GEOGRAFIA Online™ Malaysia Journal of Society and Space **7** issue **1** (1 - 13)

The Tekala Forest Reserve: A study on surface wash and runoff using close system erosion plots

Othman Jaafar[1], Sharifah Mastura SA[2], Sabry Al-Toum[3]

[1]Dept. of Civil and Structural Engineering, Universiti Kebangsaan Malaysia,
[2]School of Social, Development and Environmental Studies, Faculty of Social Sciences and Humanities, Universiti Kebangsaan Malaysia, [3]Dept. of Geography, Islamic University of Gaza, Palestine

Correspondence: Othman Jaafar (email: oj@eng.ukm.my)

Abstract

This study on surface wash and runoff using closed 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 67.49 to 233.77 gm^{-2} yr^{-1} with an average of 101.7 gm^{-2} yr^{-1}. The average rate of total surface runoff ranged from 121.9 lm^{-2} yr^{-1} to 290.8 $lm^{-2}yr^{-1}$ with an average of 194.43 $lm^{-2}yr^{-1}$. The results also showed that surface wash was positively and significantly correlated with all the rainfall parameters, the amount of rainfall being the best index. A significant and positive correlation was also found between the amount of surface wash and the amount of surface runoff in the study area.

Keywords: closed system erosion, rainfall parameters, rate of total surface runoff, soil characteristics, surface runoff, surface wash

Introduction

Rates of surface wash are a fundamental indicator to the efficiency of earth surface processes and an invaluable contribution to understanding landform evolution. Researchers have used a variety of techniques to investigate surface wash and runoff to predict surface and rill erosion in humid tropical regions such as Malaysia.

Rates of surface wash may be assessed directly by repeated measurements of surface lowering, by comparing the relief of areas which have suffered erosion with those which have not, and by measuring the volume lost from a defined area. The techniques commonly employed for erosion assessment are erosion pins, erosion plots and radioactive tracing using $^{137}C_s$. However, the erosion plot is the most frequently used technique. This paper focuses on the study of surface wash and runoff using a closed system erosion plot technique. Rates of surface wash and runoff and their relationships with the physical and chemical characteristics of soil, rainfall and erosivity indices are emphasised.

Literature review

Several researchers in Malaysia have carried out erosion plot studies (Table 1). Sharifah Mastura (1989) examined two closed system erosion plots; one on a 30^0 slope and the second on a 32^0 slope. Both had bare soil and were located on the University Kebangsaan campus at Bangi

Selangor. The results from the three months study period showed that soil loss on the first plot (30^0) was 2248 gm^{-2} which is less than the soil loss from the second plot (32^0) which experienced 2365 gm^{-2}. Mykura (1989) calculated the rates of sediment yield from urban granitic area in Mengkuang Heights were 330821 t km^{-2} y^{-1}. Baharuddin *et.al* (1995) used nine bounded, closed system erosion plots at Jengka experimental basin in Tekam forest reserved Pahang. Each plot measures 22m by 3m and were established at three different sites which were at a logging road, a skid trail and on an undisturbed forest. In the first year of the experiment after logging activity, they reported soil losses of 453.7, 10,069.7 and 13,340.7 kg $ha^{-1}yr^{-1}$ for undisturbed forest, skid trail and logging road respectively. In the second year, soil losses decreased by 80% to 2111.3 kg $ha^{-1}yr^{-1}$ for skid trail and by 77% to 3146.7 kg $ha^{-1}yr^{-1}$ for logging road.

Studies at the Mardi research station 22km west of Chukai in Southern Terengganu, on terrains of 10 to 25^0 slopes found that lack of contact at ground level increased soil loss from 5 to 104 t/ha^{-1} and that soil loss was substantially increased when large flow pathways were present (Hashim et al, 1995).

Study area

The study area is the Tekala river catchment 9.79 km^2, forest reserve covered in the Hulu Langat district of Selangor, (Figure 1) situated at 3^0 3' 12" and 3^0 5' 34" N and 101^0 50' 18" and 101^0 52' 32"E, about 40 km east of Kuala Lumpur. The Tekala river is a tributary of Semenyih river which feed into the Langat river. The Langat river system flows in the southwest direction into the Straits of Melaka The Langat river headwaters drain the western flank of the Main Range.

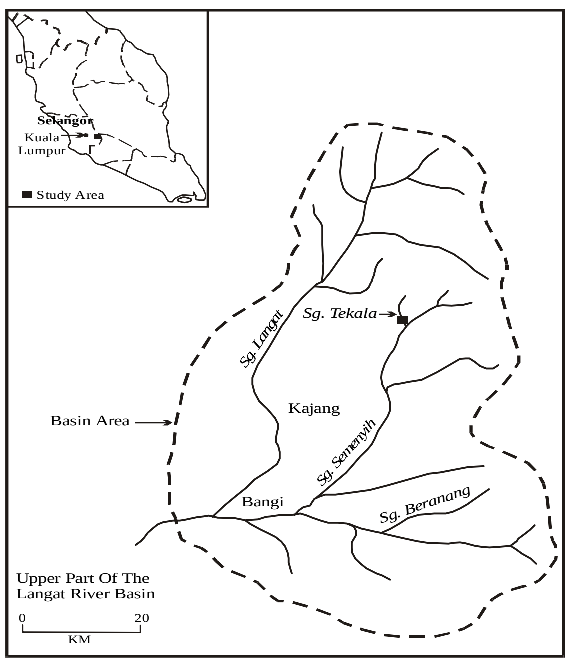

Figure 1. *Location of Study Area: Tekala river, Selangor*

Table 1. Summary of some erosion plot studies in forested areas in Malaysia and elsewhere

Author	Area	Rock & soil	Period of study	Sample frequency	Slope angle	Plot size	No. of plot	Soil erosion Rate
Peh (1978)	Pasoh F. R. Bukit Lagong F. R. Bukit Meresawa F.R.	Shales & Sandstone Granite Granite	1 year 1 year 1 year	Weekly Weekly Weekly	8-22º 8-22º 8-22º	OSP OSP OSP	9 9 6	0.7819 $cm^3\ cm^{-3}\ yr^{-1}$ 0.294 $cm^3\ cm^{-3}\ yr^{-1}$ 0.3134 $cm^3\ cm^{-3}\ yr^{-1}$
Leigh (1982)	Pasoh F. R.	Shales & Sandstone	1 year	Daily	8º-30º	OSP	11	0.294 $cm^3\ cm^{-3}\ yr^{-1}$
Baharuddin et al (1995)	Tekam F.R. (Forest) Tekam F.R. (Skid trail) Tekam F.R. (Logging road)	Shales & Sandstone	2 years	Daily	10%-20%-30%	22m*4m	3	1st year / 2nd year kg $ha^{-1}\ yr^{-1}$ 453.7 10069.7 / 2111.3 13340.7 / 3146.7
Hatch (1978)	Semongok F.R. (P.J)	Shales & Sandstone Red-Yellow Podzolics (semongok series)	5 months	-	25-30º	10m*4m	3	0.3552 t $ha^{-1}\ yr^{-1}$
Hatch (1978)	Semongok F.R. (P.J) Semongok F.R. (P.J)	Shales & Sandstone Red-Yellow Podzolics (semongok series)	1 years	-	25º	10m*4m	3 3	0.1491 t $ha^{-1}\ yr^{-1}$ 0.0573 t $ha^{-1}\ yr^{-1}$
Malmer (1996) (1987)	Mendolong (Sabah)	Sandstone, Siltstones and Shales	10 months	-	19.6%-42%	OSP	7	38kg $ha^{-1}\ yr^{-1}$
George (1987)	Mesilau, Kinabalu park (Sabah) (P.J)	Dystric Cambisol (clayloam - Sandloam)	4 months	Daily	36%-38%	25m*6m	1	0.408 t $ha^{-1}\ yr^{-1}$
Jeie (1987)	Southwestern Nigeria (S.J)	Clayloam (Egbeda Soil series)	2 years	-	10%	25m*4m	1	78.9 kg $ha^{-1}\ yr^{-1}$
Sayuke et.al (1993)	Texas, U.S.A.		2 years	Daily	-	22.13m* 9.14m	1	65 kg $ha^{-1}\ yr^{-1}$

Author	Area	Rock & soil	Period of study	Sample frequency	Slope angle	Plot size	No. of plot	Soil erosion Rate
Maass et al (1988)	Pacific coast of Jalisco Maxico	Rhyolite Sandyloam	2 years	*	22.5º		1	0.2 t ha^{-1} yr^{-1}
Kelleman (1969)	South eastern Mindanao (Philippine) (P.F)		10 months	Every 10-day	25%	8m-2	1	4.5 g $m^{-2}yr^{-1}$
Lundgren (1980)	Usambara Mts. (Tanzania)	Precambrian Rocks Soil-Humic nitosols	2 years	-	10º-15º 20º-25º	12m-2	1 1	4.2 g $m^{-2}yr^{-1}$ 10.1 g $m^{-2}yr^{-1}$
Pathak et al (1984)	Central Himalaya India	Sandyloam	8 months	3-4 day intervals	5º-25º	20m*20m	6	15.3-57.2 g $m^{-2}yr^{-1}$

Ops = Open System Plot
P.J = Primary forest
S.J = Secondary forest
*Measured for total amount of rainfall more than 30mm

Wash trap design and installation

The design used in this research is a modification of the design used by Young (1960) and Gerlach (1967). The traps were made from sheets of zinc tin and they consisted of four parts, a 100 cm by 40 cm by 50 cm collection tank, a 100 cm by 25 cm lip, a 100 cm by 60 cm cover and a divisor. The cover prevented direct rainfall from entering and also any evaporation of collected water. The divisor was fixed at the back of the highest position so as to channel the overflow discharge to a lower collection bin (Figure 2).

A large pit of 100 cm was dug to accommodate the wash tank. The lip faced the upper slope and was placed at the depth of 10cm below the soil surface. A spirit level was used to ensure that the wash trap was positioned flat inside the pit. After the tank was fixed using sand the interface between the lip and the surface of the ground was coated with a thin layer of cement to reinforce its position. The rectangular plots with upslope and the side slope margins were separated by using polyvinyl chloride (PVC) sheets that were set into the soil. The edges were extended to 40cm above the surface of the soil. Two sets of plots at 2m x 4m ($8m^{-2}$) and 2m x 2m ($4m^{-2}$), were established.

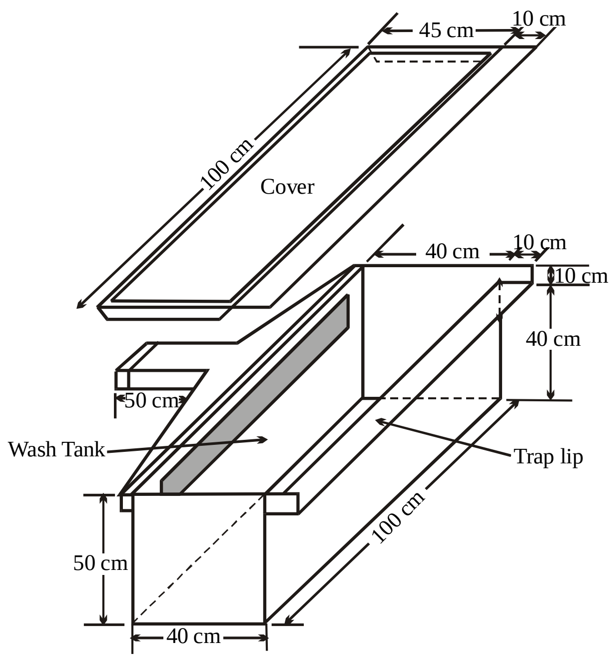

Figure 2. *Wash trap design*

Location of the erosion plots

Six erosion plots were set up along two slope profiles (A and B) in the Tekala river catchment. Three plots for each profile were placed at three different slope units at 10-18^0, 18-30^0 and 30-45^0. The erosion plots A1, A2 and A3 were located sequentially downslope on profile A on slope segments of 40.9^0, 23.4^0 and 14.4^0 respectively. Similarly, plots B1, B2 and B3 on slope profile B were located on slope segments of 39.7^0, 24^0 and 16^0 respectively (Figure 3). These slope segments were chosen because they were characteristic of the area.

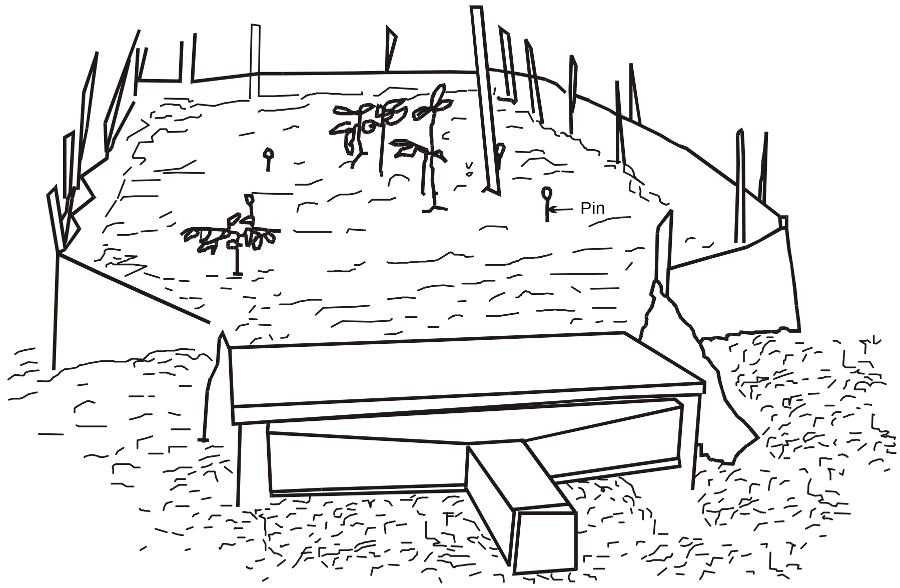

Figure 3. *Installed wash trap (closed system plot)*

Surface wash from the close system plot was expressed in gm^{-2} per unit time. It was assumed that the surface wash was uniform over the plot area and this implied that the surface wash depended on the plot size and shape. Therefore, closed system plot cannot be used to measure the surface wash under natural condition, since its fixed margins prevented the flow of water and sediment to the plot from upslope area (Hudson, 1971; Peh, 1978; Loughran, 1989).

Although the closed system plot gave the most reliable data on the soil loss per unit area, there were several sources of errors involved (Hudson, 1957; Morgan, 1986). These included the silting of the collecting troughs and pipes that led to the tanks and an inadequate covering of the troughs to prevent direct rainfall inputs maintaining the position of the trough lip at a constant level at the soil surface was also a problem. Another problem was that runoff that could be channelised along the boundaries of the plot and cause rills to form.

Sampling procedure

99 samples in total were collected from the wash traps after each rainfall event for one year beginning from 7th August 1994 to 17th August 1995. Before collecting the samples, the collected water and sediment were stirred with a plastic scoop to ensure that all the sediment was in suspension and thoroughly mixed. The samples were then collected using a one litre polyethylene bottle. This sample represented all the material suspended in the tank. The samples were then taken to the laboratory for analysis of suspended and dissolved sediment concentration.

The rainfall data collection and indices

Two rainfall stations were established in the catchment. A 16 cm rim diameter automatic recording Wilh Lambrecht gauge was placed in the middle of profile A. A storage gauge with a 12.7 cm diameter was located nearby. Altogether 14 rainfall and erosivity indices derived from 15 minutes rainfall readings (Table 2) (Sabry, 1997).

Both rain gauges were checked daily after each event during the first year (August 17, 1994 until August 17, 1995) by measuring the water inside a storage rain gauge. Then, they were compared with the volume of the rainfall according to an automatic recording chart. The time, day and date of visits were also noted on the chart. The recorder charts were changed monthly.

The second station sited in the Forest Department at Tekala catchment area used only one automatic rain gauge recorder. This station was inspected weekly and the time, day and date of visits were noted down. The charts were changed every four weeks over one year beginning from September 1995 to November 1996.

Table 2. Rainfall and erosivity indices

Symbol	Description
Rainfall Indices	
AM	The amount of rainfall for each event in mm
MI	The mean intensity of each event. AM/duration (mm/h^{-1})
AI_{15}	The kinetic energy ($joules/m^{-2}/mm$). 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 (Jm^{-2})
I_{15}	Rainfall intensity index for 15 minutes.
I_{30}	Rainfall intensity index for 30 minutes.
I_{45}	Rainfall intensity index for 45 minutes.
I_{60}	Rainfall intensity index for 60 minutes.
Erosivity indices	
I_{15}	TKE the maximum sustained intensity for 15 minutes (Jeje & Agu 1990)
I_{30}	TKE the maximum sustained intensity for 30 minutes (Wischmeier & Smith 1958)
I_{45}	TKE the maximum sustained intensity for 45 minutes
I_{60}	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)

Results

1) The physical and chemical properties of soil and their relationship with surface wash and surface runoff

Bulk density of soil
The average bulk density values of soil in the erosion plots was 0.85 g cm^{-3}, ranging from 0.67 at plot A1 to 0.99 g cm^{-3} at plot A3. The values were considered very low; hence there was more infiltration which led to low surface runoff and surface wash. The bulk density was found to be positively correlated with the rate of surface wash (r=0.67) and the surface runoff (r=0.25) but the correlation was insignificant.

Total porosity of soil
Soil porosity varies from 62% to 74% with an average of 67.8% which was considered to be high. Total porosity was negatively correlated with rate of surface wash (-0.67) and rate of surface runoff (0.26). Both the correlations are however insignificant. Consequently, this indicated that the uncompacted soil (low bulk density and high porosity) favoured infiltration, and therefore produced less surface runoff and erosion.

Soil organic matter
The percentages of organic matter were determined on soil samples taken at 10cm depth at the centre of each erosion plot. The soil organic matter content in profile A varies from 4.2 to 5.8 with an average of 4.9% and was much higher than in profile B. At profile B the content ranged from 2.5 to 4.8% with an average of 3.5%. No significant correlation existed between soil organic matter and both surface runoff or surface wash.

Soil texture
Soil texture within the erosion plots was characterized by a bimodal particle size distribution, with sand and clay being the two predominant textural classes with an average of 46% and 37% respectively. Fine sand contributed 10% while silt fraction contributed a very low proportion (5.37 %). Varying percentages of sand, clay and silt fractions in the surface soil at erosion plots gave rise to two textural classes, sandy clay loam texture prevailing at erosion plots A1, A2, B1 and B2. Meanwhile sandy clay texture was found at plots A3 and B3.

There was no significant correlation that has been established between soil textures and rate of surface wash and surface runoff except at profile B. At this profile clay is only correlated with surface wash. This may suggest that the efficiency of surface runoff increases with slope angle. Therefore, finer particles move downslope leaving the coarse fraction behind. There was an insignificant correlation between any of the soil fractions and to both the rate of surface wash and the surface runoff.

Suspended sediment texture
Particle size analysis of both *in-situ* and eroded soil was carried out to determine which soil fraction was more susceptible to erosion (Table 3). Both the fine sand and silt fractions were over twice as large as in the *in-situ* soil. The fine fractions (silt and fine sand) were easily eroded and moved by surface wash. However, as clay is more cohesive and coarse sand grains are heavier, thus they are not readily carried by surface wash.

Table 3. Suspended sediment texture of plots at tekala river catchment

Plot site	Sediment texture (%)			
	Clay	Silt	Fine sand	Coarse sand
A1	25 (33.5)	11 (7.8)	21 (7.8)	43 (48.4)
A2	22 (33.8)	13 (4.9)	24 (9.8)	41 (46.5)
A3	30 (41.5)	12 (5.3)	23 (10.3)	35 (42.5)
B1	24 (35)	9 (5.6)	26 (12.2)	41 (47.2)
B2	22 (37.8)	8 (3.9)	27 (11)	43 (47.3)
B3	25 (41.2)	9 (4.7)	29 (9.8)	37 (44.3)

( ) Soil sampled before erosion

2) The rate of surface wash between profiles

Surface wash varied from plot to plot and more on profile A than on profile B. On profile A surface wash ranged from 69.24 to 233.77 gm^{-2} yr^{-1} with an average of 133.7 $gm^{-2}yr^{-1}$(Table 4). The higher amount of surface wash registered at plot A3 was probably due to slope steepness, the soil characteristics inside the plot, absence of low vegetative cover and disturbance during the construction of the erosion plot boundary. At profile B surface wash ranged from 67.49 to 72.74 gm^{-2} yr^{-1} with an average of 69.6 $gm^{-2}yr^{-1}$ (Table 4).

Table 4. Rate of surface wash and surface runoff at plot sites

Plot site and slope angle (°)	Slope length m	Rate of surface wash ($gm^{-2}yr^{-1}$)	Rate of surface runoff l ($m^{-2}yr^{-1}$)	Rate of runoff / rainfall (Q/P)
A1 (14^0)	2	69.24	220.7	9.23
A2 (23.4^0)	2	98.07	249.7	10.5
A3 (40.9^0)	2	233.77	290.8	12.17
B1 (16.0^0)	4	67.49	121.9	5.1
B2 (24^0)	4	68.61	136.1	5.7
B3 (39.7^0)	4	72.75	147.4	6.1

The monthly surface wash was bimodal with two maxima occurring in March and September-October and two minima occurring in February and July. The highest rate of surface wash (Station A3) occurred in March recording approximately 66 $gm^{-2}yr^{-1}$ or 22 % of the total surface wash. The lowest rate, 0.2 $gm^{-2}yr^{-1}$, occurred in February at Station B1.

3) The correlation between the rate of surface wash and the rainfall parameters

A correlation analysis was undertaken to gain further insight into the relationship between surface wash and the 14 rainfall parameters used (Table 5). Surface wash was positively and significantly correlated with all the rainfall parameters. The correlation coefficient was generally high except for the mean intensity (MI) with coefficient r=0.43 and I_{15} with a coefficient of 0.67. The simplest parameter namely, the rainfall amount (AM) was better correlated (0.84) with the surface wash than all the other parameters. This means that in general, the amount of surface wash increased as the amount of rainfall increased. Other indices that have strong positive correlation are TKE, I_{60} and EV_d. Consequently, differences in the amount of surface wash from one plot to another reflected the site characteristics.

Table 5. Correlation coefficients between surface wash and rainfall parameters

Rainfall parameter	Plots on profile A			Plots on profile B			Average	n
	A1	A2	A3	B1	B2	B3		
AM	**0.83	**0.82	**0.86	**0.81	**0.88	**0.81	**0.84	77
MI	**0.50	**0.51	**0.40	**0.45	**0.38	**0.34	**0.43	77
AI	**0.64	**0.66	**0.83	**0.68	**0.83	**0.77	**0.74	77
TKE	**0.82	**0.81	**0.86	**0.80	**0.86	**0.79	**0.82	77
EI_{15}	**0.63	**0.64	**0.83	**0.67	**0.82	**0.76	**0.72	77
EI_{30}	**0.62	**0.64	**0.83	**0.67	**0.83	**0.77	**0.72	56
EI_{45}	**0.59	**0.63	**0.84	**0.64	**0.83	**0.76	**0.72	46
EI_{60}	**0.59	**0.64	**0.84	**0.68	**0.83	**0.76	**0.72	37
I_{15}	**0.69	**0.70	**0.67	**0.70	**0.66	**0.62	**0.67	77
I_{30}	**0.79	**0.77	**0.75	**0.77	**0.76	**0.69	**0.76	56
I_{45}	**0.77	**0.78	**0.82	**0.78	**0.84	**0.75	**0.79	46
I_{60}	**0.78	**0.79	**0.83	**0.80	**0.84	**0.75	**0.80	37
EVD	**0.79	**0.77	**0.85	**0.79	**087	**0.79	**0.81	46
API	**0.72	**0.78	**0.83	**0.71	**0.80	**0.78	**0.77	77

** Significant at the 0.001 level
* Significant at the 0.05 level

In Nigeria, Lal (1976) found that the rainfall parameter AI_m, which is the product of rainfall amount with its maximum 7.5 minutes intensity, gave a better correlation with sediment transport than did EI_{30} on cultivated areas. Ulsaker and Onstad (1984) reported that the rainfall amount multiplied by maximum 30 minutes intensity (AI_{30}) to be well-correlated with the surface wash in

Kenya, while in this study, AI_{15} had a high correlation with surface wash but less than many other rainfall parameters combined.

The other three rainfall parameters (TKE, EVd and I_{60}) were best correlated with surface wash, having an average coefficient of 0.82, 0.81 and 0.80 respectively. Meanwhile EI_{15}, EI_30, EI_{45} and EI_{60} were each correlated with surface wash with coefficient r=0.7. This means that rainfall intensity parameters (I_{15}, I_{30}, I_{45} and I_{60}) had better correlation with the surface wash as compared to those rainfall parameters which included energy of interaction and intensity. Finally, rainfall amount proved to be the best erosivity factor related to the amount of surface wash (0.84), while the mean intensity (MI) was considered to be the weakest index correlated with surface wash (0.43).

4) Surface runoff

The mean rainfall-runoff coefficients (Q/P) for all three erosion plots on profiles A and B were 10.63 % and 5.63 % respectively. The higher percentage for profile A was probably caused by the unequal plot size and variations in slope length. Generally, the rate of surface runoff from the closed system plots is high because of the confined boundary as well as small plot size as compared to other studies. The rate of surface runoff at each erosion plot varied considerably over the year but corresponded well with monthly rainfall. High rates of runoff were recorded in March, April, September and October (Table 4). The high surface runoff on plot A3 gave rise to high production of surface wash and a high rainfall-runoff coefficient.

5) The relationship between surface runoff and surface wash

A highly significant and positive correlation was found between the amount of surface wash (SW) and the amount of surface runoff (VW) for all the six plots (Table 6). The higher correlation of 0.95 was found at plot A1 while plot A3 had the lowest correlation of 0.74. The percentage explained of r2 was also very high, ranging from 0.51 to 0.87 percent. This means that the rate of surface wash could be explained and predicted from surface runoff data.

Table 6. The correlation coefficient and regression equations between surface wash and surface runoff at Tekala River Catchment

Plot	Regression equation	r^2	r	n
A1	W S= 0.84+0.365 VW	0.87	0.95**	80
A2	WS = -1.31 + 0.491 VW	0.76	0.90**	77
A3	WS = -17.6 + 1.88 VW	0.51	0.74**	77
B1	WS = 0.08 + 0.62 VW	0.54	0.85**	80
B2	WS = -6.44 + 0.93 VW	0.57	0.80**	82
B3	WS = -7.73 + 0.96 VW	0.57	0.78**	79
All	WS = -40 + 0.73 VW	0.59	0.77*	6

Significant at the 0.001 level

6) The effect of extreme rainfall storms upon both surface wash and surface runoff

A single storm, which exceeded 50 mm in total amount of rainfall, is considered as extreme event. There are seven such high magnitude rain events that produced 595 mm of rain, approximately 25 per cent of the annual rainfall total at the recording rain gauge. The amount of surface wash and the surface runoff in these events accounted for of 33 % and 22.3% respectively of the annual total for profile A, and 30.5% and 18.4 % respectively for profile B (Table 7). Peh (1998) reported that the percentage of surface wash from storm events at Pasoh were 30 to 45%, Bukit Lagang 30-36% and Bukit Mersawa 31-40%. After 25 years working on soil erosion, Edwards (1985) reported that a single storm accounted for at least 75% of the total soil loss in Australia.

Table 7. The proportion of surface wash and surface runoff from extreme rainfall storms at Tekala River

Process	**Profile A**			**Profile B**			**Average**
	A1	A2	A3	B1	B2	B3	Average
Surface wash %	29.2	29.8	40	24	34.8	32.5	31.7%
Surface runoff %	27	22	18	15.3	21	19	20.4%

Conclusion

The results show that even under forest cover surface wash occurred in low quantity of 133.7 $gm^{-2\ j}$ yr^{-1}. This is consistent with other research findings which reveal vegetation cover as an important factor in protecting the soil from serious erosion. Once the forest is converted to other land uses the surface erosion is expected to accelerate manifold (Mykura 1985). The results also show that surface wash has close relationship with surface runoff and all the rainfall parameters selected for this study. However, the amount of rainfall can be considered as the best parameter related to both surface wash and surface runoff. This is followed by three other important indices of TKE, EVd and $I_{60.}$ All these indices therefore could be recommended for use as splashed erosion indicators in other tropical areas. Mean intensity is the poorest index related to both. These findings of important and relevant rainfall indices are not shared by other findings elsewhere which have identified other indices (Lal, 1976).

Rates of surface wash and surface runoff are not significantly correlated with physical properties of soil such as bulk density, porosity, organic matter content and soil texture. The relationships between physical characteristics of soil and surface wash and runoff are very complex and require wider samples and more detailed research. Overall findings of high erosion rates associated with the effect of extreme rainfall events are also recorded in other studies worldwide.

References

Baharuddin K (1988) Effect of logging on sediment yield in a hill dipterocarp forest in Peninsular Malaysia. *J. Tropical Forest Science* **1** (1), 56-66.

George DA (1987) Measurement of rainfall and soil erosion from agricultural and primary jungle plots in Sabah, Malaysia. In: Tay TH, Mokhtaruddin AM, Zahari AB (eds) *Steepland agriculture in the humid tropics*, 309-331. Kuala Lumpur.

Gerlach T (1967) Hillslope troughs for measuring sediment movement. *Rev. Geomorph. Dyn*. **XVII** (4), 173-174.

Gregory KJ, Walling DE (1973) *Drainage basin form and process: A geomorphological approach*. Edward Arnold, London.

Hashim GM, Ciesiolka CAA, Wan Abdullah Y, Abdul Wahab N, Mohamad RM, Rose CW, Coughlan KJ (1995) Soil erosion processes in sloping land in the east coast of Peninsular Malaysia. *Soil Technology* **8**, 215-233.

Hatch T (1978) Preliminary results from soil erosion and conservation trials at Semangkok A.R.C. *Tech. Paper No. 6*, Dept. of Agriculture Sarawak.

Hudson NW (1957) The design of field experiments on soil erosion. *J. Agric. Engng. Res.* **2**, 56-65.

Hudson N (1971) *Soil Conservation*. Cornell University Press, Ithaca, New York.

Jeje LK. Agu AN (1990) Runoff from bounded plots in Alakowe in Southwestern Nigeria. *Applied Geography* **10**, 63-74.

Kellman MC (1969) Some environmental components of shifting cultivation in upland Mindanao. *J. Trop. Geog*. **28**, 40-56.

Lal R (1976) Soil erosion on alfisols in Western Nigeria, III. Effects of rainfall characteristics. *Geoderma* **16**, 389-401.

Lal R (1977) Analysis of factors affecting rainfall erosivity and soil erodibility. In: Greenland DJ, Lal R (eds) *Soil conservation and management in the humid tropics*, 49-56. John Wiley & Sons, Chichester.

Leigh CH (1982) Sediment transport by surface wash and throughflow at the Pasoh Forest Reserve, Negeri Sembilan, Malaysia. *Geogr. Ann*. **64A** (3-4), 171-180.

Loughran RJ (1989) The measurement of soil erosion. *Progress in Physical Geography* **13** (2) 216-233.

Maass JM, Jordan CF, Sarukhan J (1988) Soil erosion and nutrient losses in seasonal tropical agroecosystems under various management techniques. *Journal of Applied Ecology* **25**, 595-607.

Malmer A (1996) Hydrological effects and nutrient losses of forest plantation establishment on tropical rainforest land in Sabah, Malaysia. *J. Hydrol*. **174**, 129-148.

Morgan RPC (1974) Estimating regional variation in soil erosion hazard in Peninsular Malaysia. *Malay. Nat. J*. **28** (2), 94-106.

Morgan RPC (1986) The relative significance of splash, rainwash and wash as processes of soil erosion. 2. *Geomorph*. NF **30** (3), 329-337.

Pathak PC, Pandey AN, Singh JS (1984) Overland flow, sediment output and nutrient loss from certain forested sites in the Central Himalaya, India. *J. Hydrol*. **71**, 239-251.

Peh CH (1978) Rate of sediment transport by surface wash in three forested area of Peninsular Malaysia. *Occasional Paper No. 3*. Department of Geography. UM. Kuala Lumpur.

Sabry M. Al Toum (1997) *Surface erosion in the granite area of Hulu Langat, Selangor D. E. Malaysia* (PhD dissertation). Universiti Kebangsaan Malaysia. 439. pp.

Sharifah Mastura SA (1988) Soil loss from bare slope using simple erosion plots. In: Abdul Samad H. Mazlan O (eds) *Tropical urban ecosystem studies* **5**, 38-45. Universiti Kebangsaan Malaysia, Bangi.

Ulsaker LG, Onstad CA (1984) Relating rainfall erosivity factors to soil loss in Kenya. *Soil sci. soc. Am. J*. **48**, 891-61.

Wischmeier WH, Smith DD (1958) Rainfall energy and its relationship to soil loss. *Tran. Am. Geophy. Union*. **39**, 458-462.