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LAWRENCE K. JEJE (*)

# LANDUSE AND SEDIMENT YIELD IN PARTS OF SOUTH WESTERN NIGERIA

ABSTRACT: JEJE L.K., *Landuse and sediment yield in parts of South Western Nigeria*. (IT ISSN 0391-9838, 1999).

12, 3rd order drainage basis were selected from an area of similar geology (quartzite-quartz schists) and relief (ridge and valley topografy) in parts of Central Western Nigeria,noted for upland rice cultivation which has involved the virtual transformation of a dry rainforest into contiguos farmlands. The basins were monitored for one year with emphasis on runoff and sediment yield. Six basins had 55-81% forest cover while 6 had 56-89% farm coverage. All the streams were perennial. The farmed basins had significantly higher values of specific suspended sediment yield than the forested basines, while values of specific solute load from the two sets of basins were not significantly different. The mean denudation rate was significantly higher in the farmed basins.

KEY WORDS: Forest cover, Farmlands, Runoff and Sediment Yield, Nigeria.

## INTRODUCTION

One of the most important manifestation of changes resulting from anthropological impact on the enviroment is land degradation which may involve despoliation, excavation and soil dumping in case of mining or severe changes in vegetation charactristics resulting particulary from the trasformation of a climax forest vegetation to a mosaic of farmlands. Nowhere is this more manifested in South Western Nigeria than the hilly area of Ijesa and Ekiti districts where recent adoption of upland rice cultivation has led to severe changes in the rural landscape particularly in the vegetation characteristics.

First cultivated in 1849 at Ofada near Abeokuta, the crop spread into Ijesa and Ekiti districts by 1947. As a result of heavy demand for rice by the rapidly growing urban population, the crop has displaced yam as the local staple food crop, and is gradually displacing cocoa as the most important cash crop. As cocoa was already occupyng lands considered optimal for cash crop farming, rice cultivation was tried on the sandy loamy soils (the «Okemessi Association» of Smyth & Montgomery, 1962) derived mainly from quartzschist underlyng the hills and ridges in the study area. The success of the crop on these soils has further encouraged the farmers to progressively utilize the hitherto uncultivated hillsides. Between about 1960 and now, most of the virgin forests covering the hills and ridges have been cleared.

The forest is cleared and burnt and rice sown in the undisturbed top soil at the beginning of the rainy season in March or April. Given the intensively violent thunderstorms characteristic of most parts of Southern Nigeria, the exposed soils should be liable to erosion. This problem is further aggravated where farmers cultivate the same plot of land to rice for two or three consecutive years followed by a short fallow before the land is cleared and cultivated again. In some cases, within a period of seven years, the same plot would have been cultivated about four times.

The primary aim of this paper is to ascertain the pattern of runoff and sediment production from under the different broad vegetation/ landuse types as manifested in the local drainage basin channels in terms of annual runoff and sediment yield from these basins and in term of overall denudation rates in the basins. This type of study has been done by the use of erosion plots (see Jeje, 1977, 1987; Jeje & Agu, 1982, 1990; Daura, 1995 among others), but as the results from such plots are of limited application as they cannot be interpolated over large heterogenous surfaces, small drainage basins provide the best opportunity for this type of work. Kowal (1970) carried out this type of study in Samaru, but he used only one small drainage basin. The current attempt based on 12, 3rd order basins should provide better insight into the effect of anthropological impact on a marginal terrain in a humid tropical environment.

(*) *Department of Geography, Obafemi Awolowo University, ILE-IFE, Nigeria.*

## STUDY AREA

The study area covers about 230 km$^2$ and lies between longitudes 4°45' E and 5°15' E and latitudes 7°30' N and 7°45' N in the watersheds of upper Osun, Owena, Oluwa and Oni around Effon Alaye, Ogotun and Ikeji-Ile (fig. 1).

All the drainage basins studied are underlain by intercalated quartzite and quartz-schist trerding NNW-SSE, forming hills and hogback ridges and standing at 660 m to 770 m a.s.l., with local relief of 150-300 m. The rocks which frequently outcrop in the forest especially on ridge crests and summits are overlain upslope by autochtonously derived coarse grained shallow soils and downslope by deep silty to clayey drift soils all of which exhibit very high rates of permeability (Oluwatimilehin, 1991).

The study area lying within Koppen's Af humid tropical climate had rainfall which during 1994 ranged from 1356mm to 2019 mm in the 12 drainage basins, with individual rainfall event yielding values between 4.8 mm and 69.Omm. Rainfall is of high intensity at the onset (March to May) and the end (October to November) of the rainy season. Temperatures are constantly high ranging from a mean minimum of about 21°C in August to a mean maximum of about 32°C in February and March. Relative humidities are high ranging from about 70% (10 a.m. GMT) in January to about 95% in July.

Much of the natural vegetation in the drainage basins have been destroyed through cultivation, urbanization and road construction. Currently six of the 12 drainage basins have 51% to 81% of their areas covered by degraded dry rainforest. This forest is interspersed with cultivated patches and dominated to a significant extent by fallow species particularly *Chromolaena odorata*. Arable crops on the hill and valleysides include yam, maize, cassava and predominantly rice, while the valley floors and narrow floodplains are cultivated to vegetables, plantains, cocoa and kolanuts.

Bush burning during the dry season is prevalent on the hill and valleysides, and by the end of the dry season, a significant proportion of the steep slopes is bare.

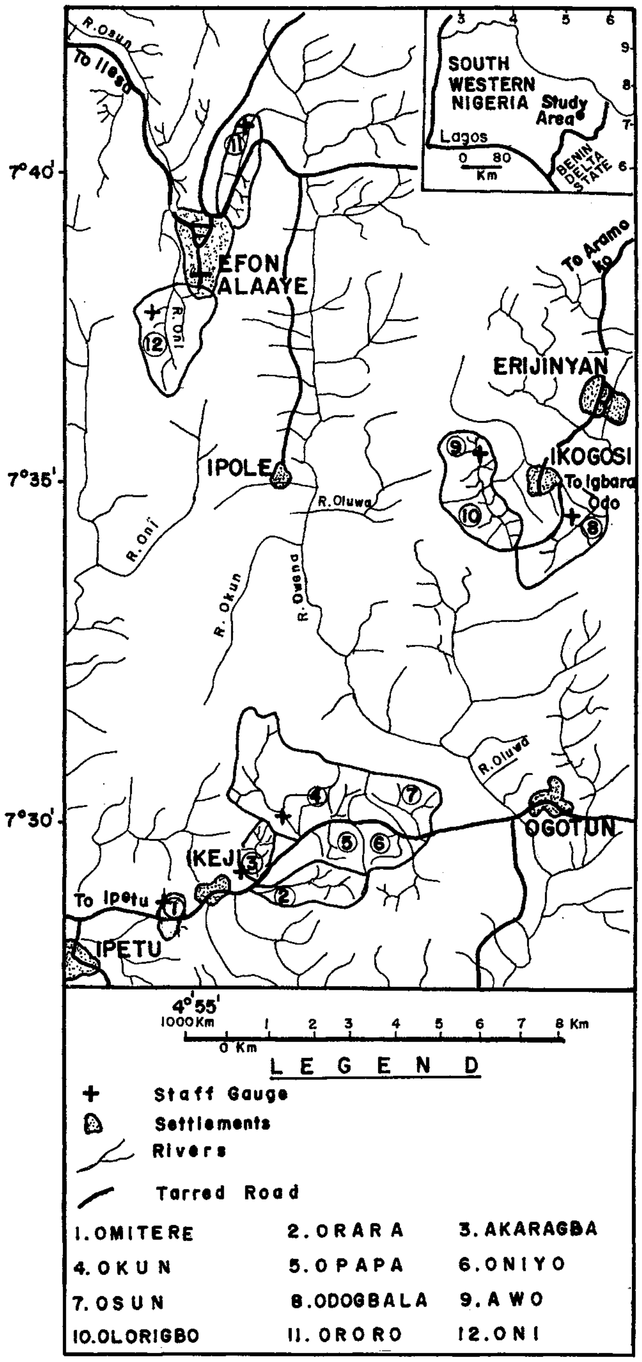


FIG. 1 - The study area and the sampled third order streams.

## STUDY METHOD

12, 3rd order drainage basins (1:50,000 topographic sheets) were selected randomly out of the 27 such basins in the study area. As geology, soil and relief are similar in all the drainage basins, the assumption is that whatever differences could be observed in the hydrological behaviour of the streams with particular regard to specific runoff, sediment yield and denudation rates are probably attributable to differences in landuse/vegetation cover.

Data on some physiographic and morphometric attributes that may affect hydrological behaviour and also reflect differences in basin characteristics notwithstanding landuse/vegetation variations in these basins were collected from 1:50,000 maps. These include basin areas, relief ratio and drainage density.

The line intercept method based on cut traverses was used to survey the vegetation/landuse in the basins. The total length of each type of the broad vegetation/landuse i.e. forest and farmlands/fallows intercepted along each traverse within a basin was expressed as a ratio of the total length of the traverse multiplied by 100. The intercepted landuse/vegetation length was made the surrogate for areal coverage. In all 4-10 transects at 0.5 km interval were cut across each drainage basin. Of the 12 basins, 6 had more than 50% forest cover, while the other six had less than 50% forest cover.

Water discharge was measured with the use of staff gauges and constant water level recorders installed at suitable sites at the exit of the main stream channel in each basin. Standard procedures for water sampling using the Depth Integrated Sampler were followed to collect sediment samples at known water discharges (Walling, 1971, Gregory & Walling, 1973; ASCE, 1975). Daily sampling and a more intensive sampling programme during storm runoffs were undertaken for each of the 12 catchments. During storm runoff, sampling was at 15 minutes interval on the rising stage and at 30 minutes interval on the falling stage of the hydrograph for at least 6 hours.

Velocity discharge measurements with OTT current metres were carried out based on a wide range of observed stage levels. Rating curves were derived for each stream to obtain sediment concentration for discharges for which sampling was not done. Each basin was equipped with an automatic British Standard Rain gauge with 30 cm orifice.

Standard methods for the determination of suspended sediment and solute loads of streams were used. That for suspended sediments involved the filtration of each 200ml of stream water using Whatman Glass Fibre Circles (GFC) and vacuum pump assembly, oven drying, cooling in dessicator and weighing the sediment residue together with the filter paper. The weight of the filter paper was subsequently subtracted. Those of the solute load were obtained by evaporating 100ml of filtrate obtained from the filtration of suspended sediments at an oven temperature of 105°C (Davis & De Wiest 1966). The residue was then weighed and expressed in mg/l.

The denudation rate was determined per unit area following the method outlined by Gregory & Walling (1973, p. 173):

$$\text{Denudation in } m^3/km^2/yr = \frac{\text{total load (tonnes)}}{\text{area } (km^2) \times \text{specific gravity}}$$

The value of specific gravity was put at 1.0 following Walling's (1971) observations that most of the sediment load in channels are derived from the soil horizons which could have a specific gravity less than 1.0.

The correlation coefficients among the determined basin physiographic, topographic attributes and sediment yield values were determined.

## RESULTS

### *Some basin physiographic parameters*

Table 1 shows the values of some basin variables including rainfall examined in this study.

Six basins had 55-81% forest coverage while the rest had 56-88% farm coverage. With a mean area of 2.73 $km^2$, the forest covered basins are larger than the farmed basins which have a mean value of 1.79 $km^2$. The mean value of drainage density in the forested basins of 2.07 is not significantly different from that of the farmed basin at 2.4. Relief ratio in all the basins vary from 0.061 to 0.266 with a mean of 0.130±0.060. With a mean value of 0.145, relief ratio is higher in the forested than in the farmed basins with a mean value of 0.115.

### *Runoff*

All the streams experienced perennial flow marked by double maxima discharge. The forested basins experienced the first maximum in July in consonance with the rainfall regime, while most of the farmed basins experienced the first maximum discharge in May and June in association with the occasional heavy rains at the onset of the rainy season (fig. 2). This is an indication of the preponderance of surface runoff and near surface through flow over baseflow in the farmed basins. Nearly all the streams experienced their second maximum discharge between September and November.

TABLE 1 - Physiographic, Landuse and Rainfall attributes of the Studied Streams

| | % Area of Basin underlain by | | | Basin Morphometry | | | Total Annual | % Area of Basin Covered By | |
|---|---|---|---|---|---|---|---|---|---|
| Basin | Q2 | Gg | Amph. | Area $km^2$ | Dd $km^{-1}$ | Rh | Rainfall (mm) | Forests | Farms |
| Okun | 96 | 3 | 1 | 4.50 | 1.6 | 0.133 | 1990 | 81 | 19 |
| Opapa | 97 | 3 | - | 2.08 | 1.8 | 0.097 | 2019 | 78 | 22 |
| Oniyo | 100 | - | - | 1.81 | 2.2 | 0.196 | 1910 | 71 | 29 |
| Osun | 100 | - | - | 1.75 | 1.9 | 0.266 | 1911 | 63 | 37 |
| Akaragba | 96 | 3 | 1 | 0.75 | 4.0 | 0.074 | 1694 | 58 | 42 |
| Oni | 100 | - | - | 5.50 | 0.9 | 0.106 | 1800 | 55 | 45 |
| Orara | 98 | 1 | 1 | 2.30 | 1.1 | 0.146 | 1681 | 44 | 56 |
| Omitere | 96 | 3 | 1 | 1.10 | 2.7 | 0.157 | 1694 | 43 | 57 |
| Odogbala | 98 | 1 | 1 | 2.10 | 1.8 | 0.084 | 1397 | 20 | 80 |
| Awo | 96 | 3 | 1 | 0.75 | 4.6 | 0.094 | 1356 | 12 | 88 |
| Olorigbo | 100 | - | - | 2.90 | 1.6 | 0.127 | 1649 | 11 | 88 |
| Ororo | 100 | - | - | 1.60 | 2.8 | 0.081 | 1563 | 11 | 88 |

Q2 - Quartzite; Gg - Granite gneiss; Amph - Amphibolite; Dd - Drainage density; Rh - Relief ratio

*Source*: Field Work and Analysis of 1:50,000 topographic maps.

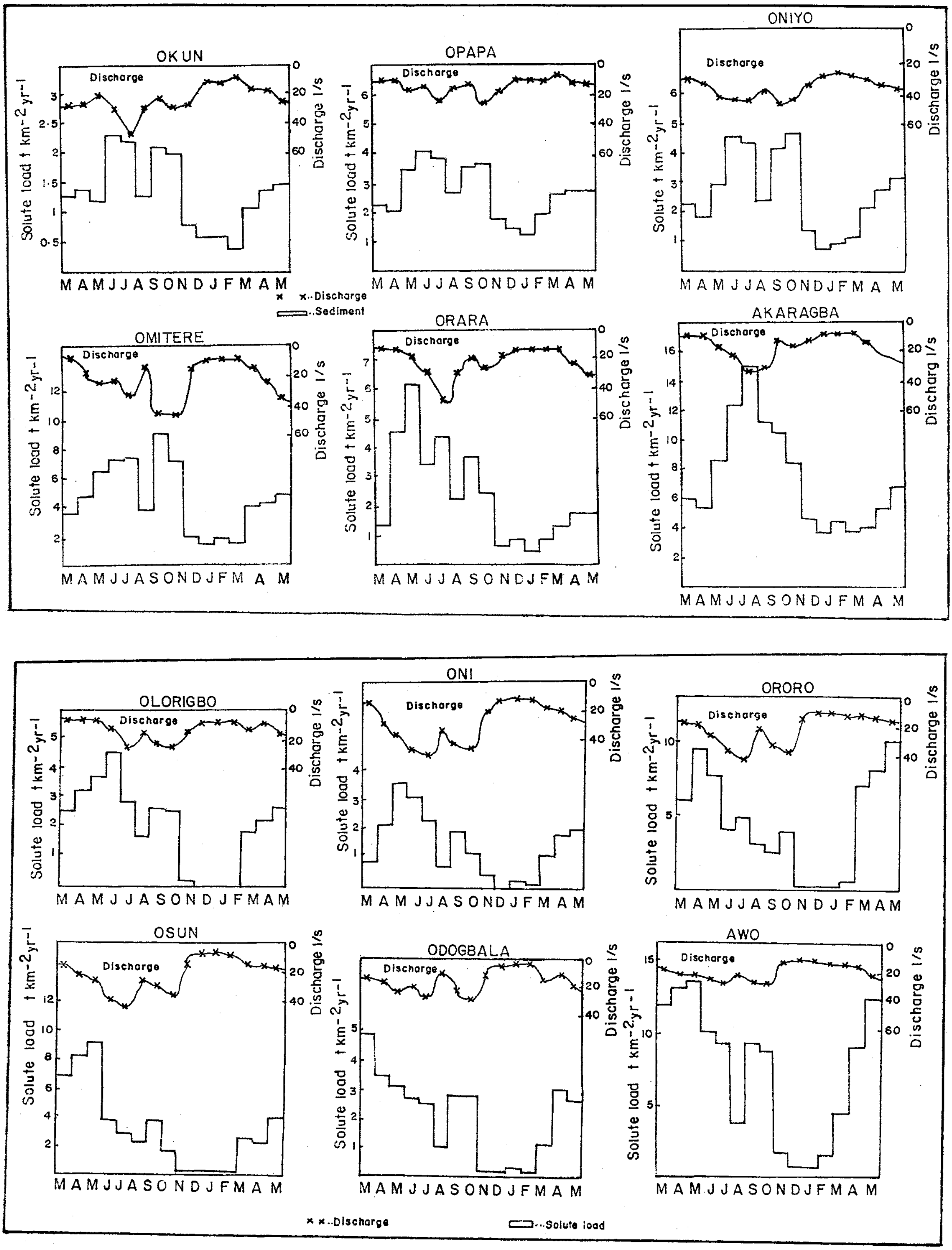


FIG. 2 - Solute and streamflow discharge regime.

Table 2 shows the values of both absolute and specific runoff from the basins. Values of absolute runoff from the forested basins averaged 133 mm and 64 mm in the farmed basins, while those of specific runoff averaged 69 mm in the former and 45 mm in the latter.

TABLE 2 - Total Annual Runoff

| Basin | Total Annual Runoff (mm) | % Runoff | Specific Runoff ($mm/km^2$) |
|---|---|---|---|
| Okun | 189 | 9.5 | 42.0 |
| Opapa | 251 | 12.4 | 120.7 |
| Oniyo | 94 | 4.9 | 51.9 |
| Osun | 172 | 9.0 | 98.3 |
| Akaragba | 72 | 4.3 | 96.0 |
| Oni | 22 | 1.2 | 4.0 |
| Orara | 49 | 2.9 | 27.1 |
| Omitete | 40 | 2.4 | 36.4 |
| Odogbala | 96 | 6.9 | 45.7 |
| Awo | 41 | 3.0 | 54.7 |
| Olorigbo | 14 | 0.8 | 4.8 |
| Ororo | 143 | 9.1 | 89.4 |

*Source*: Field Work.

Peak discharges were generally low in all the streams, generally below 8.01/s during the study period.

*Suspended Sediment and Solute Yield*

Table 3 shows the values of suspended sediment and solute yield from the streams in 1986. Suspended sediment concentration in all the streams ranged from 2.0 mg/l to 2450 mg/l with a mean of 63.25 mg/l and a standard deviation of 33.08 mg/l in all the basins. In basins dominated mainly by field crops (Olorogbo, Awo and Ororo) the highest concentration occurred in April and May in association with heavy thunderstorms when the fields were still relatively exposed, while in the forested basins, they occurred in association with heavy storms at the end of the rainy season (see Jeje, 1987; Oluwatimilehin, 1991; and Jeje & *alii*, 1991).

Values of specific sediment yield in all the streams varied from $0.9tkm^{-2}yr^{-1}$ to $46tkm^{-2}yr^{-1}$ with a mean of $10.46tkm^{-2}yr^{-1}$ and a standard deviation of $13.08tkm^{-2}yr^{-1}$. These are more or less in consonance with those obtained by Ogunkoya and Jeje (1987) in some 3rd order basins in Upper Owena in which specific suspended sediment yield ranged from $0.4tkm^{-2}yr^{-1}$ to $29.5tkm^{-2}yr^{-1}$ with a mean of $9.2tkm^{-2}yr^{-1}$.

With values of specific sediment load ranging from $3.7tkm^{-2}yr^{-1}$ to $46tkm^{-2}yr^{-1}$ and a mean of $23.5tkm^{-2}yr^{-1}$, the farmed basins had significantly higher values of specific suspended sediment load than the forested basins with values of $0.9tkm^{-2}yr^{-1}$ to $14.0tkm^{-2}yr^{-1}$ and a mean of $6.6tkm^{-2}yr^{-1}$.

As evident from Table 4, most of these sediments were associated with storm runoff which occurred infrequently.

TABLE 4 - Percentage of suspended sediment yield carried by flows $Q_{90}$, $Q_{50}$, $Q_{10}$ and $Q_1$

| Basin | % Suspended Sediment Yield $Q_1$ | $Q_{10}$ | $Q_{50}$ | $Q_{90}$ |
|---|---|---|---|---|
| Okun | 70.4 | 18.7 | 4.0 | 2.1 |
| Opapa | 70.3 | 21.4 | 3.9 | 1.4 |
| Oniyo | 82.3 | 16.8 | 13.3 | 0.1 |
| Osun | 75.4 | 22.3 | 6.3 | 0.1 |
| Akaragba | 54.2 | 33.6 | 3.3 | 0.3 |
| Oni | 15.4 | 69.8 | 11.0 | 1.0 |
| Orara | 71.8 | 21.6 | 5.5 | 1.1 |
| Omitere | 12.2 | 24.0 | 46.2 | 1.5 |
| Odogbala | 17.8 | 73.6 | 19.6 | 1.4 |
| Awo | 9.2 | 71.7 | 22.6 | 2.6 |
| Olorigbo | 18.3 | 70.8 | 16.7 | 2.4 |
| Ororo | 7.7 | 33.1 | 52.6 | 0.3 |

$Q_1$ - flow equalled or exceeded 1% of the time.
$Q_{10}$ - flow equalled or exceeded 10% of the time.
$Q_{50}$ - flow equalled or exceeded 50% of the time.
$Q_{90}$ - flow equalled or exceeded 90% of the time.

*Source*: Field Work.

TABLE 3 - Total and Specific Yield of Suspended Sediments and Solute and Denudation Rate

| Basin | Total Yield Suspended tonnes | Solute tonnes | Total load | Specific Yield Suspended $tkm^2 yr^{-1}$ | Solute $tkm^2 yr^{-1}$ | Ratio of Solute to Suspended Load | Denudation rate $m^3/km^2/yr$. |
|---|---|---|---|---|---|---|---|
| Okun | 7.4 | 142.4 | 149.8 | 1.6 | 25.3 | 15.80 | 33.2 |
| Opapa | 3.3 | 17.5 | 20.8 | 1.6 | 6.7 | 4.20 | 10.0 |
| Oniyo | 2.1 | 13.6 | 15.7 | 1.2 | 6.0 | 5.00 | 8.7 |
| Osun | 10.9 | 61.8 | 72.7 | 6.2 | 28.3 | 4.56 | 41.5 |
| Akaragba | 10.5 | 26.0 | 36.5 | 14.0 | 27.7 | 2.00 | 48.7 |
| Oni | 5.1 | 98.4 | 103.5 | 0.9 | 14.3 | 15.9 | 18.8 |
| Orara | 9.7 | 35.1 | 44.8 | 4.2 | 12.2 | 2.9 | 19.5 |
| Omitere | 51.2 | 48.2 | 99.4 | 46.5 | 34.9 | 0.75 | 90.4 |
| Odogbala | 18.1 | 36.6 | 54.7 | 8.6 | 13.9 | 1.61 | 26.5 |
| Awo | 6.9 | 39.9 | 46.8 | 9.2 | 42.6 | 4.63 | 62.4 |
| Olorigbo | 10.8 | 27.5 | 38.3 | 3.7 | 7.6 | 2.05 | 13.2 |
| Ororo | 44.4 | 13.4 | 57.8 | 27.8 | 6.7 | 0.24 | 36.1 |

*Source*: Field Work.

This is especially the case in the forested basins where 54-82% of the suspended sediment yield were in association with $Q_1$ flow. This contrasts with the situation in the farmed basins where the greater part of the suspended sediment load were produced and transported by $Q_{10}$ and $Q_{50}$ discharges.

Values of specific solute load varied from $6.0 tkm^{-2}yr^{-1}$ to $42.6 tkm^{-2}yr^{-1}$ with a mean of $18.65 tkm^{-2}yr^{-1}$ and a standard deviation of $11.92 tkm^{-2}yr^{-1}$. With a mean value of $18.05 km^{-2}yr^{-1}$, specific solute load from the forested basins was not significantly different from the situation in the farmed basins with a mean of $19.65 tkm^{-2}yr^{-1}$. Generally, values of solute load are significantly higher than those of suspended sediment load in all the forested basins and also in four out of the six farmed basins. Solute yield was 0.75-5.0 times those of suspended load in all the basins except in the Oni and Okun where it was 15.9 and 15.8 times respectively. In the forested basins, the average is 7.91 reducing considerably to 2.03 in the farmed basins. The latter ratio values compare favourably with those between 1.2 and 2.0 reported by Slaymaker (1975) while those from the forested basins compare favourably with the values of 1.0 to 10.0 reported by Meybeck (1976) for some low relief tropical basins.

The value of total soil loss from the forested basins averaged 223 kg/ha which is about three times higher than values of soil loss observed from forested erosion plots on 8° slope in Ife Area at a mean of 79 kg/ha. Also the value of soil loss frum the farmed basins which averaged 363 kg/ha is by far higher than the mean value of 94 kg/ha observed over four years from erosion plots on 4°-8° slope, cultivated to maize in Ife Area (see Jeje, 1987). This essentially indicates that the high intensity of erosion in the study area and which as shown on table 4, is more chemical than mechanical.

With a mean of $26.8 m^3km^{-2}yr^{-1}$, the denudation rate in the forested basins was significantly less than in the farmed basins with values ranging from $13.2 m^3km^{-2}yr^{-1}$ to $9.04 m^3km^{-2}yr^{-1}$ and a mean of $41.35 m^3km^{-2}yr^{-1}$. The value of denudation rate in the forested basins compare favourably with that of $21.1 m^3km^{-2}yr^{-1}$ obtained by Douglas (1967 a & b) in the Cameron Hills of Malaysia while that of the farmed basins is by far less than the value of $103.1 m^3km^{-2}yr^{-1}$ observed by Douglas in the deforested catchment of his study area.

*Interrelationship Between Sediment Yield, Physiographic Attributes and Runoff in the Basins*

Table 5, shows the correlation coefficients of the relationships between total suspended, specific suspended, total solute and specific solute load on the one hand and basin topographic and physiographic attributes on the other. The coefficients show that total suspended sediment yield correlates positively and significantly with relief ratio, weakly with % farmland cover and negatively with % forest cover. Total solute load correlates significantly and positively with basin area, weakly with % forest cover and negatively with drainage density, % farmland and specific runoff. Specific suspended sediment yield shows no clear trend with any parameter while specific solute load correlates positively and significantly only with drainage density and negatively but weakly with area.

Multiple regression analysis (table 6 and equations i and ii) confirms the importance of the influence of relief in suspended sediment production in all the basins, while only basin area appears to significantly affect the production of solute load in all the basins.

$$SY = 2679.2+33.4x+20.6x_1+110.0x_2-0.20x_3-23.4x_4-25.2x_5+0.1x_6 \quad \ldots\ldots\ldots\ldots \text{i}$$

$$SSY = 6033.682+2.32x-1.34x_1+125.72x_2-0.196x_3-56.46x_4-57.8x_5+0.099x_6 \quad ..\text{ii}$$

SY = Solute Load Yield
SSY = Suspended Sediment Yield
$x$ = Basin Area
$x_1$ = Drainage Density
$x_2$ = Relief Ratio
$x_3$ = Rainfall
$x_4$ = % Forest Cover
$x_5$ = % Farm Cover
$x_6$ = Total Annual Runoff

In all, the seven parameters in equation (i) explain about 80% of variance of the total solute load production from the drainage basins while these parameters (in equation ii) explain about 90% of the variance of the total suspended sediment yield in the drainage basins (table 6).

The above observations contrast significantly with those made by Ogunkoya & Jeje (1987) in some third order upper Owena Basins, in which sediment load shows no relationship with % forest cover or farmlands, but mainly with the total annual runoff.

Given the aforementioned relationships, it appears that both chemical and mechanical denudation in the study

TABLE 5 - Correlation between sediment yield and some basin physiographic attributes

| | Area | Drainage Density | Relief Ratio | Rainfall | % Forest Cover | % Farmland | Total Annual Runoff | Specific Runoff |
|---|---|---|---|---|---|---|---|---|
| Suspended Sed. Yield | –0.370 | –0.243 | +0.585* | –0.344 | –0.344 | +0.433 | –0.063 | +0.086 |
| Solute Yield | +0.770* | –0.424: | +0.084 | +0.355 | +0.404 | –0.404 | –0.016 | –0.458. |
| Specific Sus. Sed. Yield | –0.370 | +0.431 | –0.058 | –0.332 | –0.343 | +0.343 | –0.124 | +0.305 |
| Specific Solute Yield | –0.330 | +0.612* | +0.133 | –0.266 | –0.053 | +0.053 | –0.150 | +0.071 |

* Significant at 0.5%.

TABLE 6 - Multiple Regression

| Solute Load | Coef. | Std. Err. | t | P>/t/ | (95% Conf. Interval) | |
|---|---|---|---|---|---|---|
| area | 33.44517 | 10.44251 | 3.203 | 0.033 | 4.452121 | 62.43822 |
| ddkm | 20.6135 | 13.53164 | 1.523 | 0.202 | –16.95636 | 58.18336 |
| rh | 110.1496 | 86.01193 | 1.281 | 0.270 | –128.6578 | 348.957 |
| rainfall | –.2019154 | .2527156 | –0.799 | 0.469 | –.9035665 | .4997356 |
| forest | –23.36417 | 67.53981 | –0.346 | 0.747 | –210.8847 | 164.1564 |
| farm | –25.20104 | 69.74089 | –0.361 | 0.736 | –218.8328 | 168.4307 |
| runoff | .1035534 | .1653795 | 0.626 | 0.565 | –.3556137 | .5627205 |
| cons | 2679.238 | 7255.824 | 0.369 | 0.731 | –17466.16 | 22824.64 |

Number of obs = 12; F ( 7, 4) = 2.24; Prob > F = 0.2280; R-squared = 0.7964; Adj R-squared = 0.4401; Roof MSE = 28.506.

| Suspended Sediment | Coef. | Std. Err. | t | P>/t/ | (95% Conf. Interval) | |
|---|---|---|---|---|---|---|
| area | 2.318531 | 3.105468 | 0.747 | 0.497 | –6.303631 | 10.94069 |
| ddkm | –1.345869 | 4.024137 | –0.334 | 0.755 | –12.51866 | 9.826927 |
| rh | 125.7188 | 25.57885 | 4.915 | 0.008 | 54.70052 | 196.737 |
| rainfall | –.1962104 | .0751544 | –2.611 | 0.059 | –.4048724 | .0124517 |
| forest | –56.46129 | 20.08547 | –2.811 | 0.048 | –112.2275 | –.6950726 |
| farm | –57.87459 | 20.74005 | –2.790 | 0.049 | –115.4582 | –.2909863 |
| runoff | .0985948 | .0491818 | 2.005 | 0.115 | –.0379556 | .2351453 |
| cons | 6033.682 | 2157.789 | 2.796 | 0.049 | 42.69838 | 12024.67 |

Number of obs = 12; F (7, 4) = 4.98; Prob > F = 0.0700; R-squared = 0.8970; Adj R-squared = 0.7168; Root MSE = 8.4773.

area are controlled by the steep slopes, high local relief, basin area, drainage density and landuse/vegetal cover.

## DISCUSSION

Contrary to accepted wisdom and expectations, values of specific runoff from the forest covered basins exceeded those from the farmed basins. This phenomenon was also observed from erosion plots in Ife Area where the forest plot produced more runoff than the maize plot towards the end of the rainy season in 1980, and between July and September in 1982 (Jeje & Agu, 1982; Jeje, 1987). This was attributed to the generation of large saturated overland-flow which occurred in the plot following persistently heavy and prolonged rainstorms. The situation in the current study area is probably due to the large volume of surface runoff produced from the bare rock surfaces under the forest as from June till the end of the rainy season.

The lower yield of suspended sediment load from the forested basins relative to the farmed basins is to be expected. Although runoff generation under the forest is particularly favoured on hill crests and steep slopes where outcrops of quartzite are common, according to Ogunkoya & Adejuwon (1990) such runoff contains little material in suspension or solution. By June/July when the rains are well established, such local surface flows coalesce on the steep slopes to produce significant channel runoff in the basins. Thus denudation in the forested basins is mainly chemical.

As already observed (see Jeje, 1981), under the old fallows and in most of the degraded forests, a high percentage of the rain water still infiltrate (see table 2) into the regolith rock system especially where the latter are highly fissured. Quartzite being mainly composed of quartz is relatively insoluble, however, the deeply weathered associated quartz-schist series are susceptible to leaching. This susceptibility of schists to chemical erosion and the high rates of subsurface water movement in the associated highly fissured rocks may give rise to high solute yield particularly where the basin geology is dominated more by quartz-schist than quartzites (see Ogunkoya & Jede, 1987; Ogunkoya & Adejuwon, 1990; Oluwatimilehin, 1991). Also rain water can leach nutrient ions from the clay humus complex in the upper soil layer which are subsequently transferred either vertically downwards to form hardpans in the quartzite rubbles or laterally into the adjacent stream channels by throughflow and interflow. Either or both from the soils or/and the rocks, solute flushing is particularly pronounced when the rains are well established particularly June to September when most of the streams transport the highest concentration of solute load (fig. 2). Even at this period, the highest concentration of solute and suspended loads in the forested basin channels was in association with intense, but rare rainstorms associated with $Q_1$ discharges. Apparently, the larger the basin area, the higher the solute load that can be produced from such basins unlike in the farmed basins where it is the pattern of fertilizer application that determine the volume of solute load production.

Despite the low runoff coefficient, most of the mechanical erosion in the study area takes place in the cultivated basins especially on the steep valley and hillslopes cultivated exclusively to rice. As aforementioned, the crop is now cultivated frequently with very short fallow periods, and the application of superphosphate, nitrate of ammonia and sulphate of ammonia at about 100 kg/ha/year. Land preparation for rice cultivation involves clearing and burning of the thicket in the dry season with the consequent exposure of large areas of steep slopes to intense thunderstorms at the onset of the rainy season. As is well known, burning reduces the binding effectiveness of the colloidal materials on the inorganic fractions in the top soil, and with repeated burning on the farmlands, clay and humus colloids in the top soil may be deffloculated. The molecules become mobile and can be moved down rapidly either by slope wash or by near surface throughflow into the streams especially by the highly erosive thunderstorms. With the slow rate of replacement of organic matter into the soil due to short fallows, continuous leaching can lead to high level of acidity in the soil. With a fairly high level of acidication, clay further decomposes and could be subject to mass transfer either by percolating water or by nearsurface through flow. The upper soil horizon thus tends to be relatively rich in coarse particles and poor in clay (cf Kutiel & *alii*, 1995; Abraham & *alii*, 1995).

With the exposure of the soils to the high intensity thunderstorms at the onset of the rainy season, splash erosion by rain drop impact is highly erosive even in the coarse textured upper slope soils. As rice is characteristically cultivated from the hillcrest to the stream channel, and grown in separate stands about 0.3m apart and often clean weeded, these can facilitate splash induced downslope movement of soil aggregates right to the valley floors especially in April to June before the rice fields achieve >70% foliage coverage, and after September when the crop is harvested. Sheet, rill and occasional gully erosion are common on the lower slope segments underlain by the silty hilldrift soils. Channel erosion by basal undercutting where the stream channels are exposed is also significant.

Notwithstanding that on the average, these farmed basins produced higher loads of suspended sediment relative to the forest covered basins, the former also produced relatively large solute loads derived from the leaching of fertilizer residues from the farms. Generally the larger the percentage basin area farmed, the higher the solute load produced. Thus, not susprisingly, the two basins - Oni and Okun in which some elements of large scale mechanized agriculture involving the use of tractors and heavy application of fertilizers produced the highest ratio of solute to suspended load of 14.8 and 15.9 respectively. Most of the solute load as of the study time appeared to have been derived from the scores of bags of fertilizers abandoned in the farms. Also, it is not surprising that the solute loads of all the six basins in the farmland were dominated by $NO^{-}_{3}$ and $PO^{--}_{4}$ (Oluwatimilehin, 1991).

Perhaps a major source of solutes in all the streams in the study area is human induced pollution as all the streams are used in one form or another by the local populace for bathing and launderingwhich can increase the solute load of the streams (e.g. phosphate from detergent and soap). Other sources of pollution are related to oil palm and locust bean processing along some of streams. Both the liquid and solid wastes from these activities constitute major pollutants which apart from affecting the biological oxygen demand (BOD), can also raise the level of total dissolved solids (TDS), total suspended solids (TSS), oil and grease and the organic nitrogen content of the receiving streams e.g. Okun and Olorigbo. The presence of human settlements and the wastes generated in some of the basins is also vital in increasing the level of both suspended and solute loads in the stream channels e.g. Oni River.

With the total specific sediment load higher from the farmed than the forested basins, it is to be expected that the mean denudation rate in the former will be higher than in the latter. Also the steady increase in suspended sediment yield and the incidence of high flood peak discharges associated with the farmed basins will have implications for the development of channel patterns in these basins.

## CONCLUSION

As shown in this study, spatial variations in geomorphological processes are noticable particularly where anthropologically induced environmental changes are prevalent.

Although the drainage basins studied are too few and the study time too short to permit any firm conclusion, it appears that the case study presented here shows that with the transformation of a dry rainforest into farmland and fallows, the geomorphological processes prevalent in the forest may undergo considerable changes. Thus through flow, interflow and baseflowleaching and chemical denudation which constitute the major drainage and erosional processes under the forest may be superseded by overland flow, splash erosion, sheetwash, rilling and even gullying in the farmlands. These latter processes appear to have led to higher specific sediment yield from the farmed than the forested basins. Thus with mean values of soil loss from the forested basins at 223 kg/ha, and 363 kg/ha from the farmed basins, the mean denudation rate in the latter is about 1.5 times the former.

## REFERENCES


ABRAHAM A.D., PARSONS A.J. & WAINZIGHT J. (1995) - *Effects of Vegetation Change on Interrill, Runoff and Erosin, Walnut Gulch, Southern Arizona.* Geomorphology, 13, 37-48.

A.S.C.E. (1975) - *Task Committee: Sediment Sources and Sediment Yields.* Proceed. A.S.C.E. Journ. Hydraulics, Eiv 96, (HYb), 1283-1329.

CHORLEY R.J., SCHUMM S.A. & SUGDEN D.E. (1984) - *Geomorphology.* Methuen, London, 607 pp.

DAVISJ S.N. & DE WIEST R.J.M. (1966) - *Hydrogeology.* Wiley, New York, 463 pp.

DAURA M.M. (1995) - *Comparative Analysis of Runoff, Soil and Nutrient Loss Under Different Cropping Systems.* Unpublished Ph.D Thesis, University of Ibadan, Ibadan, Nigeria.

DOUGLAS I. (1967a) - *Natural and Man Made Erosion in the Humid Tropics of Australia, Malaysia and Singapore.* In: *Symposium on River Morphology*, General Assembly of Bern.

DOUGLAS A. (1967b) - *Man, Vegetation and the Sediment Yield of Rivers.* Nature 215, 925-928.

GREGORY K.J. & WALLING D.E. (1971) - *Field Measurements in Drainage Basin.* Geography, 56 (4), 277-292.

GREGORY K.J. & WALLING D.E. (1973) - *Drainage Basin, Form and Processes; A Geomorphological Approach*. Arnold, London, 458 pp.

JEJE L.K. (1981) - *A Preliminary Investigation into soil erosion on cultivated hillsides in parts of Western Nigeria*. Dynamique Dans Les Regions Inter Tropicale, Press Universitaries du Zaire, 175-188

JEJE L.K. (1987) - *Runoff and Soil Loss from Erosion Plots in Ife Area of South Western Nigeria*. In: Gardner V. (ed.), *International Geomorphology*, Wiley, New York, 459-472.

JEJE L.K. (1989) *Landscape Evolution in the Humid Tropics and Implications for Land Resources Evaluation*. Inaugural Lecture Series 81, Obafemi Awalowo University, 66 pp.

JEJE L.K. & AGU A. (1982) - *Runoff and soil loss from erosion plot in Ife Area of South Western Nigeria*. Geo-Eco-Trop, 6 (3), 161-181.

JEJE L.K. & AGU A. (1990) - *Runoff from bounded plots in Alakowe in Southwestern Nigeria*. Applied Geogr., 10, 63-74.

JEJE L.K., OGUNKOYA O.O. & OLUWATIMILEHIN J.M. (1991) - *Variations in suspended sediment concentration during storm periods in three small streams in upper Osun Catchment, Central Southwestern Nigeria*. Hydrological Processes, 5, 361-9.

JEJE L.K., OGUNKOYA O.O. & UYI, O.E. (1986) - *Subsurface flow from a forested slope in the Ife Area of South Western Nigeria*. Hydrological Sc. Journ., 31 (4), 489-499.

KIRKBY M.J. (1969) - *Infiltration, Throughflow and Overland Flow*. In: Chorley R.J. (ed.), *Water, Earth and Man*, London.

KUTIEL P., LAVEE H., SEGEV M. & BENYAMINI Y. (1995) - *The effect of Fire-induced surface heterogeneity on rainfall-runoff-erosion relationships in an eastern mediterranean ecosystem, Israel*. Catena, 25, 77-87.

KOWAL J. (1970) - *The hydrology of a small catchment basin of Samaru, Nigeria: Assessment of soil erosion under varied land management and vegetation cover*. Nigerian Agric. Journ., 7, 134-147.

MEYBECK M. (1976) - *Total mineral dissolved transported by world major rivers*. Hydrological Sc. Bull., 21 (2), 265-285.

OGUNKOYA O.O. & ADEJUWON J.O. (1990) - *Water chemistry of some rivers draining the Basement Complex in Southwestern Nigeria*. Rev. Hydrobiol. Tropicale, 23, 1, 3-10.

OGUNKOYA O.O. & JEJE L.K. (1987) - *Sediment yteld from some third order basins on the basement complex rocks in South Western Nigeria*. Catena, 14 (5), 383-397.

OLUWATIMILEHIN J.M. (1991) - *Sediment dynamics in some streams on Quartzites in Central Southwestern Nigeria*. Unpublished Ph.D Thesis, Obafemi Awolowo University, Ile-Ife, Nigeria, 258 pp.

SLAYMAKER O. (1975) - *Sediment yield in unglaciated alpine and tropical low to moderate relief rainforest environments*. Dynamical Geomorphology in Tropical Regions, 113-130.

SMYTH A.J. & MONTGOMERY R.F. (1962) - *Soils and Landuse in Central Western Nigeria*. Government Printer, Ibadan.

WALLING D.E. (1971) - *Sediment dynamics of small instrumental catchments in S.E. Devon*. Trans. Devonshire Ass., 103, 147-165.