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 11 2004

CHANNEL EROSION IN THE OPA BASIN, SOUTHWESTERN NIGERIA

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This study examines the relationship between topographic attributes and channel sediment yield in nineteen 1st order, five 2nd order, one 3rd order and one 4th order river basin under different land use/vegetation surfaces in the Opa basin, southwestern Nigeria. The study basins were monitored for one year with emphasis on channel specific sediment yield. The results showed that the mean channel sediment yield obtained from 1st order basins in built-up areas, cultivated field crops, cocoa dominated (perennial crops) and degraded forests were 23.09, 10.94, 8.78, and 7.10 t/km^2/yr, respectively. The mean channel sediment yield obtained for 2nd order, 3rd order, 4th order and 5th order channels, were 17.11 t/yr (17.69 t/km^2/yr), 22.30 t/yr (14.86 t/km^2/yr), 481.94 t/yr (18.19 t/km^2/yr) and 1727.41 t/yr (25.40 t/km^2/yr), respectively. Channel specific sediment yield (SSY) was negatively correlated with basin area (A) and stream length (L) with r-values of –0.601 and –0.606 at a = 0.05. However, relative relief (H-h) and relief ratio (R_h) correlated positively with the channel specific sediment yield. Also, all the land use/vegetation attributes except percent built-up area were negatively related to the rate of sediment yield. In fact, the percent built-up area was positively correlated with SSY (r = 0.659 at a =0.05). The result of the stepwise regression analysis showed that only basin area was included in the equation obtained for the study basins. It accounted for about 40.9 percent of the total variance in the channel specific sediment yield of the streams. The equation obtained for channel specific sediment yield could be used for predicting the rate of channel erosion in an area under similar geology, climate, land use, and vegetation.

INTRODUCTION

Sediment yield in a drainage basin represents the sum total of the processes of erosion, transportation and deposition operating in that basin (Walling, 1983). Fluvial sediment erosion in drainage basins focuses mainly on two major zones: slopes and river-channels. Onsite areas are subject to soil creep and other mass movements, sheet wash, rilling, piping and gully erosion, while river channels, which are produced by concentrated flow of water, are normally subject to stream bank erosion and channel bed scouring (Roechl, 1962; Hadley et al. 1984).

Several published studies exist on sediment yield from various land use surfaces based on the use of erosion plots and some third order stream basins in southwestern Nigeria (e.g. Lal, 1976; Jeje, 1977, 1987, 1999; Ogunkoya, 1980; Oyegun, 1980; Jeje and Agu, 1982; Ogunkoya and Jeje, 1987; Oluwatimilehin, 1991; Mala, 1995; Jeje et al. 1989). While some of these studies focused solely on the relationship between channel erosion and basin topographic attributes (Ogunkoya, 1980; Ogunkoya and Jeje, 1987; Oluwatimilehin, 1991; Jeje et al., 1991), others focused mainly on the relationship between channel erosion and basin vegetation/land use characteristics (Jeje, 1999). Thus, there are no known studies that focused on the combined relationship between channel erosion and basin topographic/land use and vegetation attributes from small basins, especially 1st and 2nd order streams, in this part of the world. These 1st and 2nd order basins are ideal for the study of hydrologic response pattern because they are relatively small and have homogenous physiographic and land use/vegetation attributes. More importantly, they can respond very quickly to rainfall events in form of stormflow as well as to drought in sparsely vegetated areas (e.g. urbanized catchments). Thus, this study will attempt to examine the relationship between channel sediment yield and basin topographic/land use attributes based on selected 1st, 2nd, 3rd, 4th and 5th order streams from the Opa Basin. This will further contribute to a clearer understanding of aspects of sediment dynamics from small stream basins under different topographic/land use /vegetation types.

STUDY AREA

The Opa Basin, which extends from the junction of the Opa river with the Shasha river to Osu in the Atakumosa Local Government area, constitutes the study area. The area covers about 125 km^2 and lies between latitudes 7^{o}25'N, and 7^{o}35'N, and longitudes 4^{o}25'E and 4^{o}40'E (Figure 1) (Federal Survey Topographical Sheets, Ilesha S.W. 243 and Ondo N.W. 263). The 1st and 2nd order streams selected for this study are the tributaries of Ogbe, Mokuro, Akankan, Obubu (Amuta) and Opa rivers (see Figure 1). The drainage density of the study area is 2.07 km^{-1} and stream frequency (Sf) is 2.45. The Opa channel, which is a fifth order stream segment, is produced by the convergence of the Obubu, Opa and Mokuro streams. Generally, most of the streams are narrow and shallow. The reservoir on the Opa River had a total impounded volume of 2.81 million m^3 of water on completion (Capital Project and Development Unit, OAU, Ile-Ife).

The natural vegetation of the area was tropical rain forest characterized by emergents with multiple canopy layers and lianas. However, the widespread and persistent practice of rotational bush farming, coupled with widespread cultivation of cash crops such as cocoa (*Cacao theobroma*), kolanuts (*Acuminata nitida*), oil palm (*Elaeis guineensis*), etc. has led to the destruction of the original vegetation. In fact, as shown in Figure 2, most of the area is under perennial crops (cocoa, kola, oil palm, etc.) and cultivated field crops (e.g. cassava, cocoyam, maize and yam).

The study area is classified as koppen's A_f humid tropical climate. The mean daily minimum temperature is 25 ^{o}C while the mean maximum is 33 ^{o}C (Adejuwon and Jeje, 1975). Mean annual

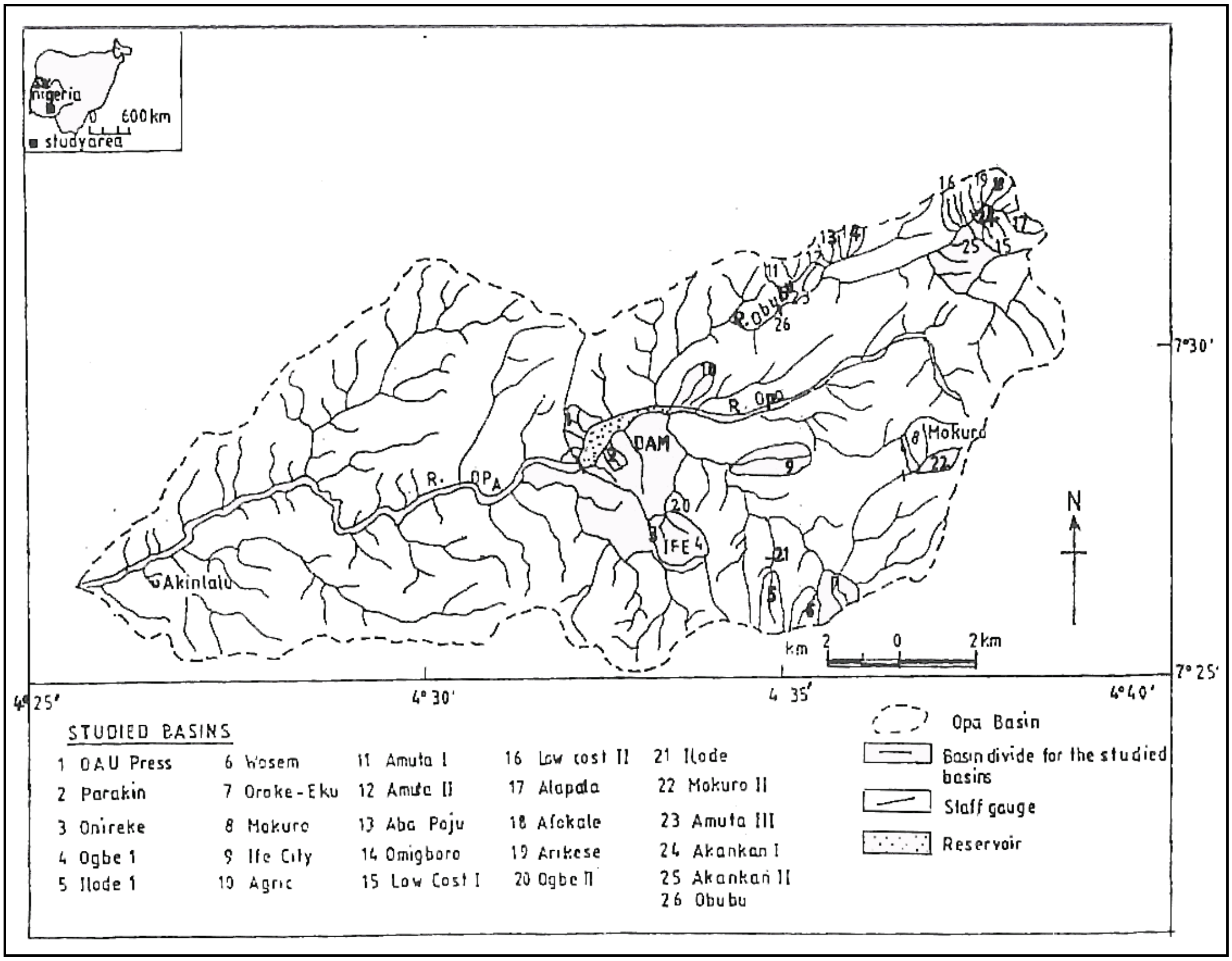

Figure 1. The study area and the studied basins in Opa reservoir catchment.

rainfall is about 1400 mm with the rainy season extending from April to October. The rainy season is marked by two maxima, one in June/July and the other in September/October. These two periods are separated by a short dry spell in August. The onset and the end of the rainy season are usually marked by high intensity thunderstorms.

STUDY METHOD

The Opa stream upstream of the Obafemi Awolowo University reservoir is comprised of 106, 30, 6 and 2, 1st, 2nd and 3rd and 4th order basins, respectively. One-sixth of the order basins upstream of the dam were selected for this study based on the land use/vegetation in the area. In addition, one out of the two 4th order basins was also selected. Thus, nineteen 1st order, five 2nd order, one 3rd order and one 4th order river basin representative of land use/vegetation in the Opa Reservoir Catchment (study area) were studied. The land use/vegetation types were analyzed from SPOT images using ILWIS 3.0 software which showed that non-vegetated and vegetated area covered 11.6 % and 86.5% of the study area, respectively. Based on the analysis of land use, which showed the vegetated area as the dominant land use in the area, about 25% of the selected 1st order basins (4) were from non-vegetated (built-up/bare surfaces) while about 75% (15) were from vegetated (cocoa, cultivated field and forested) surface. Also, two 2nd order basins were selected from non-vegetated surfaces while three were selected from agricultural and other vegetated surfaces. The studied basins were selected based on land use because it has been shown by several authors that vegetation/land use greatly

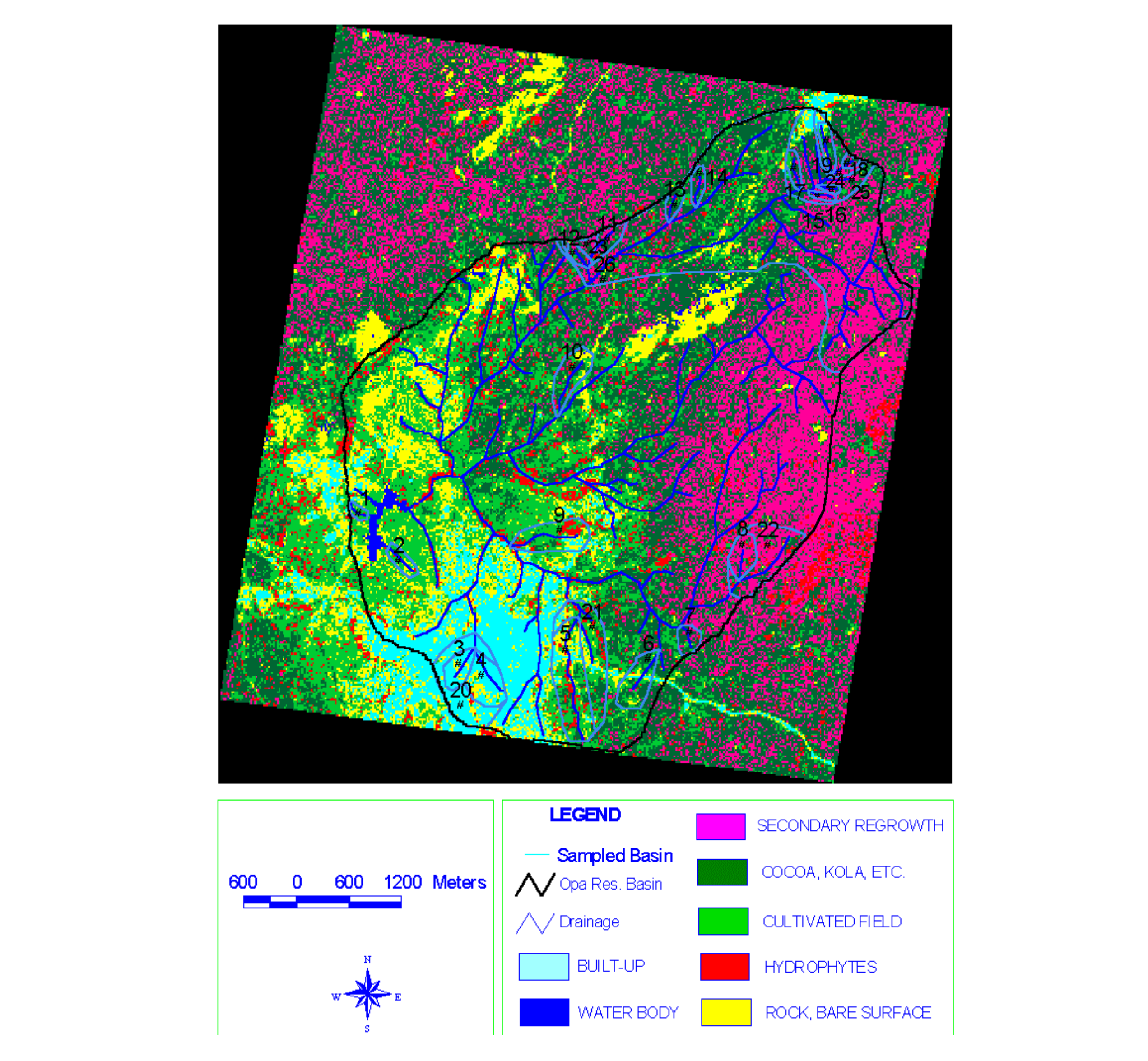

Figure 2. Classification of SPOT-XS sub-scene of the study area.

influences sediment yield from rivers (e.g. Ogunkoya, 1980; Oluwatimilehin, 1991; and Jeje, 1999).

The land use/vegetation map of the study area was compiled from SPOT images (SPOTXS IFE IMG) obtained from Regional Centre for Training in Aerospace Surveys (RECTAS), OAU, Ile-Ife. Land uses were analyzed from SPOT images (1420 by 1420 pixels) based on color, texture, shape and size using ILWIS 3.0 software (International Institute for Aerospace Survey and Earth Sciences, the Netherlands, 1997). The proportion of land use/vegetation in each of the sampled basins was determined using ILWIS software with 0.01 level of precision. The value of land use area obtained (in m^2) using ILWIS software were subsequently converted to km^2.

Basin morphometric attributes such as area (A), drainage density (Dd), relative relief (H-h), relief ratio (R_h) and stream length (L) were determined from 1:50,000 topographic maps of the study area as they have been shown to influence sediment yield of rivers in many parts of the world (see Doornkamp and King, 1971; Gregory and Walling, 1973; Ogunkoya and Jeje, 1987; Jeje, 1999). The topographic maps used in this study were corrected following the methods suggested by Morisawa

(1957) and Morgan (1971). Thereafter, the drainage network of the corrected maps was then ordered using Strahler's method. Subsequently, the basins of the selected rivers were delimited and attributes of the studied basins determined following the method outlined by Gregory and Walling (1973). Details of the procedures involved are documented elsewhere (Adediji, 2002).

All the selected streams were gauged using staff gauges to monitor change in water level from the studied basins during the study period (between June, 1999 and June, 2000). The staff gauge reading was observed twice a day, in the morning (around 7:30 am) and in the evening (around 5:30 pm). The daily average readings of the staff gauge were obtained for all the studied streams. Streamflow discharge was determined using velocity-area technique, with the streamflow velocity measured with a Valeport BFM 002 current meter with an accuracy of ±2.5%. This was carried out based on a wide range of observed stage levels.

Daily sampling of water for suspended sediment concentration determination and sampling of storm runoff that occurred during the day were undertaken during the study period for each of the studied basins. Rating curves were derived for each stream to obtain sediment concentration for discharges for which sampling was not done. Thus, the rating curve technique was used to convert the streamflow discharge (l/s) to suspended sediment concentration (mg/l) (see Miller 1961; Walling, 1977).

The water samples taken during the streamflow discharge measurement were analyzed for suspended sediment concentration using standard laboratory method (see Davis and De Wiest, 1966). Determination of suspended sediments involved the filtration of each 200 ml streamwater sample using Whatman Glass Fibre Circles (GFC) and a vacuum pump assembly, oven drying, cooling in a dessicator and weighing the sediment residue together with filter paper. The weight of the filter paper was subsequently subtracted to determine the weight of the residue expressed in mg/l. The data obtained in this study were log-transformed before they were subjected to both bivariate and multivariate statistical analyses. The data on basins topographic and land use/vegetation attributes were subjected to factor analysis in order to remove multicollinearity in the data before they were further subjected to stepwise regression.

Table 1: Merged Classes of Land Use/Vegetation Types

Classes	Percentage (%) of the Study Area	Areal Extent (Km^2)
Built-Up	8.46	5.75
Cocoa, Kola, Oil palm, etc.	38.81	26.39
Cultivated Field/Fallow vegetation	23.73	16.14
Hydrophytes	3.73	2.54
Rock Outcrop/Bare Surface	2.84	1.93
Sec Regrowth/Relict forest	20.29	13.80
Water-Body/Reservoir	0.19	0.13
Non Classified point (Reject)	1.95	1.33
Total	100.00	68.0

Source: Analysis of SPOT images of the area

Table 2. Areal Extent of Land Use/Vegetation in the Studied Basins

Sample No.	Basin	Order	Areal Extent (km^2)						
			Built Up	Rock/ bare surface	Cocoa, Kola,Etc.	Cultivatedfield fallow veg.	Sec. Regrowth	Hydrophytes	Waterbody
1.	OAUPRESS	1	-	0.0281(9.38)	-	0.2391(79.69)	-	0.0281(9.38)	0.0047(1.56)
2.	Parakin	1	0.0049(1.4)	0.0686(19.6)	0.0189(5.4)	0.2436(69.60)	-	0.014(4.0)	
3.	Onireke	1	0.215(86.0)	0.034(13.60)	-	0.001(0.40)	-	-	-
4.	Ogbe I	1	0.3686(76.79)	0.0943(19.64)	-	-	-	0.0054(1.12)	-
5.	Ilode I	1	0.0640(9.84)	0.1337(20.57)	0.0960(14.89)	0.2629(40.45)	0.0025(0.39)	0.0902(13.88)	-
6.	WOSEM	1	0.0194(4.21)	0.0478(10.40)	0.2231(48.51)	0.1560(33.91)	0.0069(1.49)	0.0069(1.49)	-
7.	Oroke-Eku	1	-	0.0059(1.17)	0.2895(57.89)	0.0848(16.96)	0.0994(19.88)	0.0205(4.09)	-
8.	Mokuro I	1	-	-	0.0714(28.57)	0.0055(2.20)	0.1566(62.64)	0.0165(6.59)	-
9.	Ife City	1	0.0506(8.44)	0.0886(14.76)	0.0527(8.79)	0.2911(48.51)	-	0.1171(19.51)	-
10.	Agric	1	-	0.0755(13.72)	0.2277(41.40)	0.1687(30.67)	0.0370(6.73)	0.0384(6.98)	0.0028(0.59)
11.	Amuta I	1	-	-	0.1417(56.69)	0.0128(5.10)	0.0908(36.31)	0.0048(1.91)	-
12.	Amuta II	1	-	-	0.1303(46.53)	0.0388(13.86)	0.1053(37.62)	0.0055(1.98)	-
13.	Aba Poju	1	-	-	0.1843(65.83)	0.0490(17.50)	0.0303(10.83)	0.0163(5.83)	-
14.	Omigboro	1	-	-	0.2258(66.42)	0.0482(14.18)	0.0533(15.67)	0.0127(3.73)	-
15.	Low Cost I	1	-	-	0.1206(37.70)	-	0.1994(62.30)	-	-
16.	Low Cost II	1	-	0.0071(2.38)	0.1214(40.48)	0.0071(2.38)	0.1643(54.76)	-	-
17.	Alapata	1	-	0.0103(3.23)	0.17.03(53.23)	0.0774(24.19)	0.0542(16.94)	0.0077(2.42)	-
18.	Afakale	1	-	-	0.2147(63.16)	0.0060(1.75)	0.1193(35.09)	-	-
19.	Arikese	1	0.0395(8.98)	0.0316(7.19)	0.2292(52.10)	0.0817(18.56)	0.0579(13.17)	-	-
20.	Ogbe II	2	1.1682(83.44)	0.1589(11.35)	-	0.023(1.65)	-	0.0171(1.22)	-
21.	Ilode II	2	0.1060(9.38)	0.0705(6.24)	0.2192(19.40)	0.4614(40.83)	0.0090(0.80)	0.1380(12.21)	-
22.	Mokuro II	2	-	0.0032(0.28)	0.3298(28.68)	0.0338(2.94)	0.6968(60.59)	0.0841(7.31)	0.0022(0.19)
23.	Amuta III	2	-	0.0052(0.51)	0.5306(52.02)	0.0799(7.83)	0.3632(35.61)	0.0413(4.05)	-
24.	Akankan I	2	0.0740(7.63)	0.0493(5.08)	0.5138(52.97)	0.1007(10.38)	0.2179(22.46)	0.0144(1.48)	-
25.	Akankan II	3	0.0888(5.92)	0.0758(5.05)	0.7221(48.14)	0.154(10.27)	0.3422(22.81)	0.0152(1.01)	-
26.	Obubu (Amuta)	4	0.2021(0.86)	0.6604(2.81)	11.7406(49.96)	3.0480(12.97)	7.2192(30.72)	0.5852(2.49)	-

Values in bracket are proportion of land use/vegetation in percentage (%)

RESULTS

Land use/Vegetation

Table 1 shows the land use/vegetation types in the study area. As evident from this table, there are great variations in the land use/vegetation types in the study area. Most of the study area was under cocoa dominated farmland and cultivated field crop/fallow vegetation, with both covering 38.81% and 23.73% of the basin areas, respectively (see Table 1). Secondary regrowth including thicket and relicts of high forest as well as hydrophytes along stream channels accounted for 20.29% and 3.73% of the study area, respectively. Also, built-up and rock outcrop/bare surfaces covered 8.46 % and 2.84% of the study area, respectively. The proportions of land use/vegetation types in the selected basins in the study area are shown in Table 2. As shown in Table 2, most of the selected basins are under cocoa dominated (perennial crops) farmland and cultivated field crop/fallow vegetation. Other selected basins were under built-up/bare surfaces.

Channel Erosion

The total channel suspended sediment yield (tonnes) and specific yield of the studied streams are shown in Table 3. As evident from this Table , the specific suspended sediment yield among the 1st order basins ranged from 5.83 t/km^2/yr to 27.66 t/km^2/yr with a mean of 11.38 t/km^2/yr and standard deviation of 4.72 t/km^2/yr. As expected, values of specific sediment yield for basins in the built-up area (Onireke, Ogbe I, Ilode I, and Ife City) were higher than those basins dominated by cultivated field crops (OAUPRESS, Parakin, Agric, and Aba-Poju). Also, the values of total specific sediment yield in the latter basins were generally higher than those obtained from basins dominated by cocoa (perennial crops) (e.g. Mokuro I, Amuta I, Amuta II, Low Cost I and II) (see Table 3).

Specific sediment yield varied between 9.09 t/km2/yr and 26.38 t/km2/yr with a mean of 17.53 t/km^2/yr and standard deviation of 5.67 t/km^2/yr in the 2nd order basins. The values of total sediment yield and specific sediment yield from the basins in the built-up area (Ogbe II and Ilode II) were higher

Table 3. Morphometric Attributes Total Suspended Sediment Yield and Specific Yield of the Studied Basins

Basins	Order	Area (km^2)	Drainage density (D_d) (Km^{-1})	Relative relief (H – h) (m)	Channel length (L) (Km)	Relief ratio (R_h)	Channel sediment yield (t/yr)	Specific sediment yield ($t/km^2/yr$)
OAUPRESS++	1	0.30	3.33	22.87	1.00	0.018	2.15	7.17
Parakin++	1	0.35	3.14	30.49	1.00	0.019	2.96	8.46
Onireke	1	0.25	4.00	22.87	1.00	0.023	6.51	26.04
Ogbe I+	1	0.48	2.50	38.11	1.20	0.027	13.28	27.66
Ilode I+	1	0.65	2.62	30.49	1.70	0.018	12.89	19.83
WOSEM++	1	0.46	2.50	22.87	1.15	0.019	8.75	19.02
Oroke-Eku+++	1	0.50	2.00	22.87	1.00	0.021	3.81	7.62
Mokuro I ++++	1	0.25	1.67	45.73	0.80	0.071	2.09	8.36
Ife City+	1	0.60	2.33	30.49	1.40	0.022	11.30	18.83
Agric.++	1	0.55	2.83	38.11	1.70	0.022	3.48	6.33
Amuta I+++	1	0.25	4.00	22.87	1.00	0.023	2.05	8.20
Amuta II+++	1	0.28	2.14	15.24	0.70	0.020	2.23	7.96
Aba-Poju++	1	0.28	2.68	30.49	0.75	0.020	2.80	10.00
Omigboro+++	1	0.34	2.65	30.49	0.90	0.022	2.95	8.68
Low Cost I++++	1	0.32	2.81	22.87	0.90	0.022	1.87	5.84
LowCost II++++	1	0.30	3.33	15.24	1.00	0.021	1.75	5.83
Alapata++	1	0.32	1.67	22.87	0.80	0.019	2.65	8.28
Afakale++	1	0.34	1.56	30.49	0.90	0.022	3.78	11.12
Arikese++	1	0.44	2.73	38.11	1.20	0.022	4.45	10.11
Ogbe II+	2	1.40	1.73	45.73	2.50	0.027	34.74	24.81
Ilode II+	2	1.13	1.55	30.49	1.75	0.019	29.81	26.38
Mokuro II++++	2	1.15	1.56	68.59	1.80	0.047	11.18	9.72
Amuta II+++	2	1.92	1.32	25.30	1.35	0.017	9.25	9.07
Akankan Ixxx	2	0.97	2.27	38.11	2.20	0.030	17.16	17.69
Akankan IIxxx	3	1.50	3.44	38.11	8.60	0.032	22.30	14.86
Obubu (Amuta)xxx	4	23.50	1.38	70.12	36.30	0.026	481.94	18.19
Opaxxx	5	68.00	2.12	70.12	144.20	0.023	1727.41	25.40

\+ = Built-up Area basin
\++ = Basin covered with fallow and cultivated field crops
\+++ = Cocoa dominated basins
\++++ = Forest basins
xxx = Complex-basins covered with fallow vegetation, cultivated field crops, cocoa as well as built-up

than those from the cultivated basins (e.g. Amuta III and Mokuro II) (see Table 3). Value of specific suspended sediment yield from the 3rd order basin (Akankan II) (14.86 $t/km^2/yr$) in the cocoa dominated part of the study area compared favorably with those obtained by Ogunkoya and Jeje (1987) in some 3rd order basins in Upper Owena in which specific suspended sediment yield ranged from 0.40 $t/km^2/yr$ to 29.5 $t/km^2/yr$. The values of suspended sediment yield obtained for the 4th and 5th order channels (Amuta and Opa) at the point of inlet into the Opa reservoir were 481.94 t/yr (18.19 $t/km^2/yr$) and 1727.41 t/yr (25.40 $t/km^2/yr$), respectively.

Relationship Between Specific Sediment Yield, Channel Suspended Sediment Yield, and Basin Morphometric and Land use/Vegetation Attributes

As evident from Table 4, basin area (A) (X_1) and stream length (L) (X_2) were negatively correlated with the specific sediment yield (Y_1) (SSY) with r-values of –0.601 and –0.606 at $a = 0.05$. However, relative relief (H-h) (X_4) and relief ratio (Rh) (X_5) correlated positively with the specific sediment

Table 4. Correlation Matrix Showing Interrelationship among Topographic/Land Uses Attribute and Hydrological Variables in the Studied Basins

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	Y_1	Y_2
X_1	1.00	0.859*	-0.600*	0.532*	0.066	-0.278	0.030	-0.194	0.130	-0.381	0.057	0.068	-0.601*	0.829*
X_2		1.00	-0.226	0.567*	0.103	-0.363	-0.157	-0.304	0.246	-0.066	0.051	-0.0219	0.606*	0.803*
X_3			1.00	-0.372	-0.271	-0.014	-0.009	-0.153	-0.235	0.549*	-0.045	-0.221	-0.319	-0.411*
X_4				1.00	0.644*	-0.177	-0.148	-0.002	0.191	-0.121	0.134	-0.096	0.449*	0.498*
X_5					1.00	0.057	-0.485*	0.393	0.305	-0.367	-0.030	-0.040	0.175	0.046
X_6						1.00	-0.200	0.256	-0.046	-0.492	0.544*	0.724*	-0.354	-0.428
X_7							1.00	0.411	-0.780*	0.248	0.104	0.650*	-0.287	-0.199
X_8								1.00	-0.661*	-0.598*	-0.168	0.798*	0.275	-0.463*
X_9									1.00	0.136	0.132	0.707*	0.659*	0.610
X_{10}										1.00	-0.058	-0.389	-0.165	0.021
X_{11}											1.00	0.319	-0.180	-0.030
X_{12}												1.00	0.447*	-0.437*
Y_1													1.00	0.796*
Y_2														1.00

n = 26

*significant at a = 0.05

Where X_1 = Basin area (A), X_2 = Total stream length (El), X_3 = Drainage density (Dd), X_4 = Relative relief (H), X_5 = Relief Ratio (Rh), X_6 = % basin area covered by perennial crops (cocoa, kola etc), X_7 = % basin area covered by arable/field crops, X_8 = % basin area covered by fallow/sec. Growth and forest, X_9 = % basin area covered by built-up, X_{10} = % basin area covered by bare surface/rock outcrop, X_{11} = % basin area covered by hydrophytes, X_{12} = % basin area covered by vegetal/crop cover (Vc), Y_1 = specific sediment yield, Y_2 = channel sediment yield.

yield (Y_1). This is to be expected as the parameter Y_1 expresses the rate of sediment yield.

All the land use/vegetation attributes except percent built-up area (X_9) were negatively related to parameter Y_1 (SSY). As expected, the percent built-up area in the basins (X_9) was positively correlated with parameter Y_1 (r = 0.659 at a = 0.05).

Further, as is obvious from Table 4, channel sediment yield correlated significantly, with most of the selected basin morphometric attributes. In fact, sediment yield from the studied streams (Y_2) correlated most significantly with basin area (A) (X_1) (r = 0.829 at $\alpha = 0.05$), thus confirming the findings of Hadley and Schumm (1961) and Walling (1983), who established that drainage area produced the best correlation with sediment yield. In the hierarchy of significance of relationship, basin area is followed by channel length (L) (X_2), relative relief (H-h) (X_4) and drainage density (X_3) with r-values of 0.803, 0.498 and –0.411, respectively. The positive relationship between sediment yield (Y_2) and channel length (L) (X_2) and relative relief (X_4), confirms the findings of Roechl (1962) in the southeastern United States and Gabris (1993) in northeast Hungary. Also, among the land use/vegetation attributes considered in this study, only percent basins area under vegetation/crop cover (X_{12}) was negatively correlated with the channel sediment yield (Y_2) (r = -0.437 at $\alpha = 0.05$) (see Table 4).

Also, the result of the stepwise regression analysis shows that variables X_2 (channel length) (L), X_3 (drainage density) (Dd), X_4 (relative relief) (H-h) and X_1 (basin area) (A) included in the Equation 1 below explained 83.6 % ($r^2 = 0.836$) of the total variance in the channel sediment yield of the studied basins. The result further shows that X_2 (channel length) (L) is the most important predictor of channel sediment yield by accounting for 74.6 % ($r^2 = 0.746$) of the total variance in suspended sediment yield of the streams. This is followed by X_3 (drainage density) (Dd) 8.1%) ($r^2 = 0.0806$), X_1 (basin area) (A) (0. 6%) ($r^2 = 0.006$) and X_4 (relative relief) (H-h) (0.3%) ($r^2 = 0.003$). The predictive equation derived for the channel sediment yield and specific sediment yield are expressed as follows:

Channel sediment yield (SY):

$$\text{Log SY} = 1.047 + 2.266 \text{ Log L} - 0.824 \text{ Log Dd} - 0.124/\text{Log A} - 0.145 \text{Log (H} - \text{h)} \qquad (1)$$

$R^2 = 0.847$, Standard error of estimate = 0.2199.

Specific sediment yield (SSY) = 1.123 $A^{0.218}$

$R^2 = 0.409$, Standard error of estimate = 0.2045

DISCUSSION

As shown in Table 3, the high values of suspended sediment yield in the built-up basins is not unexpected as the built-up areas with their almost bare surfaces and unpaved streets have very low infiltration rates. This enhances the generation of Hortonian overland flow with the potential for sheet erosion.

Also, the suspended sediment yield obtained from basins under cultivated field/arable crops was higher than those obtained from cocoa dominated basins (see Table 3). This is to be expected as the cultivation of field crops such as yam, cassava, maize and other annual crops in these areas involved maximum tillage in the process of making heaps and ridges on hillsides. In the cocoa dominated basins, tree cover and litters tend to minimize the occurrence of overland flow (runoff) and thus reduced surface generation and movement of sediment.

Another important factor that could have reduced the volume of suspended sediment yield in the rivers draining the cocoa dominated part of the study area was the presence of hydrophytes such as bracken ferns (*Pteridium aquilinum*) around the banks of some studied streams (see Figure 2). These tend to act as sediment traps preventing sediment transported by overland flow from reaching the river channels.

As shown in Table 4, the negative correlation between basin area (A) (X_1), total stream length (L) (X_2) and the specific sediment yield (Y_1) confirms the finding of Glymph (1954) and Roechl (1962) that sediment yield is that part of the erosion product which escapes deposition within the basin. Thus, the longer the length of travel of sediment (due to large basin area), the greater the risk of deposition as colluvium or alluvium instead of delivery past the basin mouth. Also, the positive relationship between relative relief (H-h) (X_4) and specific sediment yield (Y_1) ($r = 0.449$ at $\alpha = 0.05$) implies that the greater the relief, the greater the transporting capacity of overland flow/runoff and thus the greater the rate of sediment supply to stream channels. However, according to Ogunkoya (1980) soil erodibility and soil infiltration capacity coupled with the nature of vegetation may be more important in explaining variations in the rate of sediment yield among basins. In fact, the poor correlation between relief ratio (R_h) (X_5) and channel sediment yield (Y_2) ($r = 0.046$) (see Table 4), further support this suggestion. In addition, the positive correlation between percent basin area under built-up (X_9) and rate of sediment yield (Y_1) shows that the greater the percent built-up basin area, the greater the transport capacity of runoff on slopes and the greater the sediment supply to the stream channels.

The negatively significant relationship between drainage density (Dd) and channel suspended sediment yield (Y_2) (see Table 4) may be attributed to decreasing slopes and channel gradient and increasing opportunities for deposition associated with basin size (Walling, 1983). Also, the negative correlation between percent basin area under vegetation/crop cover (X_{12}) and channel sediment yield obtained in this study shows that the greater the percent basin area under crop cover (X_{12}), the less the runoff generated from such surfaces, and the less the amount of material transported to the stream channels, and thus the less the sediment yield from the streams.

CONCLUSION

This study, which focused on the topographic parameters of channel erosion (channel sediment yield), was based on nineteen 1st order, five 2nd order, one 3rd order and one 4th order river basin in the Opa basin, southwestern Nigeria. The results showed that the mean channel suspended sediment yields obtained in the built-up area, cultivated field crops, cocoa dominated and forested 1st order basins were 23.09 t/km^2/yr, 10.94 t/km^2/yr, 8.78 t/km^2/yr and 7.10 t/km^2/yr, respectively. The relatively high suspended sediment yield obtained from the streams in the built-up part of the study area may be connected with the fact that many streets and premises in the town are bare and unpaved. Such surfaces enhanced runoff and soil erosion in the built-up area. The channel suspended sediment yield obtained for the 2nd, 3rd, 4th, and 5th order channels in the study area were 17.11 t/yr (17. 69 t/km^2/yr), 22.30 t/yr (14.86 t/km^2/yr), 481.94 t/yr (18.19 t/km^2/yr) and 1727.41 t/yr (25.40 t/km^2/yr) respectively. The highest total sediment yield obtained from the 5th order Opa River at its point of inlet into the reservoir was not surprising because substantial material/sediment was discharged during storm events into the river by its tributaries, especially the Ogbe River that drains the Oja-Titun part of the Ile-Ife built-up area.

Channel suspended sediment yield (SY) correlates significantly with most of the basin attributes examined in this study. In fact, channel sediment yield (SY) is strongly correlated with basin area (A) and channel length (L) with r-values of 0.829 and 0.803, respectively. Also, the channel specific sediment yield was negatively correlated with basin area and stream length with r values of - 0.601 and –0.606. The stepwise regression analysis showed that basin area was the most important predictor of channel specific sediment yield in the studied basins. It accounted for about 40.9% of the total variance in specific yield obtained for the streams. Equations obtained for specific sediment yield can be used to predict the rate of channel erosion in an area under similar climate, geology, topography, land use and vegetation.

ACKNOWLEDGMENT

I wish to acknowledge the comments of Profs. Ekanade and Adesina in the Department of Geography, Obafemi Awolowo University, Ile-Ife, Nigeria on the draft paper.

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