (W1 & W2) of Taman pertanian University (TPU) Putra Malaysia are part of headwater of the Putrajaya – Sungai chuau river basin that drained an area of 2.29 and 0.88 $Km^2$, respectively. The watershed W1 is hydrologically divided into three major sub-watersheds; W11, W12, W13. This area is located between latitudes 329709.68 – 332000 N and longitudes 801209.68 – 803564.45 E (UPM- Selangor – Malaysia) (Fig. 1). Table 1 summarized the land use characteristics of TPU watersheds (W1, W2).

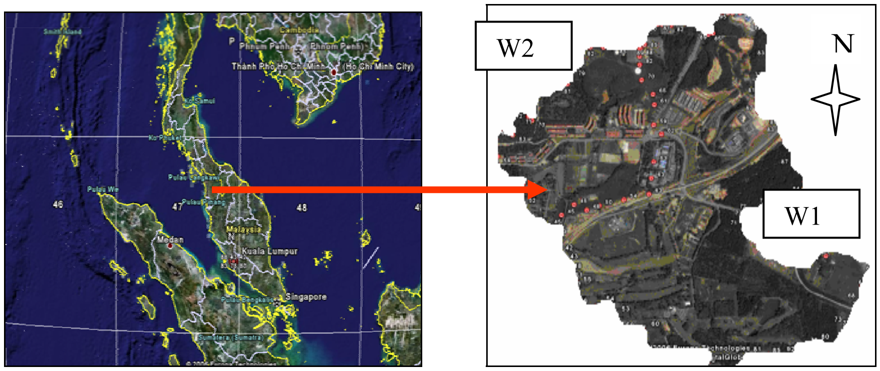


Figure 1: Location of TPU watersheds

Table 1: Characteristics of TPU watersheds (W1, W2)

| Watershed | Wood land | Pasture | Bare | Building | Road | Cemetery | sink | ∑A ($km^2$) | Impervious % |
|---|---|---|---|---|---|---|---|---|---|
| W1 | 1.422 | 0.459 | 0.025 | 0.17 | 0.086 | 0.01 | 0.114 | 2.29 | 11.6 |
| W11 | 0.498 | 0.100 | 0.025 | 0.135 | 0.057 | 0.01 | 0.021 | 0.846 | 23.8 |
| W12 | 0.86 | 0.072 | - | 0.018 | 0.029 | - | - | 0.979 | 4.8 |
| W13 | 0.064 | 0.287 | - | 0.017 | - | - | 0.093 | 0.462 | 3.7 |

| Watershed | Wood land | Pasture | Agriculture | Building | Road | Garden | Fish culture | ∑ A $Km^2$ | impervious % |
|---|---|---|---|---|---|---|---|---|---|
| W2 | 0.353 | 0.152 | 0.139 | 0.0867 | 0.039 | 0.0168 | 0.0976 | 0.88 | 14.3 |

## 2.2. Model describtion

Several methods are used to describe the saturated areas; however, VSA is a promising new concept and simple method for estimating the saturated area fraction is apply in this research. Variable Source Area model is the flexible zone adjacent to and extending the stream that contributes runoff to the channel during a runoff-producing event. The VSA method is a rainfall-runoff model that predicts a) the fraction of watershed that is saturated and b) the location of these areas**.** The main VSA assumption, rain on saturated areas becomes surface runoff, is based on the concepts of Hewlett and Hibbert (1967), Dunne and Black (1970), and more recently Boughton (1987, 1990) and Steenhuis et al. (1984). Under this assumption an area either contributes or does not, so during any short period of time the saturated area coefficient $A_f$ of the watershed can be expressed as:

$A_f = \Delta Q/\Delta P \qquad 0 \leq Af \leq 1$ 1

Where; ΔQ= Direct runoff (mm) during Δ t, ΔP=precipitation (mm) during Δ t

Saghafian and Khosroshahi (2005, 2007) proposed a simple simulation technique, Unite response, whereby the contribution of each sub-watershed unit or group of sub-watershd units to the discharge peak response can be disaggregated. This method can be used to rank diffrent subwatersheds with respect to their contribution to the flow generation at downstrems watershed areas. The subwatershed with largest decrease on the peak of discharge is given the highest rank. Two unit response indeces are defined as follows :

$\%F = (\Delta Q_p/Q_p)*100$ 2

$SFI = \Delta Q_p/A$ 3

Where F (%) and SFI ($m^3/s/km^2$) are gross and per unit area flood indeces, respectively, $\Delta Q_p$ is the amount of reduction in peak discharge due to elimination of the subwatershed ($m^3/s$), $Q_p$ is the total peak discharge ($m^3/s$), and A is the subwatershed area ($Km^2$).

## 3. Generation of data layers

The procedure of VSA model linkage through GIS begins with preparing input data. Determinations of the various factors of distributed CN-VSA method as input data are described below. Each factor of this model is considered as a thematic layer in the ArcView.

### 3.1. Determination of the SCS curve number

The spatial curve number (CN) were determined by merging the land use/ land cover and hydrologic soil groups ship files, and considering of hydrologic and Antecedent Moisture Condition ($AMC_{III}$) of study area. The spatial curve number shape file was then converted into a CN grid and was used in the model simulation. Mean values of $CN_{III}$ were computed based on distributed CN and weighted coefficient of its area (Table 2).

Table 2: Mean value of curve number (CN) of study area

| Watershed | W1 | W11 | W12 | W13 | W2 |
|---|---|---|---|---|---|
| CN(III) | 86 | 93 | 83 | 85 | 92 |

### 3.2. Runoff grid layer

The amount of storm runoff is directly related to the magnitude of the saturated areas (Kim & Steenhuis, 2001) and event rainfall characteristics. Temporal variations in rainfall (space and time) have significant impacts on runoff generation (Hua Lu, 2006). The size of the watersheds of study area is small enough, however, the rainfall variations are considered as a negligible issue by analyzing isolated rainstorm events (Kothyari et al, 1996, 2005).

### 3.4. Calculation peak discharge and priority ranking of flood source area

Instantaneous peak discharge ($Q_p$, $m^3/s$) is computed by using the SCS method (Eq.13). The hydrograph of each event rainfall at outlet of watershed and sub-watersheds were calculated by using the SCS unit hydrograph, Instantaneous peak discharge, and time to peak. The watershed flood index (FI %), specific flood index (SFI, m/s) and Volume index (VI %) and specific volume index (SVI, m) were calculated by using the SCS Equation and then it was ranked for the priority identifying of runoff source area.

## 4. Model Calibration and Validation

The model is said to be valid if its accuracy and predictive capability in the validation period have been proven to lay within predefined acceptable limits (Henriksen et al., 2003).Hence, in current study, the proposed model calibrated. For validation the proposed model in this research, next fifteen event rainfalls – runoffs based on chronological order were selected.

The predicted peak flow ($Q_p$) and coefficient of saturated area fraction ($A_f$) of the event storms were compared with observed values. For assessment acceptability of the model prediction the coefficient of efficiency of Nash-Sutcliffe (1970) statistical method (ASCE, 1993) was used which is given by:

$$R^2 = \sum_{i=1}^{n} (m_i - m)^2 - \sum_{i=1}^{n} (P_i - m_i)^2 \Big/ \sum_{i=1}^{n} (m_i - m)^2 \quad i= 1, 2, \ldots, n \qquad (4)$$

Where; $m_i$ = measured variable, $P_i$ = predicted variable, m = arithmetic mean of $m_i$ for all events i= 1 to n.

Figure 2 shows the calibration and verification between observed and simulated value of hydrological parameter in watershed W1 based on distributed CN-VSA method.

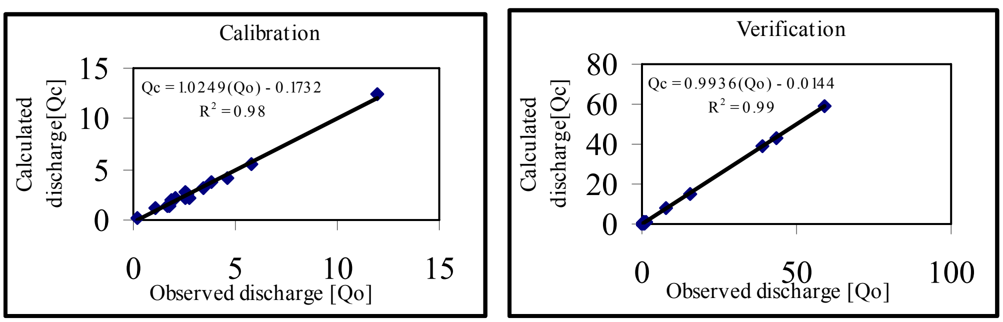


Figure 2: Relation between actual and simulated discharge and index of saturated area fraction in watershed W1

Donigian (2000) pointed that the coefficient of efficiency value ($R^2$) range 0.8 to 0.9 indicates a very good performance for a model. In other word, it indicates that the CN_VSA model has a very good mode and a goodness-of-fit to real condition of watershed of study area (W1). Therefore, it is suitable for prediction runoff in unmonitored watersheds in tropical region under same meteorological conditions.

## 5. Application of proposed model

After calibration and verification, proposed method was applied for unmonitored watershed W2 and sub-watersheds (W11, W12, W13) of watershed W1 under same meteorological condition using the end of ten observed events. Identification of saturated area fraction within a watershed and between sub-watersheds, as non-point source area to product runoff, depends on spatial coefficient value of saturated area fraction ($A_f$). Hence, values of $A_f$ is estimated using value of $P_e$ and Q. The relationship between $A_f$ and $Q/P_e$ is determined by using data of watersheds W1and its sub-watersheds (W11, W12, W13) and watershed W2 (Figure3).

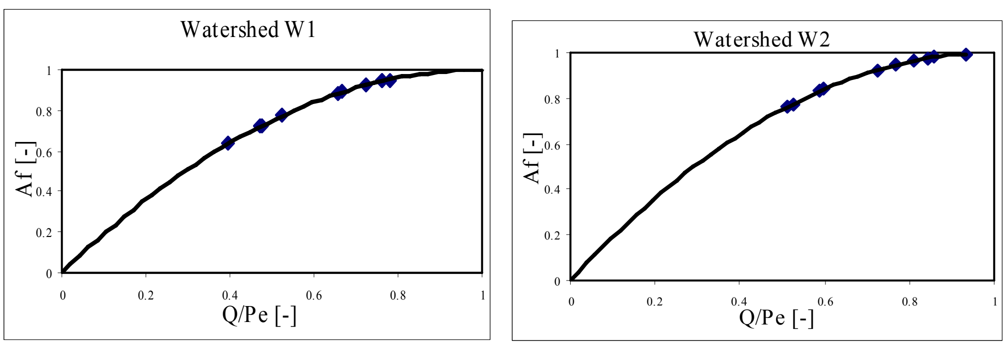


Figure 3: Relation between coefficient of saturated area fraction ($A_f$) and effective runoff coefficient ($Q/P_e$)

Reasonable relation between $Q/P_e$ and $A_f$ indicated that the areas which are more prone to product runoff and discharge has a higher value of $A_f$ than other place (Borst, M., 2005). Saturation is more likely to occur where large contributing areas and small slopes overlap (Endreny, T. A., and Wood, E. F., 2003), which are zones that receive a high $A_f$ value.

Identification of runoff source area and use it to rank diffrent subwatersheds with respect to their contribution to the flow generation at main outlet of watershed is depend on peak or volume of discharge. Hence, instantaneous peak discharge ($Q_p$, $m^3/s$) is computed by using the SCS method. Then, percentage of flood index (FI %) and specific flood index (SFI, m/s) were calculated for a given rainfall and then it was priority ranked for identification flood source area. The subwatershed with largest decrease on the peak of discharge is given the highest rank.

Table3: Results of specific volume index [SVI] ($m^3/km^2$) and percentage of volume index [VI %] for given event rainfall (P=22.86mm, 18/06/2007)

| Watershed | Sub-watershed | Area ($Km^2$) | Volume of discharge ($m^3$) | Volume of discharge without sub-watershed or watershed ($m^3$) | specific volume index SVI [$m^3$/ $km^2$] | Priority ranking based on SVI | VI% | Priority ranking based on VI% |
|---|---|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| | W11 | 0.846 | 4815 | 4736 | 5691 | 2 | 50.4 | 1 |
| | W12 | 0.979 | 2460 | 7090 | 2513 | 3 | 25.7 | 3 |
| | W13 | 0.462 | 3146 | 6405 | 6809 | 1 | 32.9 | 2 |
| W1 | | 2.290 | 9551 | 12272 | 4170 | 2 | 43.7 | 2 |
| W2 | | 0.880 | 12272 | 9551 | 13945 | 1 | 56.2 | 1 |
| Total | | 3.17 | 21823 | - | - | | - | |

The ratio of runoff depth to rainfall depth indicates the percentage of watershed area contributing surface runoff (Gbuerk et al., 2002). In addition, Eq.1 (Steenhuis, 2003; Lyon, 2004; Borst, 2005, indicates saturated area fraction within a watershed involve to runoff generation at the end of the event rainfall. Hence, the relation between the observed event rainfalls (P) and calculated direct runoff (qc) simulated which is showed by table 4.

Table 4: Percentage of area involve to a event rainfall

| Watershed | Impervious area% | Saturated area% | Other category area% |
|---|---|---|---|
| W1 | 11.6 | 15.4 | 73 |
| W11 | 23.8 | 18.2 | 58 |
| W12 | 4.8 | 15.6 | 79.6 |
| W13 | 3.7 | 33.1 | 63.2 |
| W2 | 14.3 | 8.7 | 77 |

## 6. Conclusion

The proposed method predictions are found to be approximately close to actual observed direct runoff with a partial percentage of error for selected watersheds under tropical condition. This difference could be attributed to several reasons. First, CN-VSA model is based on the CN method, which was initially developed for agricultural and natural watersheds, and extending it to Rural-Urban watersheds, for which the existing CN are not representative, can cause the model to predict approximate runoff. Secondly, in the CN method, runoff is directly proportional to precipitation with an assumption that directs runoff is produced after the initial abstraction of 20 percent of the potential maximum storage. Refsgaard (1997) suggested that multi-site runoff heads in a watershed should be measured and compared with the simulated ones for successful model validation. Even though this study did not sufficiently fulfill the distributed model's verification requirements in the manner of spatial verification, temporal calibration and verification with storm events.

This method shows a reasonable agreement with filed data. Fieldwork and measurements, which show the extent of the saturated area fraction in small watershed in tropical condition, confirmed the CN-VSA method. The concept that led to this method can also be used for watersheds with a different rainfall – runoff relation. However, research should be done to verify (test) the method for large watersheds, and to extend the concept to watersheds with different characteristics.

Since all models are simplifications of our perceptions of the real world, they cannot hope to reproduce the behaviors of the prototype in all its detail. Consequently there can be no absolute validation of any model and the term can only be applied in a relative sense with reference to some specified criterion of comparison between the real world system and the model. In fact, practical considerations may result in a model being accepted as sufficiently accurate for a given purpose without being accepted as a validated representation of the prototype. To sum up, results of this research indicated that the governing of runoff mechanism is too much close to saturated excess concept. Therefore, results of this research led to propose to planner and modeler use the CN-VSA fraction as a new method in hydrological process of rainfall-runoff and water quality models. The concept which led to this method can also be used for watersheds with a similar meteorological condition in small watershed.

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