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Influence of Catchment Characteristics on Gully Erosion: A Case Study of River Odo, South-Eastern Nigeria.

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Abstract: Gully erosion is responsible for significant soil loss from catchment area. Vast areas in Odo catchment are dissected by gullies, thus contributing to downstream sedimentation resulting in siltation of River Odo within the area. A study was undertaken to study the influence of the catchment characteristics on gully erosion in River Odo catchment. Three sub-catchment areas (Agulu, Nanka and Oko) were sampled and studied. The lemniscates ratio (ratio of square of maximum length and four times the area of the catchment) was lowest (1.60) for Agulu sub-catchment followed by Oko sub-catchment (2.08) and Nanka sub-catchment (2.37). The form factor, ratio of the average width and maximum length of the catchment was highest in Agulu sub-catchment (0.32), followed by Oko sub-catchment (0.27) and Nanka sub-catchment (0.18). The lower value of lemniscates ratio indicates a more compact shape of the catchment and hence more soil erosion. A large value of form factor is associated with more erosion hazard because of more compactness of the catchment. The average slope of the sub-catchment varied from 5.380 to 8.110. The average slope of the Agulu sub-catchments is also the highest of the three sub-catchments. Catchment shape and slope are the characteristics which determine the pattern and severity of gully erosion in the area. The gully density (length of gullies per unit area) varied from 0.94 to 1.34 km km-2 whereas gully texture (number of first order gullies per unit area) varied from 54 to 98 km-2 in the three sub-catchments.

Key words: catchment, gully erosion, slope, characteristics

Introduction

Gully erosion is one of the most conspicuous forms of accelerated erosion, which occurs in widely different climatic, geologic and land use conditions (Toy et al 2002,Valentin et al 2005). It has been a serious environmental problem in Nigeria especially in Southeastern Nigeria. It accelerates the loss of soil and decreases the productivity of agricultural land (Capira et al 2002). Eroded sediments are often transported into the receiving streams causing water quality problems and negatively impacting on biological process. Many methods now exist to estimate erosional load of a territory and transport of suspended material. They have been described in different review article and manual (vente and poesen 2005, Merritt et al, 2003). Many researchers have studied soil erosion in parts of Southeastern Nigeria (Obiadi et al.2011, Osadabe et al 2014).

Quite often expensive gully control measures fail in the region due to lack of proper knowledge about the behavior and patterns of gullies over time and space. Detailed information regarding where and when gullies form in the landscape and how their position, frequency of occurrence is affected by catchment characteristics viz., size, shape, topography etc (Hunter 2005, Verstraeten & Poesen. 2001) is therefore a prerequisite for successful soil conservation program in the area. Consequently, a gully erosion study was undertaken in River Odo catchment (Agulu-Nanka-Oko gully complex); Southeastern Nigeria to study the gully patterns in relation to catchment characteristics.

Study area

The study was conducted in Agulu-Nanka-Oko area within River Odo catchment of Southeastern Nigeria. The area is located between latitudes 6^0 $10^/$ and 6^0 $05^/$ North of Equator and longitudes 7^0 $05^/$ and 7^0 $10^/$ East of Greenwich Meridian on the topographical map, Udi sheet 301 S.W (Fig.1 and 2). The topography of Southeastern Nigeria is dominated by north-south trending Enugu cuesta or escarpment stretching from Okaba (Benue State), through Enugu to Arochukwu. This escarpment forms the major watershed between the lower Niger drainage system to the west and the Cross River and Imo drainage systems to the east.

The Awka-Orlu upland, another outstanding geomorphic feature trends roughly northwest–southeast with an east facing scarp slope overlooking the plains of the Mamu River. The upland or cuesta stretches from the northwest in Abagana via Agulu/Nanka area to

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Umuduru in the southwest of Okigwe. Gullies and ravines of variable shapes and dimensions characterize the easterly facing scarp slopes of these escarpments.

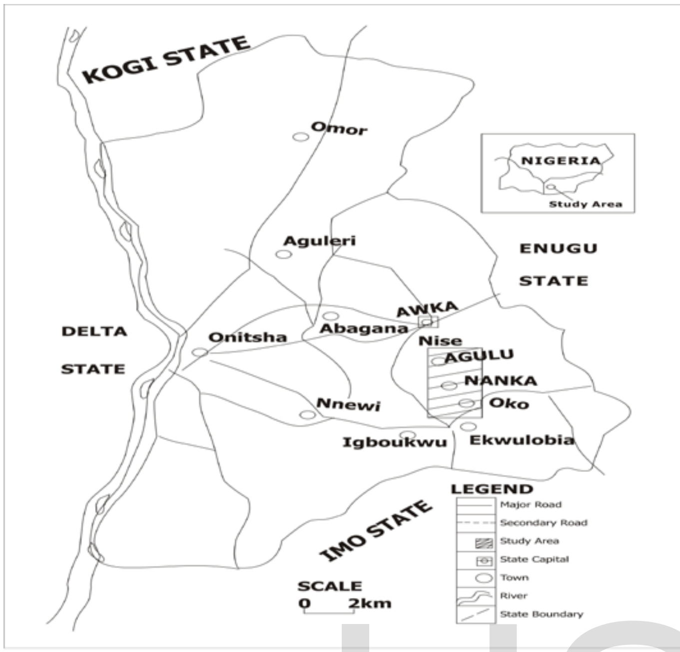

Fig 1. Location of the study Area

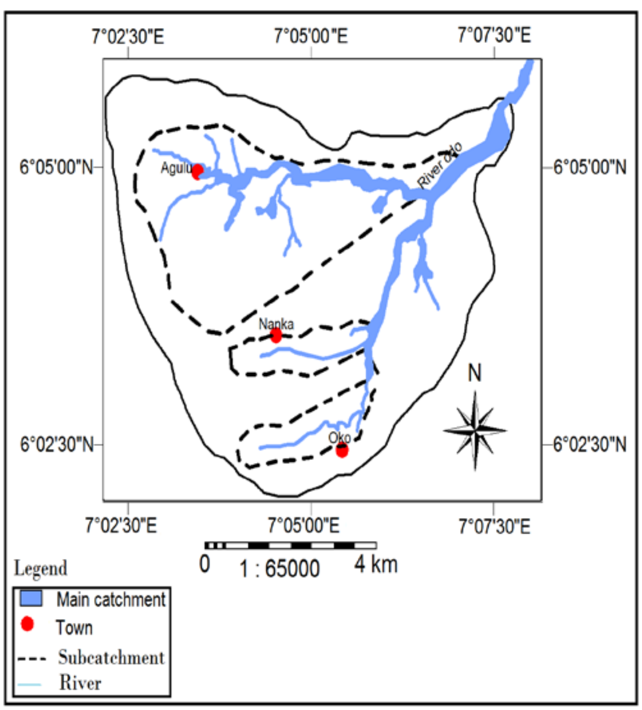

FIGURE 2 :ODO CATCHMENT MAP SHOWING THE STUDY AREA

Materials and Methods

Three sub-catchments (Agulu, Nanka and Oko) differing in shape and size were selected in South-eastern Nigeria. A detailed field survey for gully erosion was carried out in these sub-catchments. The area, length and width measurements using planimetre were recorded to calculate the values of various shape indices viz. lemniscates ratio and form factor.

Digital topographic data for the study area were obtained by digitizing 15m interval contour lines of topographical map, Udi sheet 301 S.W on 1:50,000 scale using ArcView 4.0 software. The digitized map (Fig. 3) was used to create the digital elevation model (DEM) of the study area using minimum curvature grid system (Fig.4) in a GIS Surfer 7.1 environment. The resulting DEM was processed using ArcView to derive the slope map which shows the slope angles in the study area. The DEM was created from a grid mesh size of 50m.

In creating the DEM, the digitized map was geographically referenced to the Universal Transverse Mercator (UTM) and altitude coordinates, so that points from any data source having the same geographic location also have the same (x,y) position in the digital database. These georeferenced data were used in computing the distances and elevations to generate the xyz coordinates, which were used to create the DEM in 3-D. At each point, the program computed x and y coordinates, horizontal distances, cumulative distances and elevation (z)

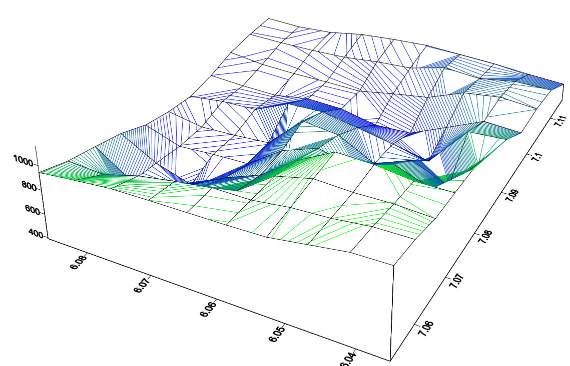

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Fig3.Digitalized Elevation model of the study Area (krigin grid system)

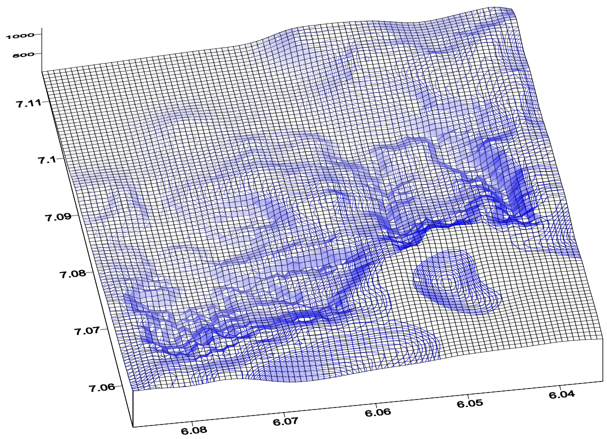

Fig 4. Digitalized Elevation of the study Area (minimum curvature grid system) in a NNE-SSW orientation.

RESULTS AND DISCUSSIONS

Catchment Characteristics

The catchment characteristics are presented in Table 1. The lemniscates ratio (ratio of square of maximum length and four times the area of the catchment) was lowest (1.60) for Agulu sub-catchment followed by Oko sub-catchment (2.08) and Nanka sub-catchment (2.37). The lower value of lemniscates ratio indicates a more compact shape of the sub-catchment and hence more soil erosion. This is because of the less time of concentration for the runoff in compact catchments compared to oblong catchment. Similar trends were indicated by the form factor (ratio of the average width and maximum length of the catchment) which was highest in Agulu sub-catchment (0.32), followed by Oko sub-catchment (0.27) and Nanka sub-catchment (0.18). A large value of form factor is associated with more erosion hazard because of more compactness of the catchment (Kukal and Matharu, 2002). The two shape indices indicate that based on shape, Agulu sub-catchment was most prone to gully erosion followed by Oko and Nanka sub-catchments.

Similarly, the average slope of Agulu sub-catchment was highest (8.11^{0}) followed by that of Oko sub-catchment (7.79^{0}) and Nanka sub-catchment (5.38^{0}). A high slope degree increases the velocity of the runoff that causes high soil loss (Von Blanckenburg,2005, Descroix et al 2002, Trimble et al, 2000) inferred that a high slope degree is responsible for the increase of runoff and for the tendency to flow concentration. With steeper slopes, the runoff velocity increases and hastens the process of detachment and transportation of soil particles. The Agulu sub-catchment also was the least in size (1.36km^2), followed by Oko (2.65km^2) and Nanka (3.08km^2). Similar trends were indicated by the total slope length, which was least in Agulu sub-catchment ($2.56x10^3$m), followed by Oko sub-catchment ($4.29x10^3$m) and Nanka sub-catchment ($5.62x10^3$m). (NRCS 2003) identified slope angle and slope length as important factors affecting hill slope erosion. However, (Castillo et al 2003) observed that a lengthy slope contributes to increase in amount of surface runoff and its velocity.

Table 2 shows the gully characteristics in the Agulu, Nanka and Oko sub-catchment areas. The gully density (length of gullies per unit area) varied from 0.94 to 1.34 km km^{-2} whereas gully texture (number of first order gullies per unit area) varied from 54 to 98 km^{-2} in the three sub-catchments. Both the gully density and gully texture are highest in Agulu sub-catchment followed by Oko and Nanka sub-catchments. However, Agulu sub-catchment was expected to have the highest values of gully density and gully texture due to its compact shape, and greatest average slope steepness.

Gully formation is largely controlled by the generation of a sufficient volume of runoff and by a sufficient level of relief energy which depends on the slope gradient (Merritt et al 2003). Vente and Poesen (2005) indicated that the landscape positions where gullies start are more controlled by slope gradient.

CONCLUSION

Majority of these gullies are the main runoff collecting channels thus aiding in runoff production. Gullies in the area are definitely a function of catchment characteristics. Catchment shape and slope are the characteristics which determine the pattern and severity of gully erosion in the area. With steeper slopes, runoff velocity increases and hastens the process of detachment and transportation of soil particles. Valentin et al, (2005) inferred that a high slope degree is responsible for the increase of runoff and for the tendency to flow concentration. Since steep slopes are likely to result in the initiation of more gullies in the area, priority should be given in the protection of the slope. Catchments that are more

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compact in shape are more associated with more erosion hazard (Kukal and Matharu, 2002). This is because of the less time of concentration for the runoff in compact catchments compared to oblong catchment (Morgan, 2005).

Consequently, there must be proper understanding of the nature of slope, slope steepness and catchment shape best suited for effective gully control. In addition, information on terrain variables, especially slope gradient, that contribute to runoff velocity and concentration within the catchment should be identified for effective gully control.

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Table 1: Characteristics of the Agulu, Nanka and Oko sub-catchments

	Average values		
Catchment characteristics	**Agulu**	**Nanka**	**Oko**
Area (km^2)	1.36	3.08	2.65
Average width ($x10^3$m)	0.77	0.92	1.23
Maximum length ($x10^3$m)	2.44	5.00	4.52
Average slope (degree)	8.11	5.38	7.79
Maximum slope angle (degree)	11.3	16.7	16.7

Total slope length ($x10^3$m)	2.56	5.62	4.29
Maximum slope height ($x10^3$m)	0.30	0.80	0.65
Lemniscate ratio $\left(\frac{L^2 max}{4A}\right)$	1.60	2.37	2.08
Form factor (width-length ratio) $\left(W/L\right)$	0.32	0.18	0.27

Table 2: Gully characteristics in the Agulu, Nanka and Oko sub catchments

Average values			
Gully characteristics	**Agulu**	**Nanka**	**Oko**
Density (km km^{-2})	98	54	76
Texture (No km^{-2})	1.34	1.08	0.94
Area (km^2)	0.24	1.22	1.25
Maximum length ($x10^3$m)	1.32	2.60	2.92
Top width ($x10^3$m)	0.18	0.42	0.45
Maximum depth ($x10^3$m)	0.02	0.06	0.07

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