Soil erodibility and surface runoff potentiality for water pollution management of Melaka Tengah Watersheds in Malaysia

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Abstract

The relationships among surface runoff, precipitation and soil erodibility are significant in addressing environmental pollution as like water pollution and in predicting the benefits of Melaka Tengah watershed management practices. Land use pattern, soil series and slope percentage are also major factors to develop these relationships. Rainfall data (2009 to 2012) were collected from six rainfall station and analyzed for variations in precipitation at monthly and daily scale for calculating the surface runoff of these watersheds. Soil texture and structure, organic matter percentage, and hydraulic conductivity were analyzed for the particular soil series in this study area. Soil Conservation Services (SCS) and Weighted Curve Number (CN_w) methods were introduced to calculate the surface runoff on daily basis. Henceforth, monthly surface runoff was calculated by summing the daily runoff and surface runoff map was produced by ArcGIS tools. Thenceforth, Tew equation was introduced to identify the soil erodibility of watershed soils for predicting the soil erosion probability. Results indicated the weighted curve number varies from 82 to 85 and monthly runoff varies from 23% to 30% among the five watersheds. Soil erodibility varies from 0.038 to 0.06 (ton/ha)(ha.hr/MJ.mm). Linau-Telok-Local Alluvium, Malacca-Munchong, Munchong-Malacca-Serdang and Malacca-Munchong-Tavy are the dominant soil series of this region having the average soil erodibility of about 0.042 (ton/ha)(ha.hr/MJ.mm). The main focus of this study is to provide the information of surface runoff potentiality, and soil erodibility for watershed water resources management, water pollution and flood control for watersheds.

Keywords: Soil erodibility, surface runoff potential, SCS-CN methods, Tew equation, Melaka Watersheds.

Introduction

The rainfall intensity and frequency are the vulnerable criteria for the soil to erosion for watershed area. Erosion processes of the soil may be the cause of new land management practices in agricultural field. Chemical and physical properties of top soil are losing due to different factors like human activities and some natural factors such as rainfall intensity, erosion rate and textural pattern of the soil. Rainfall with high intensity causes the surface runoff and as a result causes the soil losses at plot and field scale (Uson, 1998; Ramos and Porta, 1997). Land transformations also increase the soil erosion rates (Nacci et al., 2002). Basically soil erosion by water is the process of soil particles detachments by the effect of rainfall and surface runoff. Different soil types have its own textural pattern and show its bonding characteristics.

Soil erodibility (K factor) is defined as the rate of soil loss per erosivity index unit as measured on standard criterion in a clean tilled fallow condition (Weesies, 1998). This factor is the most important for soil loss equation in USLE (Universal Soil Loss Equation). It is in RULSE (Revised Universal Soil Loss Equation) equation having the influence of soil properties on soil loss during storm events (Hasim and Wan Abdullah, 2005). Mostly eroded soil particles are silt and very fine sand and aggregated soils have less erosion capacity because of having more resistance characteristic (Kim, 2006).

After soil erosion, eroded soil particles are transported by surface runoff and deposited in reservoirs, flood plains and deltas. This surface runoff is measured by the Soil Conservation Service (SCS) method having its flexibility, simplicity and versatility (SCS, 1972; Melesse and Shih, 2002; Gaudin, et al., 2010). This method interprets the water resources management and assesses the runoff volume for a particular rainfall depth of watershed area (Hawkins, 1978; Regan and Jackson, 1980; Lewis et al., 2000). To predict surface runoff using SCS method, Curve Number (CN) is essential for the proposed method. The hydrological soil group of watershed area defines CN on the basis of several factors and this curve number represents surface runoff potentiality of a watershed. The CN represents greater runoff for soil group C and D while less for soil group A and B.

This study aims to define the soil erodibility of Melaka Tengah Watershed and for identifying the surface runoff and henceforth predict the soil erosivity and its transportation rate by surface runoff. Therefore, an attempt has been made to find out the K factor and runoff potentiality of Melaka Tengah watershed for the best water resources management practice and surface water quality monitoring.

Materials and Methods

Melaka Tengah is under the state of Melaka in Peninsular Malaysia having different soils and land use patterns (Figure 1). Watershed areas are delineated on the basis of drainage basin of this area. Elevation of this area varies from 20 - 140 m. Surface runoff of watershed area is being influenced by practicing ten land use patterns and as well as their land management criteria. Soils of this area are grouped on the basis of water infiltration rate through the soil. In general, among the soil groups, D category having the lowest rate of infiltration produces highest runoff potential like clay soils.

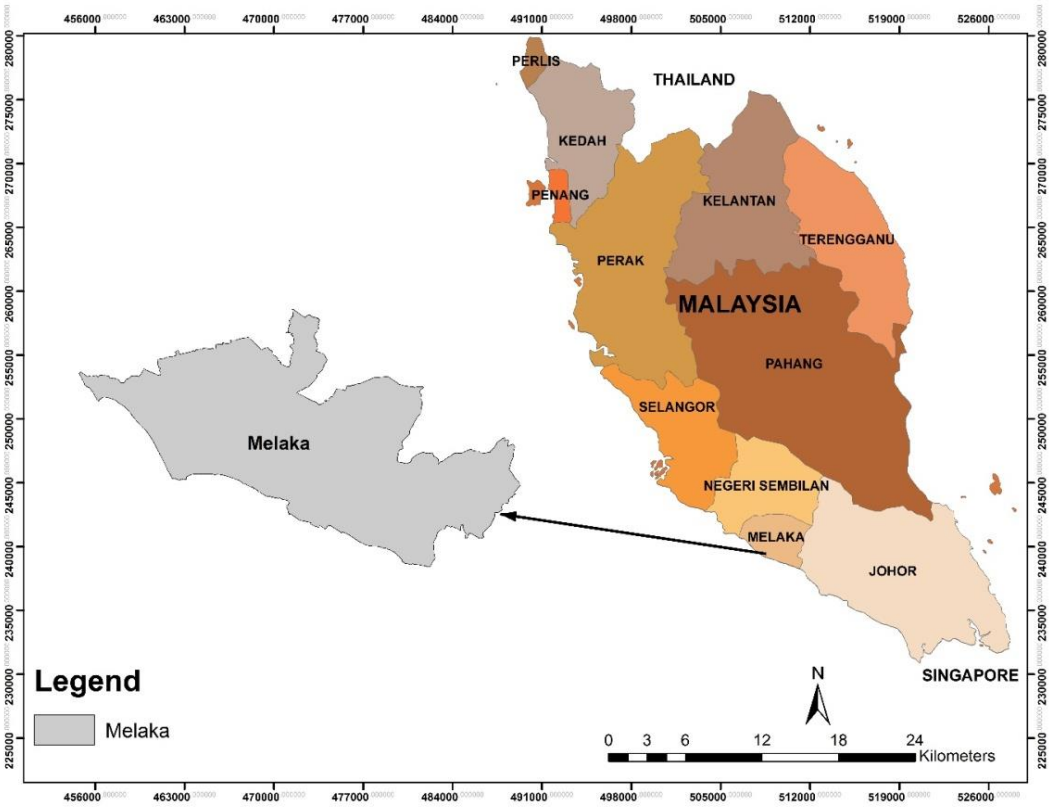

Figure 1. Location map of the study area

Soil Erodibility Factor (K)

Soil erodibility (K factor) depends on the soil texture and structure, organic matter percentage and hydraulic conductivity. This factor is measured by using a nomograph based on the factors (Wischmeier et al., 1971; Morgan, 1980). In this regards, soils were analyzed for calculating the soil erodibility and the proposed equation was used for Malaysian soil (MASMA, 2000). The following equation is given as:

$$K = \frac{[2.1 \times 10^{-4}(12 - OM\%)(N1 \times N2)^{1.14} + 3.25(S - 2) + 2.5(P - 3)]}{100} \quad (1)$$

Where, OM is the organic matter; N1 is the percentage of silt and very fine sand; N2 is the percentage of silt, very fine sand and sand; S is soil structure code (Scwab et al., 1993) and P is soil permeability class (Hydraulic Conductivity) based on permeability criteria (Table 1). After getting the K value of the soil series, it was added into the soil map shape file and was created a soil erodibility map of the watershed area by ArcGIS.

Table 1: Hydraulic conductivity class and their rank (Mustafa Kamal, 1984)

Hydraulic Conductivity (cm/hr)	Permeability Class	Rank
<0.125	Very slow	7
0.125-0.50	Slow	6
0.50-2.00	Moderately slow	5
2.00-6.25	Moderate	4
6.25-12.50	Moderately rapid	3
12.50-25	Rapid	2
>25	Very rapid	1

Surface Runoff Calculation

The Soil Conservation Service method is considered to measure the surface runoff of different watersheds in Melaka Tengah and the equation is expressed as:

$$R_{wi} = \frac{\{P - (I_a)_{wi}\}^2}{\{P - (I_a)_{wi}\} + S_{wi}} \quad (2)$$

Where, *wi* indicates different watershed number, R_{wi}= Runoff, P = Rainfall, S_{wi}= Potential maximum retention after runoff begins and $(I_a)_{wi}$= Initial abstraction which is the water losses before surface runoff begins. $(I_a)_{wi}$ is as:

$$I_a)_{wi} = 0.2S_{wi} \tag{3}$$

S_{wi} and P are to be allowed to yield the runoff amount and expressed as:

$$R_{wi} = \frac{(P - 0.2S_{wi})^2}{P + 0.8S_{wi}} \tag{4}$$

S_{wi} is related to the soil and land cover conditions of a particular watershed of Melaka through the weighted curve number (CN_{wi}) and expressed as:

$$S_{wi} = \frac{25400}{CN_{wi}} - 254 \tag{5}$$

Where, CN_{wi} is a weighted runoff curve number. It is a dimensionless number and lies $0 \le CN_{wi} \le 100$.

Results and Discussion

This watershed is associated with eleven soil series having different soil texture (Figure 2) and is classified on the basis of soil properties and hydrological soil group classification (Table 2). Based on the calculated data, soil erodibility factor for eleven soil series varies from 0.038 to 0.06 (ton/ha)(ha.hr/MJ.mm) (Figure 3). Most of the area about 150 square km is under Linau-Telok-Local Alluvium series and the K value of this soil series is 0.04 (ton/ha)(ha.hr/MJ.mm). Munchong-Malacca-Serdang, Malacca-Munchong and Malacca-Munchong-Tavy occupy the area 107, 104 and 82 square km respectively, whereas soil erodibility values 0.041, 0.044 and 0.046 (ton/ha)(ha.hr/MJ.mm) respectively. Disturbed land and steep land have high K value of 0.06 (ton/ha)(ha.hr/MJ.mm) in this watershed distributing about 16 square km whereas Rengam series has low k value of 0.038 (ton/ha)(ha.hr/MJ.mm).

Most of the soils fall under only C and D hydrological soil groups. In accordance with the soil characteristics, this area exhibits ten land use patterns (Figure 4).This pattern are responsible to control the runoff potentiality of this area where as tree-palm-permanent crops and urban-settlement occupy 36 and 26% of the total watershed area contributing the runoff of this region.

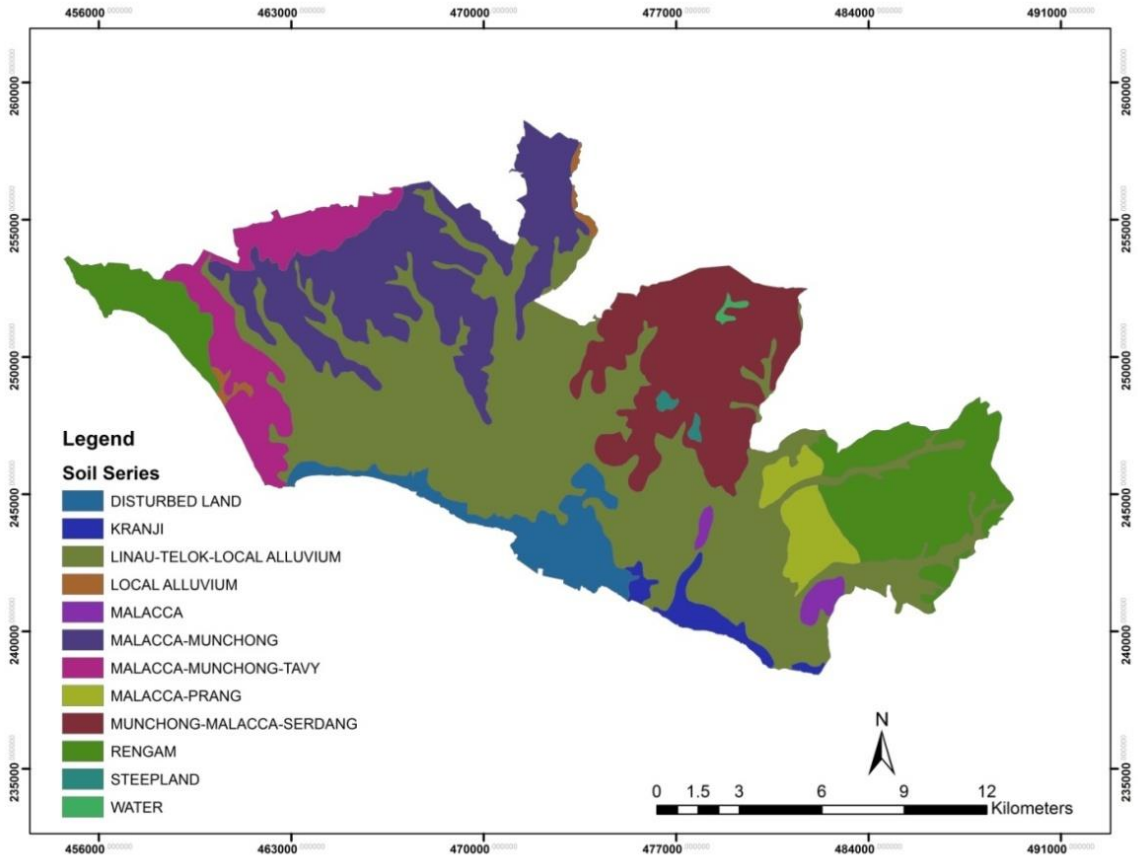

Figure 2. Soil series map of the Melaka watershed

Table 2. Hydrological soil group classification of Melaka

Soil Mapping Unit	***Hydrologic Soil Group (HSG)***
Melaka	D
Kranji	D
Melaka Prang Association	D
Rengam	C
Linau-Telok-Local Alluvium Complex	C
Munchong-Melaka-Serdang Association	D
Melaka-Munchong-Tavy Association	D
Melaka-Munchong Association	D
Local Alluvium Complex	C

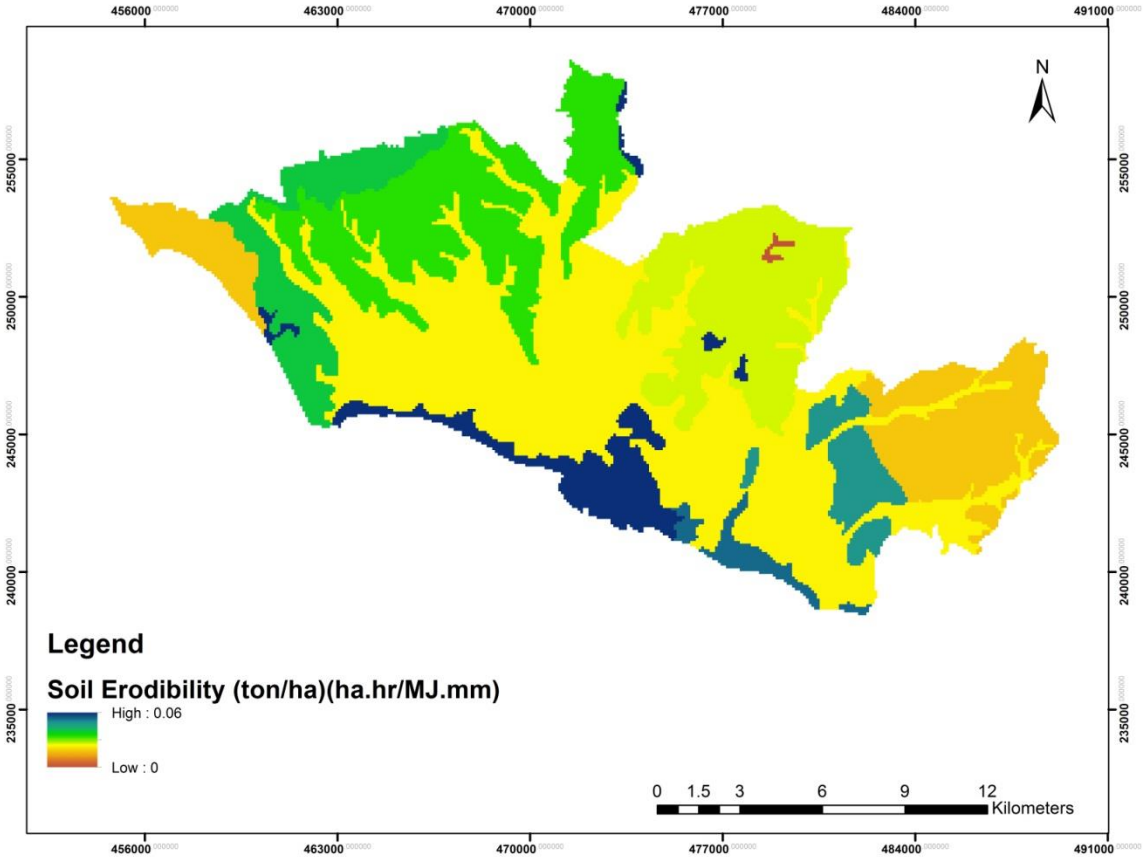

Figure 3. Soil erodibility map of Melaka Tengah

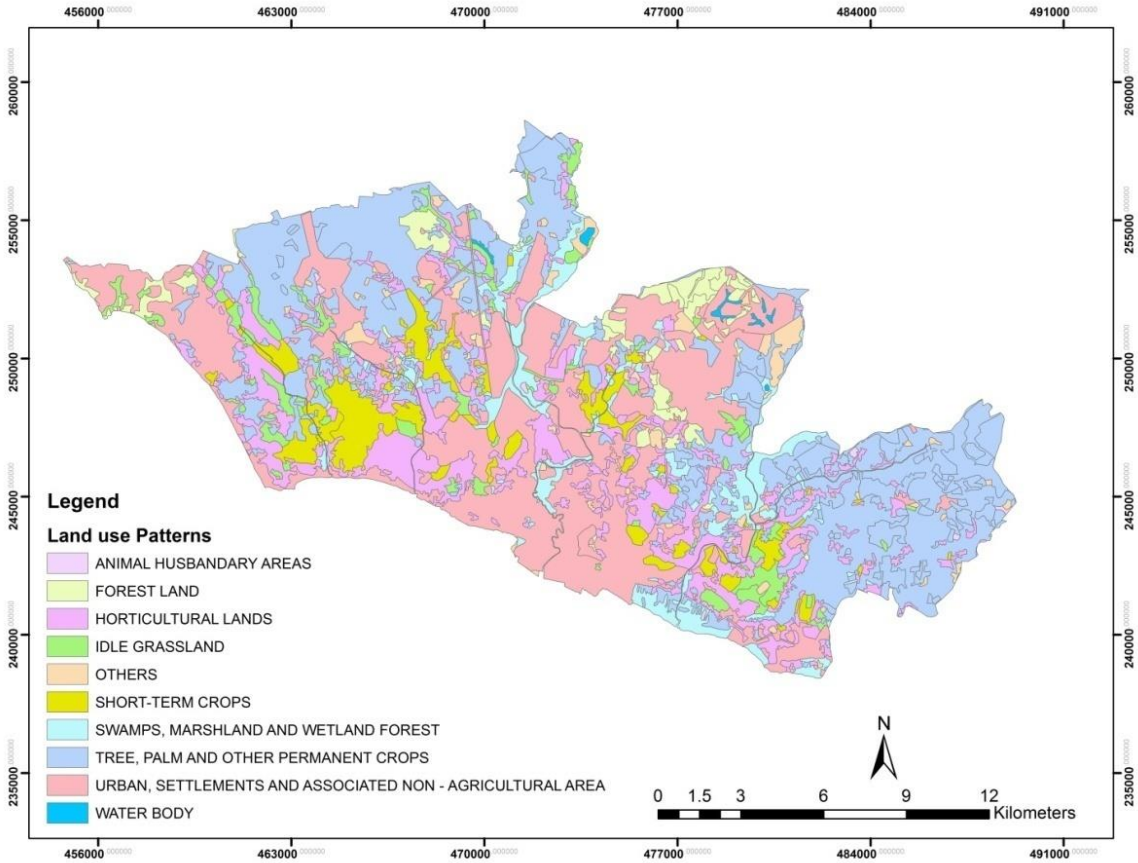

Figure 4. Land use map of Melaka

Runoff curve numbers are considered on the basis of land cover and hydrological soil condition. The weighted runoff curve number can be calculated by weighting the CN's of the different subareas in proportion to the land cover associated with each CN value for a catchment.

S_{wi} is calculated by using the equation 5 after getting the weighted CN_{wi} of each watershed. The daily rainfall data of 2009 to 2012 are considered to analyze the runoff of Melaka catchment. The runoff depth (R_{wi}) is measured for each watershed after putting rainfall data and S_{wi} values in equation 4. This equation is valid only for the condition of $P > 0.2S_{wi}$. Every watershed of Melaka region follows this condition. The weighted CN_{wi} value and S_{wi} of each watershed of Melaka are shown in Table 3.

Table 3. Weighted CN_{wi}, S_{wi} and monthly mean runoff for each watershed

Watershed	***Weighted CN_{wi}***	***Value of S_{wi} (mm)***
1	82	55.76
2	83	52.02
3	85	44.82
4	84	48.38
5	83	52.02

Daily runoff was calculated using SCS method from the daily rainfall data throughout the time period from 2006 to 2012. After getting the daily runoff, monthly runoff was calculated by summing the daily runoff data. Eighty four data sets were prepared for monthly runoff analysis. These data sets present the monthly rainfall-runoff pattern of Melaka watersheds. The runoff varies with the different value of CN in Melaka watershed. Henceforth, runoff percentage was calculated for a particular watershed, and average runoff in Melaka Tengah watershed is 26% and it reveals that watershed 3 contributes monthly more surface runoff of about 30% (Table 4). Figure 5 shows the surface runoff of the watersheds of the study area.

Table 4. Monthly runoff of particular watershed area of Melaka

Watershed	***Runoff R_{wi} (m)***	***Rainfall P (m)***	***Runoff (%)***
1	0.030	0.13	23
2	0.034	0.13	26
3	0.039	0.13	30
4	0.028	0.11	25
5	0.037	0.14	26
Average			26

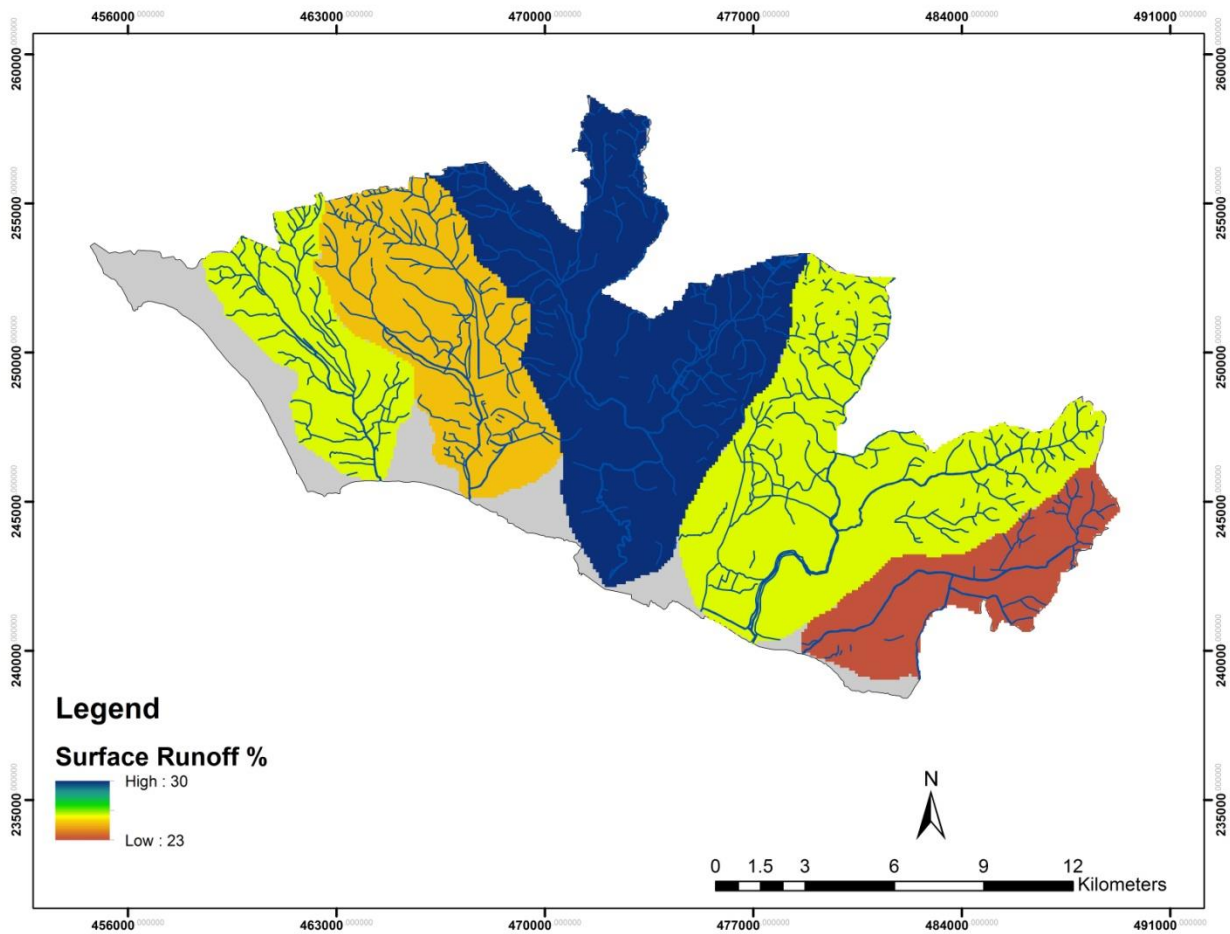

Figure 5. Surface runoff percentage of the watersheds of the area

Conclusion

The Tew equation and SCS method were considered to assess the soil erodibility and surface runoff of watersheds in Melaka Tengah basin. Linau-Telok-Local Alluvium occupies most of the area contributing soil erodibility values of 0.04 (ton/ha)(ha.hr/MJ.mm). This soil series exhibits sandy clay loam. Malacca-Munchong, Munchong-Malacca-Serdang and Malacca-Munchong-Tavy also occupy the area of about 104, 107 and 82 square km and soil erodibility values of soil series are 0.044, 0.041 and 0.046 (ton/ha)(ha.hr/MJ.mm) respectively. The average soil erodibility of this region is about 0.042(ton/ha)(ha.hr/MJ.mm). Most of the soils of this region are under C and D soil groups on the subject of soil texture and hydrological condition. The area averaged weighted curve number was calculated for the entire watershed and varies from 82 to 85 for different

watershed in Melaka Tengah basin. The runoff values fluctuate due to the seasonal variation of monsoonal rainfall. Based on the runoff data, the monthly runoff percentage was identified and the value is 23, 26, 30, 25 and 26 % for the watershed 1, 2, 3, 4 and 5, respectively. Watershed 3 had most of the surface runoff of this region and 30% of rainfall water goes directly to the river. About 26% volume of water from rainfall directly goes to the river through surface runoff in this watershed. This runoff and soil erodibility provides the firsthand information for rainwater distribution, contribution and soil erosion for surface water quality. It may be helpful for useful planning of surface water management and for contribution and potentiality of groundwater recharge.

Acknowledgement

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