

## A Study on Surface Wash and Runoff Using Open System Erosion Plots

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### ABSTRAK

Kajian tentang hakisan dan aliran permukaan ini yang menggunakan plot hakisan sistem terbuka dijalankan di hutan simpanan Tekala, Hulu Langat, Selangor. Tujuannya ialah untuk mengukur satu proses geomorfologi yang penting tentang hakisan dan aliran permukaan. Kadar variasi bagi kedua-dua hakisan dan aliran permukaan dianalisis dengan merujuk kepada sifat tanah kawasan kajian dan 14 parameter hujan. Hasil kajian menunjukkan bahawa kadar hakisan berada di antara  $49.5 \text{ g m}^{-2} \text{ yr}^{-1}$  ke  $137 \text{ g m}^{-2} \text{ yr}^{-1}$  dengan purata sebanyak  $85.04 \text{ g m}^{-2} \text{ yr}^{-1}$ . Sedimen ampaiian merupakan lebih 80% daripada jumlah sedimen yang diangkut oleh hakisan permukaan. Kadar purata tentang jumlah aliran permukaan ialah  $133.8 \text{ lm}^{-2} \text{ yt}^{-1}$ . Hasil kajian juga menunjukkan bahawa korelasi antara hakisan permukaan, aliran permukaan dan sifat tanah adalah berbeza-beza. Bagaimanapun, korelasi antara aliran permukaan dengan hakisan permukaan didapati sangat signifikan dengan kebanyakan parameter hujan. Jumlah keseluruhan hujan adalah parameter hujan yang terbaik untuk meramal kedua-dua hakisan dan aliran permukaan.

### ABSTRACT

This study on surface wash and runoff using open system erosion plots was carried out in Tekala forest reserve, Hulu Langat, Selangor. Variations in the rates of surface wash and runoff were analysed with reference to soil characteristics of the site and 14 rainfall parameters. The results showed that the rate of surface wash ranged from  $49.5 \text{ g m}^{-2} \text{ yr}^{-1}$  to  $137 \text{ g m}^{-2} \text{ yr}^{-1}$  with an average of  $85.04 \text{ g m}^{-2} \text{ yr}^{-1}$ . Suspended sediment constituted approximately 80% of the total sediment transported by surface wash. The average rate of total surface runoff was  $133.8 \text{ lm}^{-2} \text{ yt}^{-1}$ . The results also showed that correlations between surface wash, surface runoff and soil characteristics varied. However, the correlation between surface runoff and surface wash was found to be highly significant with most rainfall parameters. The total amount of rainfall was most suitable rainfall parameter to predict both surface wash and runoff.

### INTRODUCTION

Soil erosion resulting from deforestation and agricultural practice is a serious problem in Malaysia and the tropics in general. A recent study in the Sungai Tekala catchment, east of Selangor, indicated that soil loss under forests on moderate to steep hills can range from  $0.5 \text{ t ha}^{-1} \text{ yr}^{-1}$  to  $1.38 \text{ t ha}^{-1} \text{ yr}^{-1}$  (Sabry 1997) while Hatch (1981), in the Semangkok Forest Reserve, reported soil loss of  $0.15 \text{ t ha}^{-1} \text{ yr}^{-1}$ . The erosion is caused primarily by the process of rainsplash erosion and surface wash. Under tropical cli-

mate, the processes of erosion are accelerated due to the fast pace of land use change such as the replacement of natural forest by agricultural land or from agricultural land to urban development. Soil loss estimates during land use conversion from forest to oil palm range from 220-250  $\text{t km}^{-2} \text{ yr}^{-1}$  while that in construction sites was reported to be phenomenal, from 40,000 - 50,000  $\text{t ha}^{-1} \text{ yr}^{-1}$  (JAS 1996).

The low rate of soil loss in forest area is attributed to the function of the forest itself. Forest protects the underlying soil from direct

effect of rainfall. The rain forest vegetation intercepts between 21.8 % and 26.0 % of annual rainfall (Nik Mohamad et.al 1979). Runoff is therefore greatly reduced. Tree roots bind soil, and under undisturbed conditions, provide relatively high infiltrability rate. The litter layer in the forest also protects the ground from rainsplash erosion. This paper reports on a soil erosion study conducted in the Sg.Tekala forest catchment using an open system erosion plot.

## METHODOLOGY

### Study Area

The 9.8 km<sup>2</sup> Sungai Tekala catchment is located in the Hulu Langat, Selangor, at 3° 3' 12" and 3° 5' 34" N and 101° 50' 18" and 101° 52' 32" W (Fig. 1). Situated about 40 km east of Kuala Lumpur, Sg. Tekala is a tributary of Sg. Langat, which drains the western flank of the Main Range.

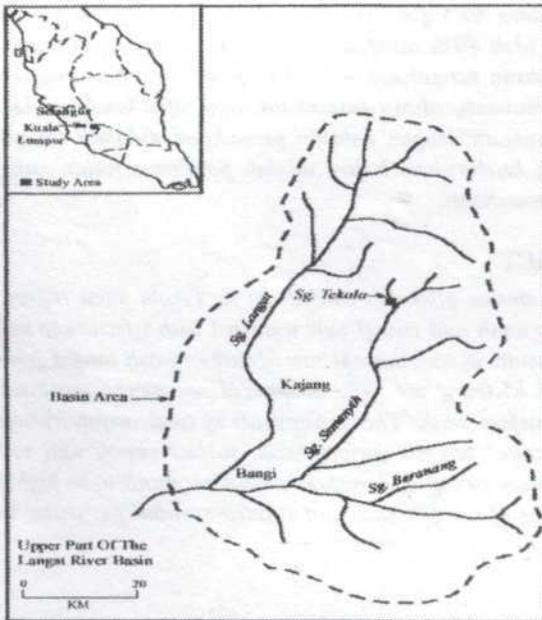


Fig. 1. Location of study area

### Wash Trap Design

The wash trap used in this study was similar to that used by Gerlach (1967) but with some modification. The traps, made from sheets of zinc tin has a collection tank which measures 100 cm × 40 cm × 50 cm. The trap lip measured 100 cm × 25 cm and the cover was 100 cm × 60 cm (Fig.2). A cover was used to prevent direct rainfall entering the trap and subsequent evapo-

ration of collected water. A divisor was fixed at the highest position so as to channel the overflow discharge to another lower collection bin as shown in Figure 2.

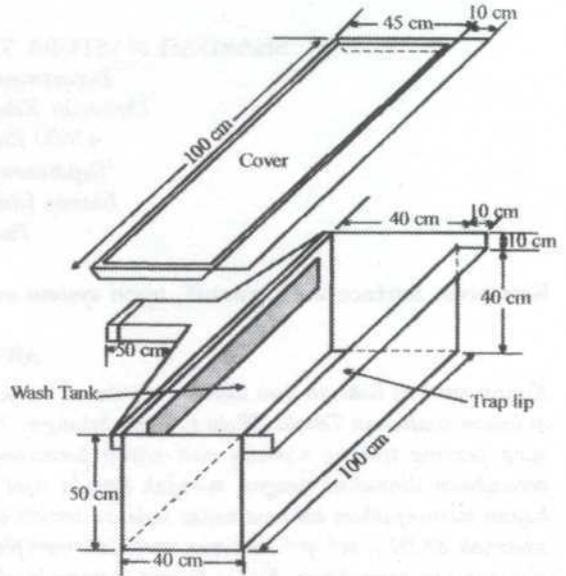


Fig. 2. Wash trap design

### Location of Trap Sites

Four wash traps were installed on each of the three slope profiles, A, B, and C selected for study. Four wash traps were located on each profile. At profile A, wash traps were labeled as A1, A2, A3, and A4 and were installed on four slope segments of 8°, 14.4°, 23.4° and 40.9° respectively (Fig.3). At profile B, four wash traps namely B1, B2, B3 and B4 were also installed on slope segments of 70°, 16°, 24° and 39.7° respectively. Profile C had four wash traps namely C1, C2, C3 and C4, located at 6.5°, 17.4°, 20° and 37.2° respectively. The wash traps were located at convex points of the slope except for wash trap C3, which was located at concave points, while two other plots (A1 and A3) were located on an exposed ground area without any vegetative cover except for litter.

### Sampling Procedure

Surface wash samples were collected from the traps after individual rainfall events over a year from 7<sup>th</sup> August 1994 to 17<sup>th</sup> August 1995. Ninety-nine samples were collected during the study period. Prior to sample collection, the water and sediment in the collecting tank were mixed so

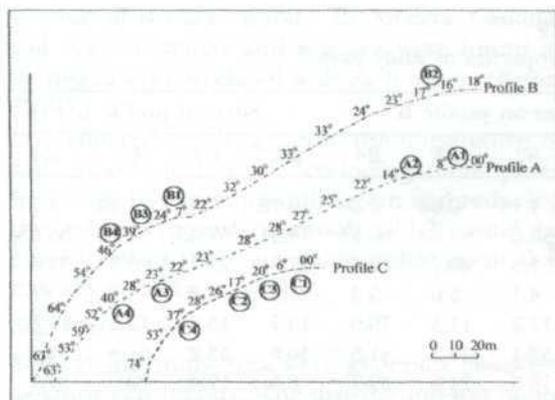


Fig. 3. Location of the open system plots at Tekala Catchment

that the samples, then collected using a one litre polyethylene bottle, represented the surface wash in the tank. The samples were then taken to the

laboratory for analysis of suspended and dissolved sediment and concentration.

*Rainfall Data Collection and Indices*

Two rainfall stations were established in the catchment. A 16 cm rim diameter automatic reading Wilh. Lambrecht gauge was placed in the middle of profile A. A storage gauge with a 12.7 cm diameter was located nearby. The second station was sited in the Forest Department at Sg. Tekala catchment using one automatic rain gauge recorder. Both the stations were checked daily after each event during the first year. The first station recorded rainfall data from August 17, 1994 to August 17, 1995 while the second station recorded rainfall data from September to November 1996. Fourteen rainfall and erosivity indices used were based on the rainfall data collected at 15 minutes interval (Table 1).

TABLE 1  
Rainfall and erosivity indices

Symbol	Description
<b>Rainfall Indices</b>	
AM	The amount of rainfall for each event in mm
MI	The mean intensity of each event. AM/duration (mm h <sup>-1</sup> )
AI <sub>15</sub>	The kinetic energy (joules m <sup>-2</sup> mm). Calculation on 15 min interval from KE = 29.8 - 127.5/I; I is rainfall intensity.
TKE	The total kinetic energy for each storm which was used to determine rainfall erosivity for all events together (J m <sup>-2</sup> )
I <sub>15</sub>	Rainfall intensity index for 15 minutes.
I <sub>30</sub>	Rainfall intensity index for 30 minutes.
I <sub>45</sub>	Rainfall intensity index for 45 minutes.
I <sub>60</sub>	Rainfall intensity index for 60 minutes.
<b>Erosivity indices</b>	
I <sub>15</sub>	TKE the maximum sustained intensity for 15 minutes (Jeje & Agu 1990)
I <sub>30</sub>	TKE the maximum sustained intensity for 30 minutes (Wischmeier & Smith 1958)
I <sub>45</sub>	TKE the maximum sustained intensity for 45 minutes
I <sub>60</sub>	TKE the maximum sustained intensity for 60 minutes
Evd	Daily erosivity = 16.64 Rd-173.82 where Rd is the daily rainfall (Morgan 1974)
API	Antecedent precipitation index. API = pt. 1/t or pt.kt Where pt is precipitation for a given day; t is time (number of days hours) since last rainfall; k is recession factor that is less than one but ranges from 0.85 to 0.98 (Gregory and Walling 1973)

TABLE 2  
Physical and chemical soil properties of study plots

Characteristic of the Plot Site	Sites on profile A				Sites on profile B				Sites on profile C			
	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4
Bulk density	1.12	0.78	0.96	1.08	1.02	1.15	0.96	0.88	0.78	0.82	1.20	1.17
Pore space %	57.42	70.33	63.73	59.22	61.33	56.6	63.67	66.71	70.21	67.45	54.56	55.63
Clay %	30.2	46.0	43.0	44.9	33.6	31.5	36.7	42.2	37.5	27.7	30.5	31.4
Silt %	4.4	5.0	6.0	3.3	4.4	4.1	5.6	5.4	5.3	5.2	4.2	4.5
Fine Sand	11.2	10.0	9.0	8.8	11.0	12.2	11.5	10.9	10.7	13.6	13.5	11.5
Coarse sand %	54.2	39.0	42.0	43.5	51.0	52.1	46.2	41.5	46.5	53.2	51.8	52.6
Slope Degree	8	14.4	23.4	40.9	7.0	16.0	24.0	39.7	6.5	17.4	20	37.2
Organic matter	2.71	7.06	5.45	2.45	4.09	1.76	3.36	6.44	4.97	2.11	2.8	3.19

## RESULTS

### Soil Characteristics and their Relationship with the Rate of Surface Wash

#### Bulk Density

The average bulk density in the study area ranged from 0.79 to 1.20 ( $\text{g cm}^{-3}$ ) with an average of 0.99  $\text{g cm}^{-3}$  (Table 2). Compared to other studies in Malaysia, the values were comparable at between 0.94  $\text{g cm}^{-3}$  and 0.93  $\text{g cm}^{-3}$  for Bukit Lagong and Bukit Mersawa respectively (Peh 1978). About 0.97  $\text{g cm}^{-3}$  was reported for the undisturbed soils at Tekam Forest Reserve (Kamaruzaman 1987) while 1.13  $\text{g cm}^{-3}$  was measured at the undisturbed forests of the Jengka Experimental Basin in Pahang (Baharuddin *et al.* 1995).

High bulk density indicates a more mineralised, compact and coarse-textured soil and therefore led to lower infiltration properties. Insig-

nificant correlation was found between bulk density and both the rate of surface wash and the value of runoff at the study area (Table 3).

#### Total Porosity

The average porosity in the study area was 62.2 per cent with a range of 54.5 % to 70.3 % at C3 and A2 respectively (Table 2). High values of pore space leads to higher infiltration rates and reduced runoff. This value was found to be close to the value reported at Bukit Lagong and Bukit Mersawa which were 61.6 % and 61.1% respectively (Peh 1978). Porosity in this study were much higher than that found at Jengka Experimental Basin which was only 29% (Baharuddin *et al.* 1995). Correlation analysis showed that the total porosity was significantly and positively correlated with the amount of organic matter but insignificant and negatively correlated when calculated with the rate of surface wash and volume of surface runoff (Table 3). At the study area, it was expected that the rate of infiltration would be very high and hence led to very low surface runoff and may therefore be potentially less erodible.

#### Soil Organic Matter

The average organic matter was low (3.8 %) when compared to Bukit Lagong (9.8 %) and Bukit Mersawa (10.6 %) (Peh 1978). However, organic content was comparable with soils at the Jengka Experimental Basins which was 2.8 % (Baharuddin 1995).

Correlation coefficient showed that a significant relationship was found between soil organic matter and both bulk density (0.65) and pore space (0.69), but insignificantly correlated with both the rate of surface wash and the

TABLE 3  
Correlation coefficient between sites characteristics with both surface wash and surface runoff

Characteristics of the Plot Site	Rate of Surface Wash	Rate of Surface Runoff
Bulk density	0.31	0.20
Pore space %	-0.29	-0.20
Clay %	0.37	0.10
Silt %	0.14	0.27
Coarse Sand %	-0.32	-0.17
Fine Sand %	-0.36	0.10
Slope Degree	0.92**	0.97**
Organic matter	0.04	0.04

\*\* Significant at the 0.001 level

\* Significant at the 0.05 level

volume of surface runoff. In Alberta, Canada, soil organic matter and soil loss were found to be negatively correlated with each other (Bryan 1974).

This reflects, in general, the importance of soil organic matter in developing more pores hence leading to more infiltration and reducing the volume of surface runoff which could be considered as the main geomorphic agent that has led to surface erosion.

#### Soil Texture

Soils at the study area were generally classified as sandy clay texture. The distribution was bimodal with coarse sand and clay being the two predominant textural classes (Table 4). This was probably due to the removal of fine silt and fine sand by surface wash. Two textural classes, sandy clay and sandy clay loam were identified in the study area. The former was more prevalent at profiles A and B while the latter was more prominent at profile C.

Correlation analysis on soil texture showed that clay and silt fractions did not have significant relationship with the rate of surface wash and the amount of surface runoff (Table 3), a finding similarly reported elsewhere (e.g. Bryan 1974 and Mutter and Burnham 1990). In contrast however, Epstein and Grant (1967) reported that soil loss increased in soils with high clay content. But in another study, it has been found that soil loss increased with an increase in the clay fraction up to its maximum at 19%. Insignificant and negative correlations were found between coarse sand fraction with both

the rate of surface wash and the volume of surface runoff (Table 3). In Africa, it was reported that there was a negative correlation between sandy soil and surface runoff and soil loss (Obi et al. 1989).

#### Particles Size Distribution of Suspended Sediment

The eroded soil contained a higher proportion of silt and fine sand compared to the insitu soil. Presumably the fine fraction (fine sand and silt) was more susceptible to erosion and transportation by surface wash than coarse sand or clay (Table 4). The findings were similar to that found in Hulu Langat, Malaysia (Sharifah Mastura, 1988) and Nigeria (Lal, 1988). It may also be attributable to the clay fraction which was found to be less erodable than sand if only the factor of rainfall was taken into consideration (Le Roux and Roos 1988).

#### Surface Wash and Influence of Rainfall

##### The Rate of Surface Wash

Surface wash ranged from 20.3 g m<sup>2</sup> yr<sup>-1</sup> for plot C1 to 137.7 g m<sup>2</sup> yr<sup>-1</sup> for plot A 4 (Table 5). The average rate was 85.04 g m<sup>2</sup> yr<sup>-1</sup> (0.85t ha<sup>-1</sup> yr<sup>-1</sup>). There was considerable variations in the extent of surface wash due largely to differences in slope angles and soil characteristics.

In all plots, surface wash increased directly with slope angles. The plots A 4, B 4 and C 4 with slope angles of 37° - 40° showed rate of surface wash between 130-137 gm<sup>2</sup> yr<sup>-2</sup>. Surface wash was highest in March 1995 and second highest in October 1994. Lower rates occurred

TABLE 4  
Suspended sediment texture of plot sites at Sg. Tekala (OSP)

Plot Site	Texture(%)							
	Clay		Silt		Fine Sand		Coarse Sand	
A1	22	<i>30.2</i>	11	<i>4.4</i>	23	<i>11.2</i>	44	<i>54.2</i>
A2	29	<i>46</i>	11	<i>5.0</i>	27	<i>10</i>	33	<i>39.0</i>
A3	29	<i>43</i>	13	<i>6.0</i>	23	<i>9.0</i>	35	<i>42.0</i>
A4	25	<i>44.9</i>	9	<i>3.3</i>	30	<i>8.8</i>	36	<i>43.5</i>
B1	17	<i>33.6</i>	11	<i>4.4</i>	30	<i>11</i>	42	<i>51.0</i>
B2	17	<i>31.5</i>	11	<i>4.1</i>	29	<i>12.2</i>	43	<i>52.1</i>
B3	16	<i>36.7</i>	12	<i>5.6</i>	34	<i>11.5</i>	38	<i>46.2</i>
B4	21	<i>42.2</i>	12	<i>6.4</i>	33	<i>10.9</i>	34	<i>41.5</i>
C1	17	<i>37.5</i>	12	<i>5.3</i>	32	<i>10.7</i>	39	<i>46.5</i>
C2	17	<i>27.7</i>	12	<i>5.2</i>	27	<i>13.6</i>	44	<i>53.2</i>
C3	18	<i>30.5</i>	9	<i>4.2</i>	33	<i>13.5</i>	40	<i>51.8</i>
C4	18	<i>31.4</i>	10	<i>4.5</i>	30	<i>11.5</i>	42	<i>52.6</i>

Data in italic indicate before erosion.

TABLE 5  
Rate of surface wash and surface runoff at plot sites

Site	Slope (degree)	Rate of Surface wash (g m <sup>2</sup> yr <sup>-1</sup> )	Rate of Surface Runoff (1m <sup>2</sup> yr <sup>-1</sup> )	Rate of Runoff/Rainfall (Q/P)
A1	8°	60.98	80.17	3.36
A2	14.4°	71.31	143.97	6.02
A3	23.4°	96.032	123.7	5.18
A4	40.9°	137.74	137.5	5.76
B1	7°	56.46	85.5	3.78
B2	16°	77.66	160.4	6.71
B3	24°	113.31	145.45	6.09
B4	39.7°	135.67	189.43	7.92
C1	6.5°	20.32	69.6	2.91
C2	17.4°	49.54	130.8	85.48
C3	20°	70.96	145.6	6.09
C4	37.2°	130.51	187.71	7.86

in February and July 1995. The monthly surface wash distribution suggest bimodal with maximum peaks occurring in March and October and two minima occurring in February and July. This was similar to the monthly rainfall distribution recorded at the study area.

In Malaysia, similar studies under forest cover land use have been carried out which used erosion plot techniques. Peh (1978) studied at Bukit Lagong and Bukit Mersawa and found that the rates of sediment loss were 0.30 and 0.31 cm<sup>3</sup> cm<sup>-1</sup> yr<sup>-1</sup> respectively. In his study at the Pasoh Forest Reserve, Negeri Sembilan, Leigh

(1982) reported that the average suspended sediment transport was 0.29 cm<sup>3</sup> cm<sup>-1</sup> yr<sup>-1</sup>. Other studies on the rate of soil loss in forest area is given in Table 6.

*Correlation between Surface Wash and Rainfall parameters.*

The correlation coefficients were generally significant and positive for all the rainfall parameters except for mean intensity (MI), where the correlates were low but significant (Table 7). The total amount of rainfall (AM) total kinetic

TABLE 6  
The rate of soil loss in forest areas

Study Area	Period of Study	Slope Angle	Plot Size	No. of Plots	Soil Loss	Author
Mesilau, Kinabalu Park Sabah	4 months	36-38%	25m x 6m	1	0.408 t ha <sup>-1</sup> yr <sup>-1</sup>	George (1987)
Mendolong, Sabah	10 months	19.6-42%	Open Plot	7	38 kg ha <sup>-1</sup> yr <sup>-1</sup>	Malmer (1996)
Semongkok F.R.	5 months	25°-30°	10m x 4m	3	0.3553 t ha <sup>-1</sup> yr <sup>-1</sup>	Hatch (1978)
Semongkok F.R. (Primary Forest)	One year	25°	10m x 4m	3	0.1491 t ha <sup>-1</sup> yr <sup>-1</sup>	Hatch (1981)
Semongkok F.R. (Secondary Forest)	One year	25°	10m x 4m	3	0.0573 t ha <sup>-1</sup> yr <sup>-1</sup>	Hatch (1981)
Southwestern Nigeria (Secondary Forest)	2 years	10%	25m x 4m	1	78.9 kg ha <sup>-1</sup> yr <sup>-1</sup>	Jeje (1987)
Usambara Mts Tanzania	2 years	10°-15° 20°-25°	12m x 2m 12m x 2m	1	14.2 g m <sup>-2</sup> yr <sup>-1</sup> 10.1 g m <sup>-2</sup> yr <sup>-1</sup>	Lundgren (1980)
Central Himalaya India	8 months	5°-25°	20m x 20m	6	15.3-57.2 g ha <sup>-1</sup> yr <sup>-1</sup>	Pathak et al (1984)

TABLE 7  
Correlation coefficients between surface wash and rainfall parameters

Rainfall Parameter	Sites on Profile A				Sites on Profile B				Sites on Profile C				Average	n
	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4		
<b>AM</b>	**0.83	**0.87	**0.82	**0.86	**0.75	**0.80	**0.82	**0.79	**0.88	**0.86	**0.85	**0.73	**0.82	77
<b>MI</b>	**0.39	**0.49	**0.38	**0.46	**0.37	**0.41	**0.40	**0.35	**0.51	**0.43	**0.47	**0.50	**0.43	77
<b>AI<sub>15</sub></b>	**0.74	**0.74	**0.78	**0.85	**0.65	**0.68	**0.76	**0.74	**0.77	**0.75	**0.66	**0.79	**0.74	77
<b>TKE</b>	**0.81	**0.86	**0.82	**0.86	**0.73	**0.78	**0.80	**0.77	**0.85	**0.83	**0.83	**0.73	**0.80	77
<b>EI<sub>15</sub></b>	**0.73	**0.73	**0.79	**0.84	**0.64	**0.67	**0.75	**0.72	**0.76	**0.74	**0.65	**0.77	**0.73	77
<b>EI<sub>30</sub></b>	**0.72	**0.74	**0.78	**0.85	**0.63	**0.67	**0.74	**0.72	**0.75	**0.73	**0.64	**0.73	**0.72	56
<b>EI<sub>45</sub></b>	**0.73	**0.74	**0.79	**0.86	**0.60	**0.63	**0.75	**0.72	**0.74	**0.73	**0.62	**0.73	**0.72	45
<b>EI<sub>60</sub></b>	**0.74	**0.75	**0.80	**0.86	**0.60	**0.64	**0.76	**0.72	**0.74	**0.74	**0.62	**0.73	**0.73	37
<b>I<sub>15</sub></b>	**0.68	**0.70	**0.64	**0.69	**0.66	**0.64	**0.72	**0.68	**0.73	**0.70	**0.72	**0.76	**0.69	77
<b>I<sub>30</sub></b>	**0.73	**0.80	**0.72	0.77	**0.69	**0.72	**0.74	**0.72	**0.81	**0.76	**0.78	**0.76	**0.75	56
<b>I<sub>45</sub></b>	**0.77	**0.84	**0.78	**0.84	**0.68	**0.74	**0.78	**0.75	**0.82	**0.79	**0.78	**0.73	**0.77	45
<b>I<sub>60</sub></b>	**0.78	**0.86	**0.79	**0.85	**0.68	**0.74	**0.78	**0.74	**0.81	**0.80	**0.79	**0.72	**0.78	37
<b>EVD</b>	**0.79	**0.84	**0.80	**0.86	**0.69	**0.76	**0.78	**0.76	**0.82	**0.82	**0.81	**0.66	**0.78	44
<b>API</b>	**0.80	**0.81	**0.78	**0.83	**0.69	**0.65	**0.80	**0.80	**0.69	**0.82	**0.77	**0.72	**0.76	75

\*\* Significant at 0.001 level

\* Significant at 0.05 level

energy (TKE), storm erosivity (Evd) and maximum intensity for 60 minutes ( $I_{60}$ ) were the highest correlated rainfall parameters of surface wash. The  $EI_{60}$  index was therefore highly correlated with the rate of surface wash as compared to  $EI_{15}$ ,  $EI_{30}$  and  $EI_{45}$ . The correlation coefficients between the rate of surface wash with maximum rainfall intensity for 15, 30, 45 and 60 minutes were higher than the rainfall parameter that contained the interaction of energy and intensity ( $EI_{15}$ ,  $EI_{30}$ ,  $EI_{45}$  and  $EI_{60}$ ). Other studies reported positive correlation between one or more rainfall parameters and the rate of surface wash for different land use such as forest and agriculture (Lal 1976, Sharifah Mastura 1988, and Armstrong 1990).

Wischmeier and Smith (1958) showed that the product of the kinetic energy of the storm and the maximum  $EI_{30}$  was most significantly correlated with soil loss. The study in Rhodesia reported that in a bare area within agricultural use, the use of  $EI_{30}$  was a better predictor for soil loss than  $EI_{15}$ . In Malaysia, Peh (1978) found that  $EI_{30}$  had the highest correlation with surface wash at Bukit Lagong. Hudson (1981) however, found that total kinetic energy of rainfall intensities which was greater than  $25 \text{ mm hr}^{-1}$  to be a more significant predictor of soil loss than the  $EI_{30}$  index. Mutter and Burnhan (1990) reported that kinetic energy was the most successful rainfall parameter related to soil erosion. At Pasoh, Malaysia, Peh (1978) found that total kinetic energy,  $EI_{15}$ ,  $EI_{30}$ ,  $EI_{45}$  and  $EI_{60}$  were significantly correlated with sediment transport but the correlation coefficients were lower than that between the amount of rainfall and sediment transport. At Bukit Mersawa, the same author found that the total kinetic energy index and the maximum intensity for  $EI_{15}$  had the highest correlation with sediment transport.

Pinczes (1982) and Ruangpinit (1985) found positive correlation between soil loss and both amount of rainfall and intensity. In South Africa, Garland (1987) found that the best relationship was between sediment transport and  $I_{60}$ . But in America, Wischmeier and Smith (1958) found that the correlation between soil loss and the amount of rainfall as well as the maximum intensity for 5, 15, or 30 minutes intervals was poor. This result was supported by Armstrong (1990) who found that the correlation between various erosivity indices and soil loss was poor.

Highly significant and positive correlation was found between surface wash and antecedent precipitation index. Chang and Ting (1986) also reported a significant positive correlation between sediment transport and the antecedent precipitation index while Jeje (1987) found no significant correlation between antecedent precipitation index and soil loss in Nigeria.

Overall other results did not show consistency in identifying the best rainfall and erosivity indices. This is probably because the experiments have been carried out in different climatic regions with different techniques applied to it. This is also an indication of the complexities involved in erosion studies and more research is required in the future.

### *Relationship between Surface Runoff and Surface Wash*

#### *Rate of Surface Runoff*

The rate of annual surface runoff for all erosion plots at the study area is shown in Table 5. The average rate of total surface runoff at the Sg. Telaka was  $133.8 \text{ lm}^2$ , with a range from  $69.6$  at plot CI to  $189.4 \text{ lm}^2$  at plot B4. The low surface runoff at the study area was probably due to the vegetative cover that intercepted a certain amount of total rainfall that subsequently evaporated to the atmosphere. It was found that in Peninsular Malaysia the amount of rainfall intercepted ranged from 20% to 25% (Ffolliott 1990) and 27% according to Nik Muhammad and Shaharuddin (1979). The presence of canopy provide the soil with more time to receive the rainfall and thus allowing time for more infiltration before surface runoff starts. Soil characteristics, such as low bulk density, high porosity and high percentage of sand, also led to a higher rate of infiltration, hence reducing the amount of surface runoff.

In order to compare with other studies, the rate of surface runoff was converted to rainfall (P)/ runoff (Q) coefficient or Q/P. The average percentage of Q/P for all plots at Sg. Tekala was 5.6 %, with a range of 2.91 to 7.92 %. In other areas, the Q/P coefficient is given in Table 8. The results varied from 2.3% at Jengka Pahang to as high as 6.8 % in Thailand.

As discussed above different percentages of Q/P have been reported for different rain forest areas. This showed that the tropical forest was far from being uniform, as there existed differ-

TABLE 8  
The value of rainfall/Runoff coefficients

Study Area	P/Q Coefficients (%)	Author
Jengka, Pahang	2.3	Baharuddin <i>et al.</i> (1995)
Sabah	2.9	Malmer (1996)
Sabah	4	George (1987)
Nigeria	3.2	Jeje and Agu (1990)
Thailand	6.8	Thongmee and Vannapraset (1990)

ences in canopy structure, in the composition of the ground layer and in the rate of litter fall. Differences in the experimental sites and differences in plot sizes used have also caused different results. In addition, other climatic factors also contributed to the differences in the Q/P coefficient, such as the total amount of rainfall and its annual pattern of distribution.

Analysis of the monthly surface runoff was bimodal with two maximum results registered in March and October. The highest maximum value occurred in March. The two minima occurred in February and July. Overall the rate of surface runoff distribution was highly linked to the rainfall distribution of the study area.

*Correlation between Surface Runoff and Surface Wash*

A significant and positive correlation was found between the rate of surface wash (WS) and surface runoff (VW) at all the 12 erosion plots in the study area as shown in Table 9. Another study showed similar results (Mutter and Burnham, 1990). The strongest correlation was registered at plots C 3 and C 4 with  $r = 0.96$  and highly significant at 0.001 level. A lower correlation was registered at plot A 3 with  $r = 0.68$  but

the correlation was also highly significant at 0.001 level.

**CONCLUSION**

Soil loss from the Sg. Tekala catchment is low. Changes to its forest cover would result in considerable increase in erosion rates. The relationships between both surface runoff and surface wash with soil characteristics and 14 selected rainfall parameters were analysed. Out of the fourteen used rainfall amount, total kinetic energy, h<sub>ij</sub>storm erosivity and maximum intensity 60 minutes indices were found to be highly correlated with the rate of surface wash. These indices, therefore, can be recommended as predictor indices for erosion studies in tropical region. Comparisons of results made with previous studies carried out in Malaysia and elsewhere showed that the results differed in some because of differences in land cover, plot size and methods adopted.

The relationship between surface wash and runoff was significantly correlated, hence the close link between the rate of surface runoff and rainfall distribution in the study area. Although the relationships between surface wash, surface runoff with soil characteristics were not clear except for slope angle, further research in this area is suggested to establish a better understanding between these parameters.

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TABLE 9  
Correlation coefficient between rate of surface wash and surface runoff.

Study Plot	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4	All
Correlation coefficient	**0.92	**0.93	**0.68	**0.79	**0.89	**0.83	**0.76	**0.81	**0.95	**0.92	**0.96	**0.78	**0.75

\*\*Significant at 0.001 level

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