JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 14 2006

LAND USE, RUNOFF, AND SLOPEWASH IN THE OPA RESERVOIR BASIN, SOUTHWESTERN NIGERIA

A. Adediji
Department of Geography
Obafemi Awolowo University
Ile-Ife, Nigeria

This study aimed at examining the effect of land use/vegetation types and slope on slopewash in the interstream surfaces of 19 first order basins within the Opa Reservoir catchment. Runoff and soil loss on slope (slopewash) in the studied basins were monitored for one year using Gerlach Troughs. The results of this study showed that the slopewash (soil loss on slope) was highest in the built-up basins (with mean specific yield of 30.07 t/km^2/yr). This was distantly followed by field crops, cocoa dominated, and forested basins with mean specific yield of 18.04 t/km^2/yr, 16.88 t/km^2/yr, and 14.20 t/km^2/yr, respectively. Also, soil loss from the valley slopes of the studied basins correlated significantly with runoff (R) and slope angle (Sa) with r-values of 0.799 and 0.413 and $\alpha = 0.05$, respectively. This implied that runoff was the most important predictor of soil loss on slopes in this part of the world. Thus, to prevent deleterious slope wash in this part of the world, runoff should be minimized on slopes through planting of cover crops.

INTRODUCTION

According to Denise (2001), surface slope wash erosion occurs when wind, rain or frost detach soil particles from the surface, allowing them to be washed down the slope. Surface erosion can occur on any land which is exposed to rain or wind (Sayer et al. 2004).

Several studies exist on runoff and soil loss (slopewash) from erosion/runoff plots (e.g. Ruxton, 1967; Roose, 1973; Stocking and Elwell, 1973; Aina et al. 1977; Jeje, 1977; Jeje, 1987; Jeje and Agu, 1982, 1990; Mala, 1995; Lahlou, 1996). In fact, some of these studies (e.g. Roose, 1973; Lal, 1976 and Jeje and Agu, 1982) examined the effect of land use/vegetation and rainfall erosivity parameters on runoff and soil loss on slopes (slopewash) from experimental plots. However, apart from the work of Sunderland and Bryan (1987) in Kenya, there are no known studies on slopewash from Gerlach Troughs in this part of the world. Gerlach Troughs has been used worldwide by geomorphologists for collection of transported sediment and water on slopes (see Saunder and Young, 1983). It is a simple, rapid technique for measuring slope wash. Therefore, this study attempts to determine runoff and soil loss on slopes (slope wash) under different land use/ vegetation types using Gerlach Troughs located in the interstream surfaces of 1st order basins in Opa Reservoir catchment. The study also attempts to examine the effect of slope on soil loss and runoff under different land use types identified in the study area. The findings of this study will further contribute to the existing body of literature on the influence of land use/vegetation and slope on sediment loss on slope in this part of the world.

STUDY AREA

The Opa Reservoir Basin, which extends from Obafemi Awolowo University, Ile-Ife, to as far away as Osu in the Atakumosa Local Government Area, constitutes the study area. The area lies between latitudes 7o27'N and 7o35'N and longitudes 4o30'E and 4o40'E (Federal Survey Topographical Sheets, Ilesha S.W. 234 and Ondo N.W. 263, see Figure 1).

Interstream surfaces of the 19 first order basins within the Opa Reservoir catchment constitute the study sites. Gerlach Troughs were located on the 1st order valley side on different slope angles (between 2?35? and 12?40?) and under different land use/ vegetation types in the sampled basins within the study area (see Figure 1). The troughs were located on the rectilinear slope segment.

The study sites in the OAUPRESS, Parakin, Ogbe, and Osu area are underlain by Iwo soil series, which according to Smyth and Montgomery (1962) developed on coarse grained rocks while sites around Alakowe, Agric village are underlain by Egbeda soil series developed on deeply weathered fine grained biotite-gneisses and schists (Jeje and Agu, 1982). Other study sites around Mokuro and Ilode are underlain by red clayey soil of Itagunmodi soil series (Smyth and Montgomery, 1962; Adejuwon and Jeje, 1975).

The Opa Reservoir Basin is in southwestern Nigeria characterized by tropical rain forest climate of Koppen's Af with a mean annual rainfall of 1400mm experienced from March to October with double peaks in July and September, and a short dry spell in August. The mean annual temperature of the area is 27oC (Adejuwon and Jeje, 1975).

STUDY METHOD

Data for this study were obtained from 38 Gerlach Troughs installed in the interstream surfaces of 19 first order basins within the Opa Reservoir Basin. Specifically, data on runoff and slopewash from interstream areas were collected using the Gerlach Troughs, which were established on

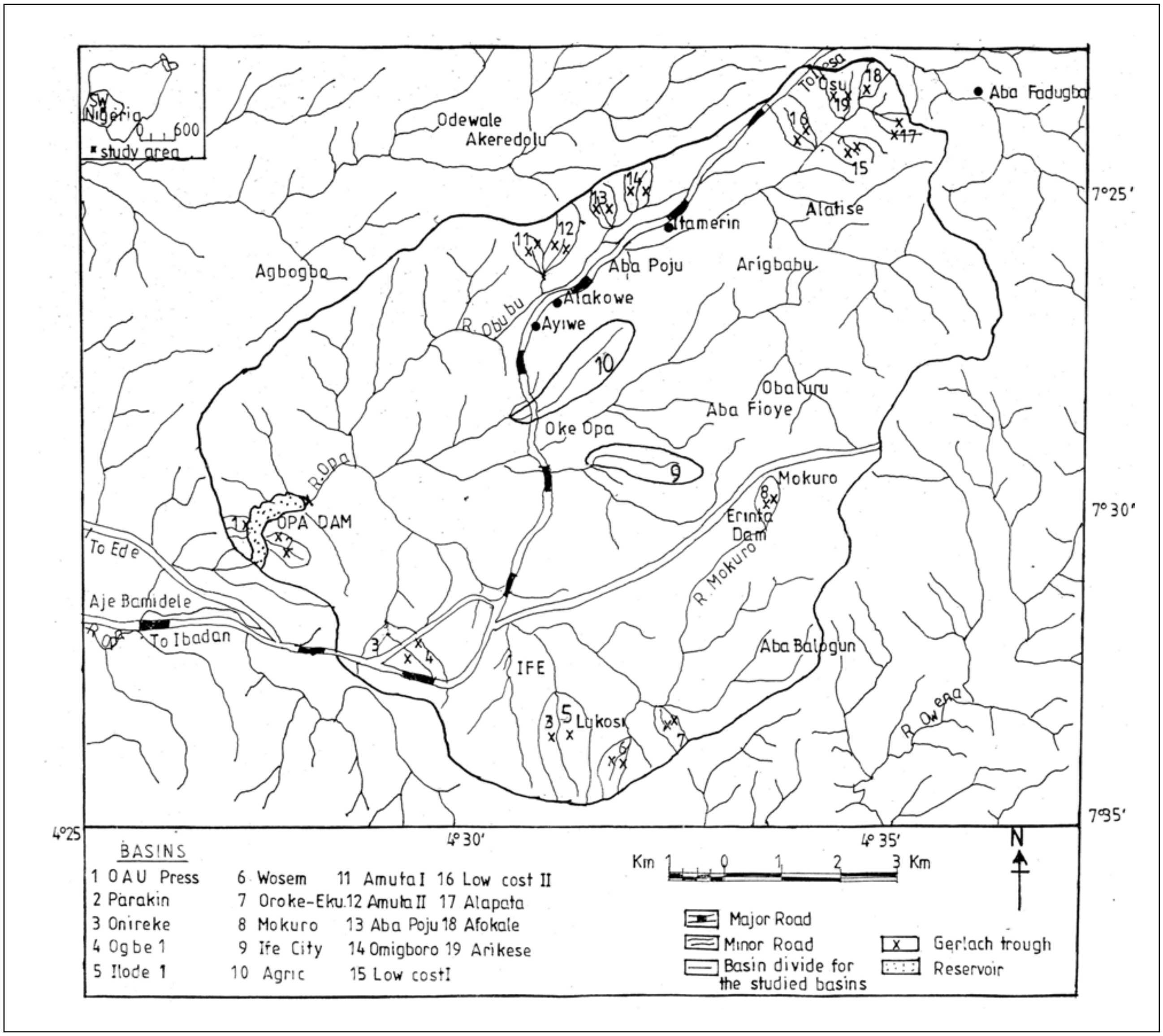

Figure 1. The study area.

various categories of slopes under different land uses. The slopes contributing runoff and sediment into the Gerlach Troughs were ranged and measured from both edges of the collector's lip to the crest of the slope (with allowance of 5^{o} on both edges) using equipment such as the Abney level, ranging poles, prismatic compass and tape (Adediji, 2002). This was done in order to determine the mean width of the contributing area . The mean width multiplied by length of the slope gives the contributing area. The width of the Gerlach Trough in this study is 0.4m.

Based on the analysis of SPOT images of the area using ILWIS 3.0 software (International Institutes for Aerospace Survey and Earth Sciences, the Netherlands, 1997), the 1st order basins studied can be categorized into two main groups: four non-vegetated (built-up) basins and 15 vegetated (agricultural) basins. Two Gerlach Troughs were installed on different slope angles in each of the vegetated and non-vegetated basins. This was done so that average soil loss per unit surface area (g/cm^2) under the same land use association could be established. For example, in the OAUPRESS basin, which was dominated by fallow/cultivated field crops, one trough was located under fallow vegetation (*Chromolaena odorata*) while the second trough was installed under a cassava farm (e.g. arable/field crops). In addition, 30 liter Gerlach Troughs were installed in the built-up areas of the catchments so as to determine the volume of runoff in excess of 10 liters usually associated with heavy storms in such built-up areas. The troughs in the built-up part of the basin were monitored on a daily basis to ensure that their positions were not disturbed. Runoff collected from the Gerlach Troughs was measured with calibrated bucket and recorded in liters. After each storm, the content of the trough was stirred vigorously and a 240 ml plastic bottle was used to take water cum sediment sample from the runoff collected for analysis of suspended sediment concentration. The product of runoff collected (in unit liter) and sediment concentration (mg/l) gives the storm soil loss for the rainfall event. Storm soil loss for each runoff event was summed up to obtain the gross soil loss from the Gerlach Troughs during the study period between June, 1999 and June, 2000.

The determination of suspended sediment concentration involved the filtration of each 200 ml of runoff collected from the Gerlach Trough using Whatman Glass Fibre Cycles (GFC), oven drying, cooling in a desiccator and weighing the sediment residue together with filter paper. The weight of the filter paper was subsequently subtracted to determine the weight of residue expressed in mg/l.

Data obtained on runoff, slope angle and length and soil loss were log-transformed before they were subjected to bivariate statistical analysis using the statistical packages for social scientists (SPSS) software for Windows 2000.

RESULTS

Runoff

The total runoff (in liters) obtained from the Gerlach Trough under different land use/vegetation types in the studied basins is shown in Table 1. The total runoff recorded was high in Ilode (GI) (196.20 liters) (5.62mm) located on the cleared land within the built-up part of the Ilode basin, followed closely by the basin designated as Ife G2 (103.35 liters) (5.24mm) also located on a cleared land.

The least value of runoff (17.25 liters) (1.09mm) was recorded in the basin designated as Omigboro G2 which was located within thicket/bush regrowth part of Omigboro basin.

Generally, the mean total runoff obtained from the basins in the built-up area was higher than the mean total runoff recorded in basins located in the cultivated field crops, cocoa farmlands and forested basins. This further confirmed the findings of Jeje and Agu (1982, 1990) on runoff under different land use surfaces in the same part of southwestern Nigeria.

Soil Loss

Soil loss obtained from valley slopes from the studied basins is shown in Table 2. As evident from the table and as expected, high soil loss was recorded in the basins located in the built-up areas (e.g. Onireke, Ogbe 1, Ilode 1 and Ife City in Ile-Ife) with a mean total soil loss of 905.60g (30.50g/m^2) from these basins. In fact, the highest total soil loss (1433.52g) (31.86g/m^2) (31.86t/km^2 / yr) was obtained from cleared land (CL) in the built-up area and was distantly followed by those obtained from basins cultivated to field crops/annual crops (e.g. OAUPRESS, Parakin, Agric and Aba-Poju), cocoa dominated (e.g. Mokuro I, Amuta I and II, Low cost I and II) and the forested basins with mean total soil loss of 456.25g (18.04t/km^2/yr), 322.15g (16.88t/km^2/yr) and 246.06g (14.20t/km^2/yr) respectively.

Table 1. Total Runoff (in Liters) From the Gerlach Troughs in the Studied Basins

Basins	Runoff (litre) Gerlach Trough(G)		
	G1	G2	$\bar{x}$
OAUPRESS^{++}	36.95(1.20)	67.30(1.93)	52.13(1.57)
Parakin $^{++}$	38.75(1.10)	49.30(1.50)	44.03(1.30)
Onireke $^{+}$	107.45(3.08)	40.25(1.34)	73.85(2.21)
Ogbe I^{+}	66.50(2.10)	165.25(4.34)	115.88(3.22)
Ilode I^{+}	196.20(5.62)	53.50(2.65)	124.85(4.14)
WOSEM^{++}	102.10(2.81)	29.35(1.30)	65.73(2.06)
Oroke-Eku $^{+++}$	73.30(1.85)	27.70(0.97)	50.50(1.41)
Mokuro I $^{++++}$	61.80(1.92)	30.50(0.68)	46.15(1.30)
Ife City $^{+}$	103.35(5.74)	58.90(1.80)	81.13(3.77)
Agric. $^{+}$	77.50(2.58)	90.50(2.01)	84.00(2.29)
Amuta I $^{+++}$	63.40(2.26)	39.40(1.64)	51.40(1.95)
Amuta II $^{+++}$	45.10(1.73)	61.90(2.21)	53.50(1.97)
Aba-Poju $^{+++}$	40.20(1.83)	18.90(1.28)	29.55(1.56)
Omigboro $^{+++}$	43.10(1.79)	17.25(1.09)	30.18(1.44)
Low Cost I $^{++++}$	51.10(1.20)	73.90(1.80)	62.50(1.50)
Low Cost II $^{+++}$	67.20(1.46)	32.00(1.14)	49.60(1.30)
Alapata $^{++}$	65.70(2.05)	30.80(1.40)	48.25(1.73)
Afakale $^{++}$	61.80(2.20)	89.40(2.18)	75.60(2.19)
Arikese $^{++}$	86.80(2.49)	95.00(2.26)	90.90(2.38)

$^{+}$ = Built up area basins
$^{++}$ = Fallow/cultivated field crop basins
$^{+++}$ = Cocoa dominated basin

Table 2. Total Soil Loss Obtained From the Gerlach Troughs in the Studied Basins

Basins	**Total soil loss (g) Gerlach Trough(G)**			**Non-channel specific yield (t/km²/yr)**
	G1	G2	$\bar{x}$	
OAUPRESS^{++}	421.34	646.69	534.02(15.97)	15.97
Parakin^{+}	369.90	578.08	473.99(13.74)	13.74
Onireke $^{+}$	498.19	1281.76	889.98(31.79)	31.79
Ogbe I^{+}	426.22	1388.77	907.50(32.41)	32.41
Ilode I^{+}	1433.52	396.16	914.84(28.06)	28.06
WOSEM^{++}	955.27	307.75	631.51(28.71)	28.71
Oroke-Eku $^{+++}$	348.18	201.15	274.67(19.61)	19.61
Mokuro I $^{++++}$	393.30	102.33	247.82(14.80)	14.80
Ife City $^{+}$	847.98	496.60	672.29(28.01)	28.01
Agric. $^{++}$	374.47	567.35	470.91(13.53)	13.53
Amuta I $^{+++}$	382.00	240.40	311.20(14.15)	14.15
Amuta II $^{+++}$	380.85	467.50	424.18(15.15)	15.15
Aba-Poju $^{++}$	235.65	115.22	350.87(15.59)	15.59
Omigboro $^{+++}$	247.61	194.53	221.07(15.79)	15.79
Low Cost I $^{++++}$	156.48	332.09	244.29(13.59)	13.59
Low Cost II $^{+++}$	269.07	77.63	346.70(13.64)	13.64
Alapata $^{++}$	164.92	76.71	170.82(12.65)	12.65
Afakale $^{++}$	323.94	188.41	256.18(17.67)	17.67
Arikese $^{++}$	524.46	142.26	333.36(14.49)	14.49

Values in brackets are soil loss per unit area (m^2) in grams (g)
$^{+}$ = Built up area basins
$^{++}$ = Fallow/cultivated field crop basins
$^{+++}$ = Cocoa dominated basin
$^{++++}$ = Forested basin

Relationship between Soil Loss on Slopes and Slope Runoff, Slope Gradient and Length

The relationship between soil loss on slopes and runoff and slope characteristics is shown in Table 3. Soil loss from valley slopes of 1st order basins correlated most significantly with runoff (R) ($r = 0.799$ at $\alpha = 0.05$). This confirmed the findings of Jeje and Agu (1982), Jeje (1987) in the Ife area, Lal (1976) and Aina et al., 1977) in the Ibadan area, southwestern Nigeria, that runoff was strongly correlated with soil loss from erosion plots. Also, soil loss on slopes correlated significantly with slope angle (Sa) ($r = 0.413$ $\alpha = 0.05$). But, soil loss was poorly correlated with slope length ($r = 0.225$). This confirms the findings of Aina et al. (1977) in the Ibadan area and Wischmeier and Smith (1958) in the Eastern United States, that effects of slope length may be compounded by the nature of slope.

Table 3. Correlation Between Soil Loss on Slopes and Slope Runoff, Slope Angle and Length

Soil loss from slopes (Y) correlated with	**r (correlation coefficient)**
Runoff (R)	0.799*
Slope angle (Sa)	0.413*
Slope length (S_l)	0.225

DISCUSSION

As shown in Table 1 and 2, the relatively high total runoff and soil loss obtained from Gerlach Troughs located in the built-up basins may not be unconnected with the fact that most of the built-up parts of the basins are exposed to direct rain drop impact. The bare street and unpaved surfaces promote high runoff and soil loss in the built-up part of the study area. Also, the mean specific yield of 30.07t/km^2 /yr obtained from the built-up basins of the study area, though lower, compares favorably with the value of 56.76t/km^2/yr obtained by Douglas (1996) from Penang, urban catchment in Thailand.

As expected, the values of the total runoff and soil loss obtained from slopes on the built-up area was higher than those obtained from basins cultivated to field crops, cocoa dominated farmlands and forested area (see Table 1 and 2). This is because the crop/plant cover protects the ground from direct impact of raindrops, and thus reduces runoff and soil loss from such surfaces.

The least soil loss of 4.75g/m^2 (4.75t/km^2/yr) (47.50kg/ha/yr) obtained from the troughs under forest in the Mokuro and Low Cost I basins as shown in Table 2 were not unexpected as the tree canopy shielded the ground from direct raindrop impact (Morgan, 1979; Jeje and Agu, 1982; Jeje 1987) thus retarding the generation of overland flow and the rate of surficial soil erosion under such vegetal cover.

The strong correlation between soil loss on slopes and runoff (see Table 3) in this study shows that while raindrop impact may be very important in soil detachment, it would appear that, without a transporting agent (runoff), rain drop impact would be incapable of causing significant downslope movement of sediment in this part of the humid tropics. With R^2 value of 0.638, runoff accounts for 63.8% of the soil loss variance from slopes of the studied basins. This indicates that runoff is an important predictor of soil loss from slopes and that any attempt to prevent deleterious sediment loss on slopes in the study area should involve minimization of runoff. This can be achieved mainly by enhancing rainwater infiltration into the ground through mulching and planting of cover crops. Also, the positively significant correlation between soil loss and slope angle/gradient in this study further confirmed the findings of De Ploey and Savat (1968) who reported an increase in the proportion of materials detached with increase in slope angle up to 30^o.

CONCLUSION

Sediment loss on slopes from different land use/vegetation types and under different categories of slopes within the Opa Reservoir Basin was investigated between June, 1999 and June 2000.

This study showed that the highest slope wash (slope soil loss) (31.86g/m^2) (31.86 t/km^2/yr) was obtained from cleared land (CL) in the built up part of Ilode in Ile Ife. This is distantly followed by values of soil loss obtained from basins cultivated to field crops (annual crops) (18.04 t/km^2/yr), cocoa dominated (16.88 t/km^2/yr) and the forested basins(14.20 t/km^2/yr) respectively. This implied that land use greatly affected the proportion/volume of materials transported on valley slopes within the basins. Also, soil loss from the valley slopes of the 1st order basins correlated most significantly with runoff (R) with r-value of 0.799 at $\alpha = 0.05$. In addition, sediment loss on slopes correlated significantly with slope angle (Sa) (r=0.413 at $\alpha = 0.05$). The findings of this study implied that runoff is most the important predictor of sediment loss on slope, and any attempt to control slope wash in this part of the world should involve minimization of surface runoff through mulching and planting of over crops.

REFERENCES

Adediji, A. 2002. Sediment Delivery Ratios in Opa Reservoir Catchment, Southwestern Nigeria. Unpublished Ph.D Thesis, Department of Geography, Obafemi Awolowo University Ile-Ife , Nigeria.

Adejuwon, J.O., and L.K. Jeje. 1975. Land element of the Environmental System of Ife Area. In : Ojo , A. (ed) Environment Resource Base Project, No 2 Department of Geography, University of Ife.

Aina, P., R. Lal, and G.S. Taylor. 1977. Social and Crop Management in Relation to soil Erosion in the Rainforest of Western Nigeria. Soil Conservation Society of America S.P.Publ 21, 75-82.

Douglas, I. 1996. The impact of land use changes, especially logging , shifting cultivation, mining and urbanization on sediment yields in humid tropical southeast Asia. A review with special reference to Borneo IAHS publ. 23b, 463-471.

Denise, F.C. 2001. Soil Conservation Technical Handbook. Prepared by the Ministry of the Environment. Published by the New Zealand Association of Resource Management. pp. 2-5.

De Ploey, J., and J. Savat. 1969. Contribution a l'etude de l'erosion par le splash. Zeitschrift fur Geomorphologie, 12, 174-193.

Jeje, L.K. 1977. Some Soil Erosion Factors And Losses From Experimental Plots in Ife Area, Southwestern Nigeria. The Nigeria Geographical Journal, 20 (1), 59-69.

Jeje, L.K., and A.N. Agu. 1982. Runoff and Soil Loss from Erosion Plots in Ife Area of Southwestern Nigeria. Goe-Eco-Trop; 6 (3), 161-181.

Jeje, L.K. and A.N. Agu. 1990. Runoff from Bounded Plots in Alakowe of Southwestern Nigeria. Applied Geography , 10,62-74.

Jeje , L.K. 1987. Runoff And Soil Loss From Erosion Plots in Ife Area Southwestern Nigeria" International Geomorphology, part II(ed) by V. Gardiner , 456-469.

Lahlou, A. 1996. Environmental and socio-economic impacts of erosion and sedimentation in North Africa. IAHS Publ, 236, 491-500.

Saunders, I., and A. Young. 1983. Rate of Surface Processes on Slopes, Slope Retreat and Denudation. Earth Surface Processes and Landforms, 8, 473-501

Sayer, A.M, R.P.D. Walsh, M.A.Clarke, and K. Bidin. 2004. The role of pipe erosion and slope wash in sediment redistribution in small rainforest catchments. IAHS publ. 288, 255 pp.

Sunderland, R.A., and R.B. Bryan. 1987. Sediment Budget Studies in the Katiorin Catchment , Baringo : A Preliminary Report , IAHS publ. Soil and Water Conservation in Kenya , Chapter 7, pp 88-98.

Smyth, A.J., and R.F. Montgomery. 1962. Soil and Land use in Central Western Nigeria. Publ. Ministry of Agriculture and Natural Resources.

Wishmeier, W.H., and D.D. Smith. 1958. Rainfall Energy and its Relationship to Soil Loss" Am. Geophys. Union Trans, 39,289-291

A. Adediji
Department of Geography
Obafemi Awolowo University
Ile-Ife, Nigeria

Email:remiadediji2003@yahoo.co.uk