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Soil Erodibility for Water Pollution Management of Melaka Watershed in Peninsular Malaysia

Md. Ibrahim Adham [a], Sharif Moniruzzaman Shirazi [b], Faridah Othman [a], Noorul Hassan Zardari [b], Zulkifli Yusop [b] and Zubaidah Ismail [a]

[a] *Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia*
[b] *Centre for Environmental Sustainability and Water Security, Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM), 81310 Skudai, Johor, Malaysia*

Abstract

The relationships between surface runoffand soil erodibility are significant in water pollution and watershed management practices. Land use pattern, soil series and slope percentage are also major factors to develop the relationships. Daily rainfall data were collected and analyzed for variations in precipitation for calculating the surface runoff of these watersheds and surface runoff map was produced by GIS tools. Tew equation was utilized to predict soil erodibility of watershed soils.Results indicated that the weighted curve number varies from 82 to 85 and monthly runoff 23% to 30% among the five watersheds. Soil erodibility varies from 0.038 to 0.06 ton/ha (MJ.mm/ha/h). 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 (MJ.mm/ha/h). The main focus of this study is to provide the information of soil erodibility to reduce the water pollution of a watershed.

Keywords: soil erodibility; surface runoff;Tew equation; Melaka watersheds.

1. Introduction

The rainfall intensity and frequency are the vulnerable criteriafor soil erosion of a watershed. 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 resulted in soil losses at plot and field scale (Ramos and Porta, 1997; Uson, 1998; Bartokova *et al*., 2014; Pongpetch *et al*., 2015; Meher *et al*., 2015). Land transformations also increase the soil erosion rates (Nacci *et al*., 2002; Ismail *et al*., 2013). 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).

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; Adham *et al*., 2014). This method interprets the water resources management and assesses the runoff volume for a particular rainfall depth of watershed area (Hawkins, 1978; Ragan and Jackson, 1980; Lewis *et al*., 2000; Shirazi *et al*., 2011; Chow *et al*., 2013). 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 due to have sandy loam or deep sand soil characteristics.

This study aims to investigate the soil erodibility of Melaka Watershed and 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 Melakawatershed for surface water quality monitoring.

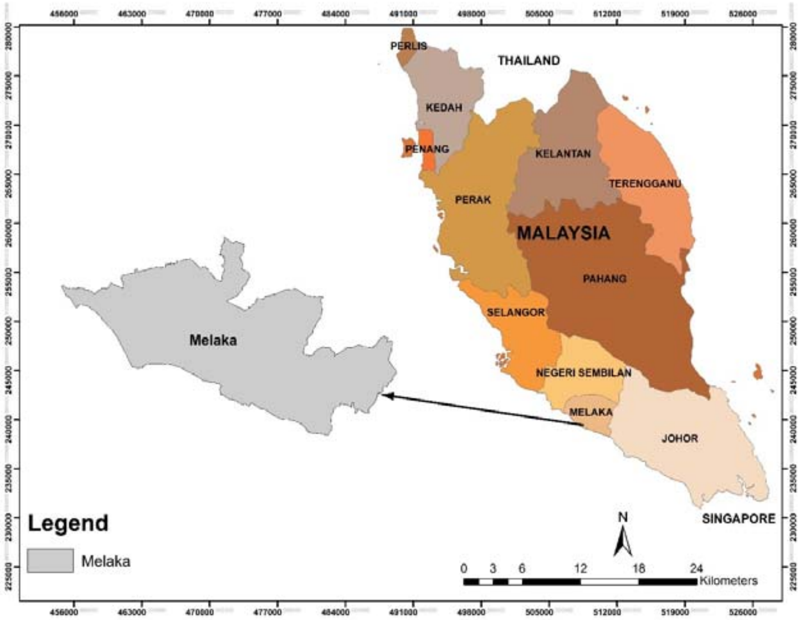

Figure 1. Location map of the study area

2. Materials and Methods

Melaka in Peninsular Malaysia consists of different soils and land use patterns as shown in Fig. 1. Watersheds are delineated on the basis of drainage basin. 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 areaare grouped on the basis of water infiltration rate through the soil. In general, among the soil groups, the lowest rate of infiltration produces highest runoff potential like clay soils.

2.1. 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 regard, soils were analyzed for calculatingthe soil erodibility. The Tew equation (Tew, 1999) was used for Malaysian soil (MASMA, 2000) expressed as Eq.1.

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

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 (Schwab *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.

2.2. Surface runoff

The Soil Conservation Service method is considered to be suitable to measure the surface runoff of different watersheds in Melaka (Eq.2).

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

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 (Eq. 3) which is the water losses before

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 begins.

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

S_{wi} and P are to be allowed to yield the runoff amount (Eq.4).

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

Swiis related to the soil and land cover conditions of a particular watershed of Melaka (Eq.5) through the weighted curve number CN_{wi}.

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

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

3. Results and Discussion

This watershed is associated with eleven soil series having different soil texture (Fig. 2) and is classified on the basis of soil properties and hydrological soil group classification (Table 2). Soil erodibility factor for eleven soil series (Fig. 3) varies from 0.038 to 0.06 ton/ha (MJ.mm/ha/h). 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 (MJ.mm/ha/h). 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 (MJ.mm/ha/h) respectively. Disturbed land and steep land have high Kvalue of 0.06 ton/ha (MJ.mm/ha/h)in this watershed distributing about 16 square km whereas Rengam series has low k value of 0.038ton/ha (MJ.mm/ha/h).

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 (Fig. 4).These patternsare responsible to control the runoff potentiality whereas the tree-palm-permanent crops and urban-settlement occupy 36 and 26% of the total watershed area contributing the runoff of this region.

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.

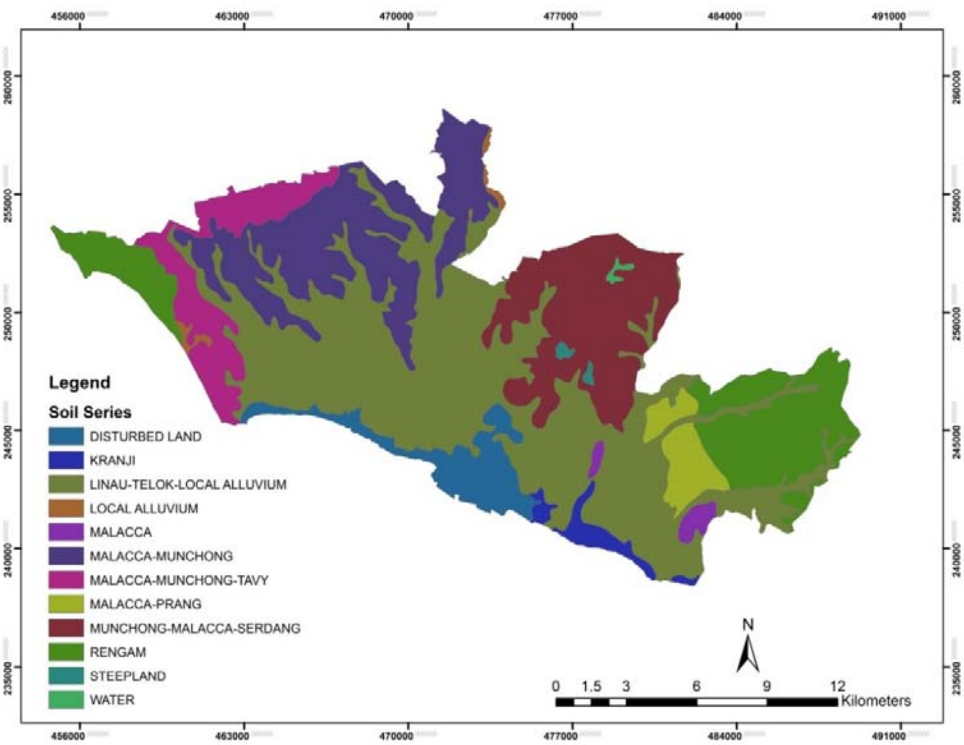

Figure 2. Soil series map of the Melaka watershed

Table 2. Hydrological soil group classification of Melaka watershed

Soil mapping unit	Soil description	Hydrologic Soil Group (HSG)
Melaka	Dispersible fine-grained clays: about 5% of dispersible materials	D
Kranji	Dispersible fine-grained clays: about 5% of dispersible materials	D
Melaka Prang Association	Dispersible fine-grained clays: about 5% of dispersible materials	D
Rengam	Dispersible fine-grained clays: about 10% of dispersible materials	C
Linau-Telok-Local Alluvium Complex	Dispersible fine-grained clays: about 10% of dispersible materials	C
Munchong-Melaka-Serdang Association	Dispersible fine-grained clays: about 5% of dispersible materials	D
Melaka-Munchong-Tavy Association	Dispersible fine-grained clays: about 5% of dispersible materials	D
Melaka-Munchong Association	Dispersible fine-grained clays: about 5% of dispersible materials	D
Local Alluvium Complex	Dispersible fine-grained clays: about 10% of dispersible materials	C

Daily runoff was calculated using SCS method for daily rainfall during 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 3). Fig. 5 shows the surface runoff of the watersheds of the study area.

4. Conclusion

Tew equation and SCS method were considered to assess the soil erodibility and surface runoff of Melaka

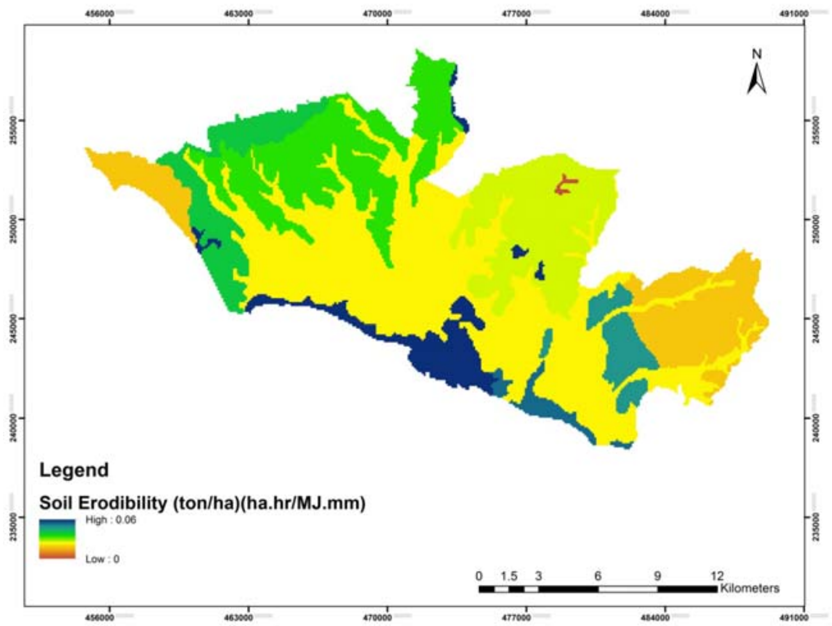

Figure 3. Soil erodibility map of Melaka watershed

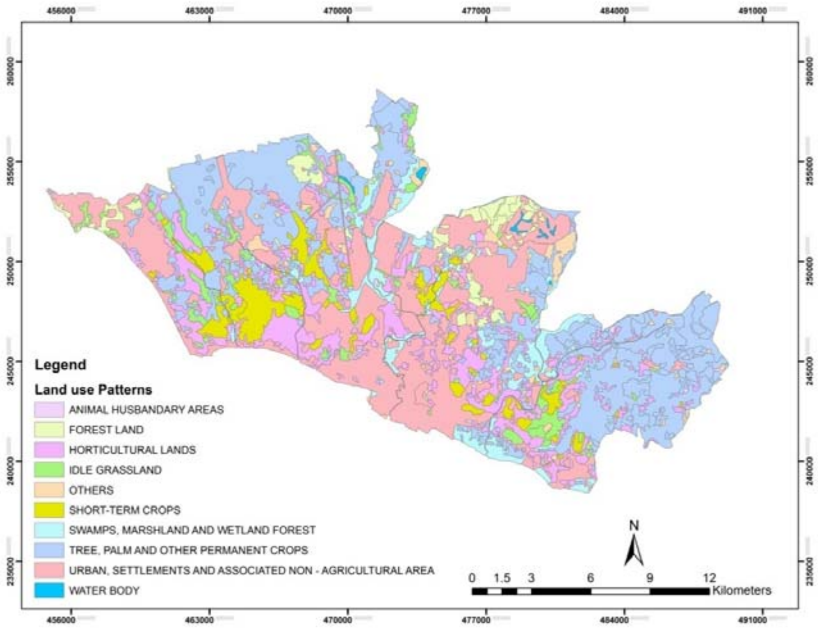

Figure 4. Land use map of Melaka watershed

Table 3.Weighted runoff curve number (CN_{wi}), soil and land cover conditions of the watershed (S_{wi}) and monthly mean runoff for each watershed.

Watershed	Weighted curve number (CN_{wi})	Max. retention after runoff begins, S_{wi} (mm)	Runoff, R_{wi} (m)	Rainfall, P (m)	Runoff (%)
1	82	55.76	0.030	0.13	23
2	83	52.02	0.034	0.13	26
3	85	44.82	0.039	0.13	30
4	84	48.38	0.028	0.11	25
5	83	52.02	0.037	0.14	26

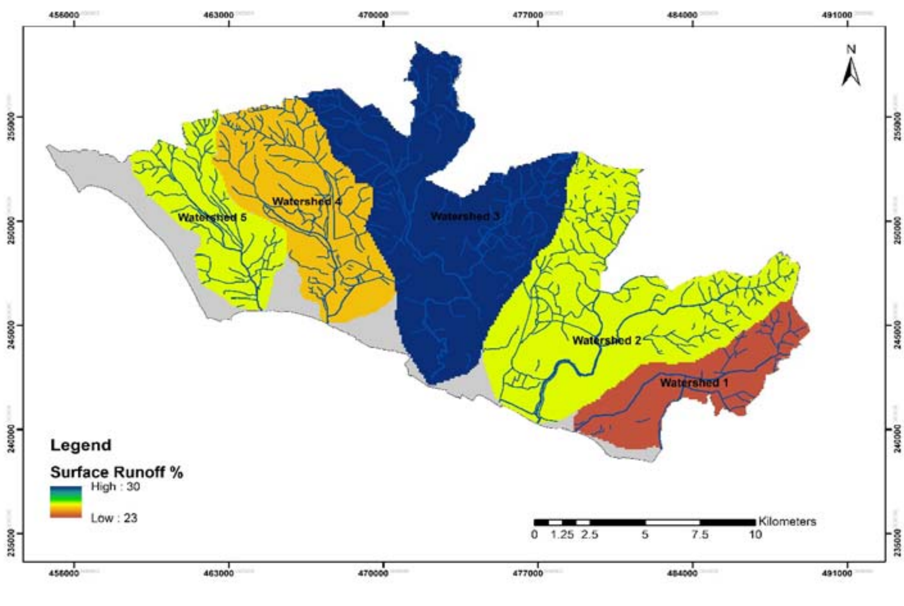

Figure 5. Surface runoff percentage of the watersheds of the area

watershed. Linau-Telok-Local Alluvium occupies most of the area contributing soil erodibility values of 0.04 ton/ha (MJ.mm/ha/h). 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 (MJ.mm/ha/h), respectively. The average soil erodibility of this region is about 0.042ton/ha (MJ.mm/ha/h). The runoff fluctuates due to the seasonal variation of monsoonal rainfall. 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.

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Correspondence to
Associate Professor Dr. Sharif Moniruzzaman Shirazi
Centre for Environmental Sustainability and Water Security,
Faculty of Civil Engineering,
UniversitiTeknologi Malaysia (UTM),
81310 Skudai, Johor,
Malaysia
E-mail:smshirazi@gmail.com