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Relationship between three scales of erosion measurement on two small basins in Sierra Leone

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ABSTRACT A soil erosion and sediment yield study at three scales for two small drainage basins in Sierra Leone is described. The relationship between erosion pin and erosion plot measurements is examined for cultivated plots. Erosion rates, obtained by small scale measurement techniques, are assigned to each land use category. These are summed for the areas of each land use in each basin and the predicted erosion rates thereby obtained are compared to those from actual sediment yield data. The lack of fit of the predicted and observed basin erosion rates is discussed with reference to soil dynamics, channel erosion and sedimentation and operator errors.

Interrelations entre des mesures d'érosion de trois échelles de surface dans deux petits bassins versants en Sierra Leone
RESUME On décrit une étude d'érosion des sols, mesurée à trois échelles de surface dans deux petits bassins versants en Sierra Leone. Le relation entre les résultats obtenus sur parcelle expérimentale et ceux obtenus par le technique de mesure d'érosion par aiguilles est présentée. Les degrés d'érosion, obtenus par de techniques de mesure à petite échelle ont été définis pour chaque type d'utilisation des terres considérés. On cumule ensuite ceux ci, par type d'utilisation des terres, pour chacun des bassins versants et les résultats globaux ainsi calculés sont ensuite comparés a ceux obtenus sur parcelle expérimentale. Le disparité entre les résultats obtenus par les deux méthodes est discutée sous l'angle de la dynamique des sols, l'érosion en rigoles et la sédimentation, sans oublier les erreurs expérimentales.

INTRODUCTION

Soil erosion rates are rarely measured in drainage basins in which sediment yields are also calculated. Therefore little is known of the relationship between soil erosion and sediment yield models, although a theoretical model encompassing both aspects has been developed by Negev (1967). This problem is thought basically to be due to the different scales at which erosion measurements are made. A review of measurement scales in erosion studies has recently been made by Douglas (1981).

DESCRIPTION OF DRAINAGE BASINS

Two dammed second-order basins located in the highly dissected Freetown Peninsula Mountains in Sierra Leone have been monitored for soil and sediment dynamics since 1978, and the first analysis of the results in presented here.

The basins have similar geomorphological and topographical elements (Figs 1(a) and 2(a)), except for an area of swamp in Mountain Torrent basin. The soils are mainly thin entisols and ferralsols developed over norite and gleisols in the swamp. The two essential differences between the basins are the land use patterns and, to a lesser degree, basin shape. Mature secondary rain forest is dominant in Bambara Spring basin (Fig. 2(b)), whereas Mountain Torrent basin has a much more diverse land use pattern (Fig. 1(b)); in addition Mountain Torrent basin has a more linear shape.

Hydrometeorological data from a meteorological station located on the eastern drainage divide of Bambara Spring basin are summarized in Table 1.

Table 1 Hydrometeorological summary of the two basins (1955-1978)

Month	Precipitation (mm)	Penman ETP (mm)	Runoff (mm)
Jan.	3.5	115.85	0
Feb.	1.8	118.46	0
March	19.0	139.45	0
April	54.2	123.31	0
May	191.6	108.72	0
June	362.8	86.58	59.1
July	783.9	71.01	712.9
Aug.	856.2	70.76	785.4
Sept.	616.6	77.37	538.8
Oct.	296.2	96.29	199.9
Nov.	99.7	94.4	5.3
Dec.	26.7	101.21	0

SEDIMENT YIELD (MACROSCALE) MEASUREMENTS

Both basins have two dams or tanks in which the water level is low enough each year for a sediment survey to be undertaken. Transects were made across the dam or tank beds; sediment depths were recorded and samples taken from the different sediment facies. From the recorded depths sediment isopach maps were calculated and the sediment volumes computed. The weight of sediment deposited was obtained by multiplication of the facies volume by the mean facies bulk density. The two tanks in the Bambara Spring basin are also cleared of sediment each year and therefore annual sedimentation rates have been obtained.

All tanks, except for the Lower Mountain Torrent Dam, have concrete inlet flumes to divert some of the water into bypass channels. By observation of selected wet season flows a semi-quantitative estimate of the amount of water entering the dam

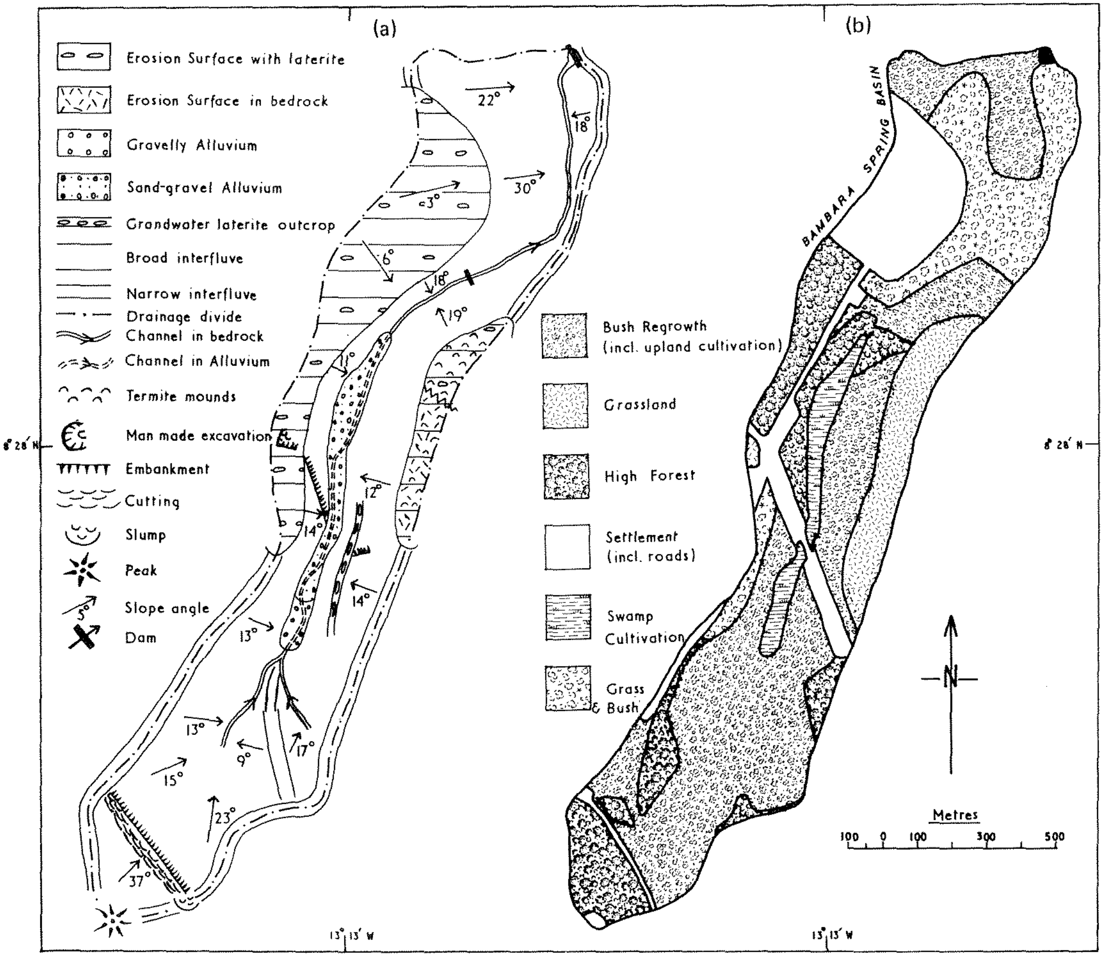

Fig. 1 Mountain Torrent basin: (a) geomorphology, (b) land use.

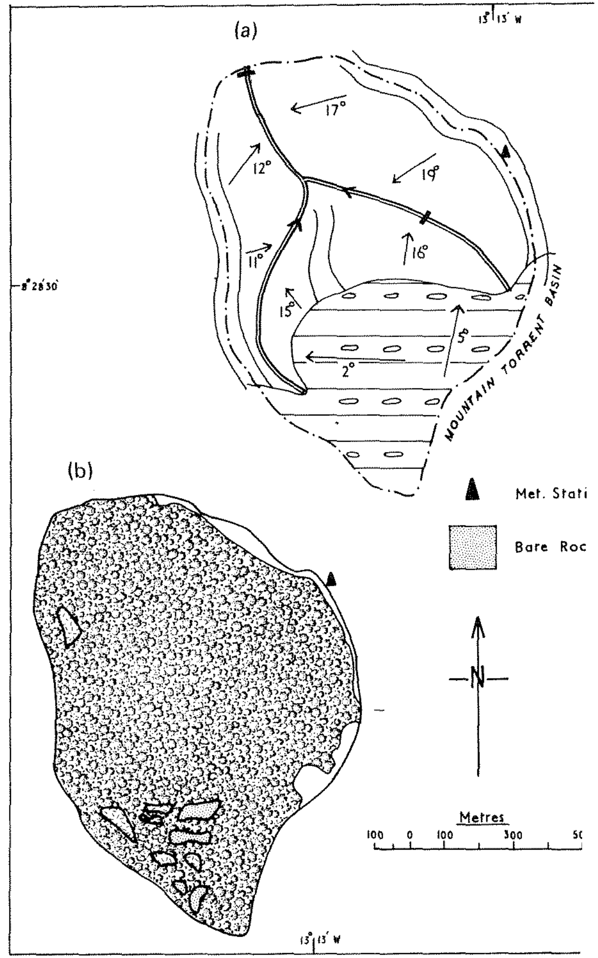

Fig. 2 Bambara Spring basin: (a) geomorphology, (b) land use; same keys as Fig. 1 (a) and (b).

annually was made. It was also assumed that the sediment loads of the bypassing water would be similar to that entering the dam. Basin erosion rates were produced by dividing the total sediment trapped in the dam, and that bypassing it, by the basin areas. These data are summarized in Table 2.

EROSION PLOT (MESOSCALE) MEASUREMENTS

Within each basin erosion plots were established under forest, grass and upland cultivation of rice and cassava. Bush-regrowth was not sampled at this scale as a pilot survey revealed little difference in fallow and forest rates. Swamp cultivation was also not sampled as the area is farmed during the dry season and the swamps are flooded during the wet season.

The plots, which varied in size (Table 3), were monitored by 0.5 m wide modified Gerlach troughs which collected surface flow, eroded soil and subsurface flow in the upper 10 cm of the soil. Samples were taken after each storm and the suspensions filtered through Whatman no. 1 filter papers. The oven-dry weights of the filtered suspensions were added to the weights of the oven-dry soil collected from the troughs to obtain total soil eroded weights.

EROSION PIN (MICROSCALE) MEASUREMENTS

Within the upland cultivation erosion plots, transects of 30-cm-long iron erosion pins with washers were laid parallel with the slope. Pin transects were placed adjacent to other plots. These pins were measured on a monthly basis and the data are summarized in Table 4.

RELATIONSHIPS BETWEEN MICROSCALE AND MESOSCALE MEASUREMENTS

This discussion is restricted to the two upland cultivation plots. In the cassava erosion plots pins were located in sets of three corresponding to mound tops, mound sides and inter-mound depressions; the rice erosion plots had single pin transects. The mean monthly surface altitude changes were converted to mean soil losses by multiplication with a mean soil bulk density of 1160 kg m^{-3}. These pin-derived soil losses were compared to the soil losses computed from the trough sediments (Table 5). Soil losses obtained from the pin measurements tended to be much higher in most cases, and more so in the cassava than the rice plots.

There appeared to be a cyclic pattern of soil erosion and deposition in the plots. This pattern was seen after each pin monitoring interval (although the pattern in the first set of cassava mound readings was different from the later reading (Fig. 3(b) and (c)), and therefore only the total annual pattern is presented (Fig. 3). The transect in the rice plot shows three erosional and two depositional areas. As there was no soil

Table 2 Mean basin sediment yields

Basin	Years	Sediment yield ($t\ km^{-2}\ year^{-1}$)
Mountain Torrent	1940-1980	2.00
Bambara Spring	1977-1979	0.07

Table 3 Soil losses from erosion plots

Land use	Slope (°)	Year(s)	Soil loss ($t\ km^{-2}\ year^{-1}$)
Rice cultivation	16.5	1980	40.68
Cassava cultivation	16.5	1980	1.79
Bare soil	3.0	1979	30.05
Grass	3.0	1979	7.45
High forest	16.0	1979-1980	0.05

Table 4 Erosion rates of selected pin transects

Land use	Slope (°)	Year(s)	Soil loss ($t\ km^{-2}\ year^{-1}$)
Rice cultivation	27.5	1979	1.5
	27.0	1979	17.3
	16.5	1980	54.5
Cassava cultivation	22.5	1979	55.1
	22.0	1979	11.2
	16.5	1980	Net deposition
Bush regrowth	20.0	1978-1979	1.0
Forest	16.0	1978-1979	1.2

Table 5 Comparison of pin and plot soil losses

Plot	Month	Pin soil losses ($t\ km^{-2}\ year^{-1}$)		Plot soil losses ($t\ km^{-2}\ year^{-1}$)
Rice	July*	15.1		30.94
	Aug.	6.9		0.41
	Sept.	5.8		5.55
	Oct.†	20.9		0.02
Cassava §		I	II	
	July*	580.0	313.2	4.94
	Aug.	12.8	45.2	0.61
	Sept.	17.4	11.6	0.83
	Oct.†	7.0	11.6	0.02

* Includes June.
† Includes until the end of the wet season.
§ Mound tops and depressions are areas of net deposition, I — Mound sides and II — lowest set of pins.

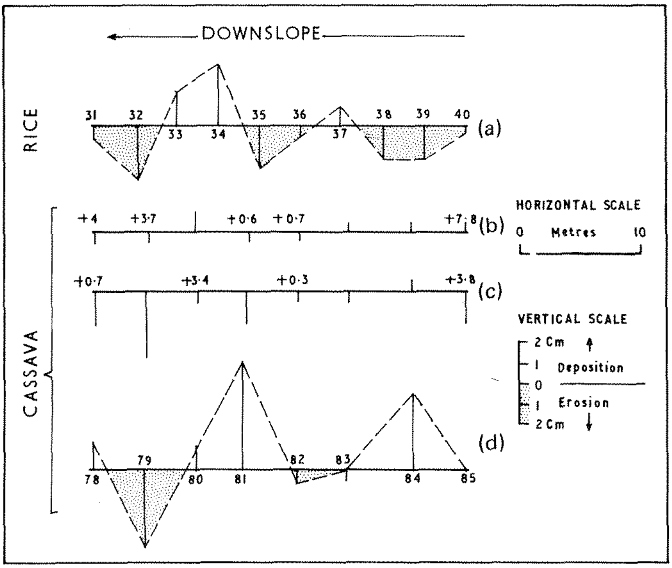

Fig. 3 Annual patterns of soil altitude changes in cultivated plots. (a) The rice plot; (b) the cassava mound tops; (c) mound sides and (d) intermound depressions. The numbers 31-40 and 78-85 refer to pin locations and the other numbers in (b) and (c) refer to the altitude changes after the first monitoring interval when they were out of phase with the annual pattern.

damming caused by obstructions at the pins the increase in surface altitude was due to dynamic soil deposition. The top-soils are very porous and stony and it is thought that surface flow occurred in only short discrete lengths of 7-10 m. After this length the flow velocity decreased due to surface roughness and the water infiltrated into the soil depositing the previously entrained fines. This hypothesis is to be tested using soil micromorphological techniques.

The cassava mound systems could not be treated in the same way as the mounds are discrete microtopographical units. The inter-mound depressions are, however, a continuum - a manmade rill - and like any other channel have eroding and depositional stretches. This is seen in Fig. 3(d). It is difficult, therefore, to correlate the pin measurement data with trough collected soil. Although the trends in the data follow, to a certain extent, the pattern of soil deposition in the troughs, only in the mound-side data was there net erosion. The best correlation between pin and trough data was with the set of pins on the lowest mound adjacent to the trough.

The evidence from both plots suggested that the soil collected in the troughs originated within the vicinity of the trough itself.

RELATIONSHIPS BETWEEN PREDICTED AND OBSERVED BASIN EROSION RATES

Predicted basin erosion rates were made by the following technique. The mean erosion rates obtained by both plot and pin measurements for each land use type were multiplied by the areas of the respective land use in each basin. The product corresponded to the mean amount of soil loss for each land use in the basin; these were then added to obtain the erosion rate for the whole basin. These values are shown in Table 6, and should be compared to the actual erosion rates in Table 2.

Table 6 Predicted sediment yields for the two basins

Land use	Mean erosion rate (t km^{-2} year^{-1})	Bambara Spring		Mountain Torrent	
		Area (km^2)	Soil loss (t)	Area (km^2)	Soil loss (t)
Bare rock	0	0.019	0	0	0
Bush fallow	0.05	0	0	0.542	0.027
Cultivation*	21.24	0	0	0.06	1.274
Grass	7.45	0.015	0.112	0.239	1.781
Forest	0.05	0.725	0.036	0.155	0.008
Settlement A†	18.75	0	0	0.209	3.919
Settlement B†	7.45	0.043	0.32	0	0
Totals		0.802	0.468	1.205	7.009
Predicted sediment yields			0.584		5.817

* From field surveys upland cultivation accounted for 10% of that mapped as bush regrowth and the mean erosion rates are the means of rice and cassava cultivation.
† Settlement A comprises mainly earth roads and gardens of the African villages and Settlement B comprises grassland of the University campus.

The overestimation of predicted basin erosion rates has also been noted by Hadley & Lusby (1967) in a semiarid environment and can be attributed to the following factors.

(a) Although the water course gradients are steep, because streams rarely cut through alluvium, channel sediment production is low. In fact, field evidence suggests there is much damming behind channel obstructions.

(b) The location of different land use types relative to altitude is important. In Bambara Spring basin and half of Mountain Torrent basin the lower slopes are covered by forests and fallow bush. The leaf litter in these land use types filters out downwashed sediment.

(c) Temporal variations in slope erosion, i.e. interrupted surface flow, effect sediment production as a number of erosive events are required to transport soil downslope causing a time lag between soil detachment and appearance in the stream.

(d) Evidence of fines being transported by subsurface flow has been noted by Roose (1970) in West Africa, but this is not considered here.

(e) Lower slope concavity and related deposition is rare.

(f) Finally, the possibility of operator errors cannot be ignored considering the number and nature of parameters measured.

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