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MORPHOMETRIC AND HYDRAULIC GEOMETRY ASSESSMENT OF A GULLY IN SE NIGERIA

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ABSTRACT

Gully erosion represents one of the most devastating form of land degradation in the Sedimentary Formations underlying south eastern Nigeria leading to both onsite and off- site adverse effects on the environment. In this paper, a surveyed section of a second-order gully located in Uyo, Akwa Ibom State, SE Nigeria is analyzed. Along the gully, 20 cross-sections were established and measured with a Rover GNSS and the Base GNSS. The sections were located at variable distances, placing them in areas where active erosion was evident. In total, 19 field measurements were carried out, and the geometric characteristics of 19 cross-sections were obtained. Morphometric analyses were carried out in 421m surveyed Udo Inwang segment of the 860m long main gully. The results indicated that Udo Inwang gully was a mature gully, measured gully depth varied from 1.1m to 29m, while the shoulder or top width ranged from 26m to 98m. It is worth noting that the bed width is typically narrow ranging from 4m to 33m wide. The cross-sectional profiles were indicative of U-shape to V- shape, all with very narrow bed width and steeply sloping gully sides, which are feature of gullies developed on very loose and incoherent soils that slumps/collapses on exposure. The total volume of soil lost from the watersheds was 480,376.26m3, which translated to 18,593.64 tons/ha and the average rate of soil loss has appeared to be 476.76 ton/ ha /year. The annual average growth rate of the gully length was 22m/year. Hence, the average growth rate of gullies in the study watershed with 22 m/ year-1 laid under catastrophic or destructive type of gully erosion.

KEYWORDS: Gully Morphometric analysis GIS, Downstream hydraulic geometry, gully cross sections

INTRODUCTION

Soil and parent materials are usually removed by gully erosion and severe on-site effects take place: loss of soil nutrients and organic matter, breakdown of soil structure, soil moisture reduction, decrease in vegetation cover and overall land degradation leading to reduced crop yields. Gullies also function as sediment sources, stores, and conveyors that link hillslopes to downstream channels. Hence, gullies represent a link between upland areas and river networks, which allows a rapid water and sediment transport into lowland river systems producing off-site effects such as water pollution, flooding, reduction of dam's lifespan, and changes in river morphology (Moges and Holden, 2008; Frankl, (2012); Vijith, 2019). Poesen, (2003) noted that gullies contribute to the total sediment yield increases with the size of the considered study area, varying from10% to 95%. In the fluvially dissected landscape of Akwa Ibom State, studies on sediment loss from gully channels are few despite the interplay of natural predisposing factors such as high precipitation rates in recent years (as recorded in 2012 (see Udosen,2017), weak and loosely packed soils, steep valley-side slopes fringing water courses, and anthropogenic forces which interact to trigger erosion processes. This is made worse by absence of regulations/enforcement by government agencies on the cultivation/building around gully prone valley slopes. There is therefore the need to estimate soil loss from gully erosion due to its downstream effects on stream morphology/water quality.

The Study Area The study area is located in Uyo, Akwa

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Ibom State, SE Nigeria specifically along Udo Inwang Street (Fig.1). The investigated gully is a second order and discontinuous permanent gully incised into the loosely packed Coastal Plains Sands. The main gully and tributary reach have lengths of 860 m and 421m, respectively. The initiation of the main gully might have occurred between 1976 and 1980, while the tributary reach appeared in 1979 (Udosen, 2000). Important land use changes took place in the study area in the 1990s due to an increased demographic pressure accompanying the creation of Akwa Ibom State. More specifically, drastic extension of the gully took place when the land use within the catchment was dedicated to urban expansion and the vegetation cover was reduced. During the period 1979–2016, the appearance of several headcuts was also observed within the main gully and tributary reach, probably due to urban expansion. The climate of the study area belongs to the Af Koppen class, i.e. humid tropical. The mean annual temperature is approximately 27 °C, ranging from a minimum of 22oC to over 33oC. There are two distinct seasons viz; four dry months (Nov.-Feb./ March and eight to nine wet months (March/April -October). Average annual rainfall for 43years (1977 – 2020 is 2566.0mm. Variability in the yearly amount of rainfall is evident with 3837.9mm in 2012 being the highest and 1,599.4mm in 1983, the lowest Udosen, 2017).

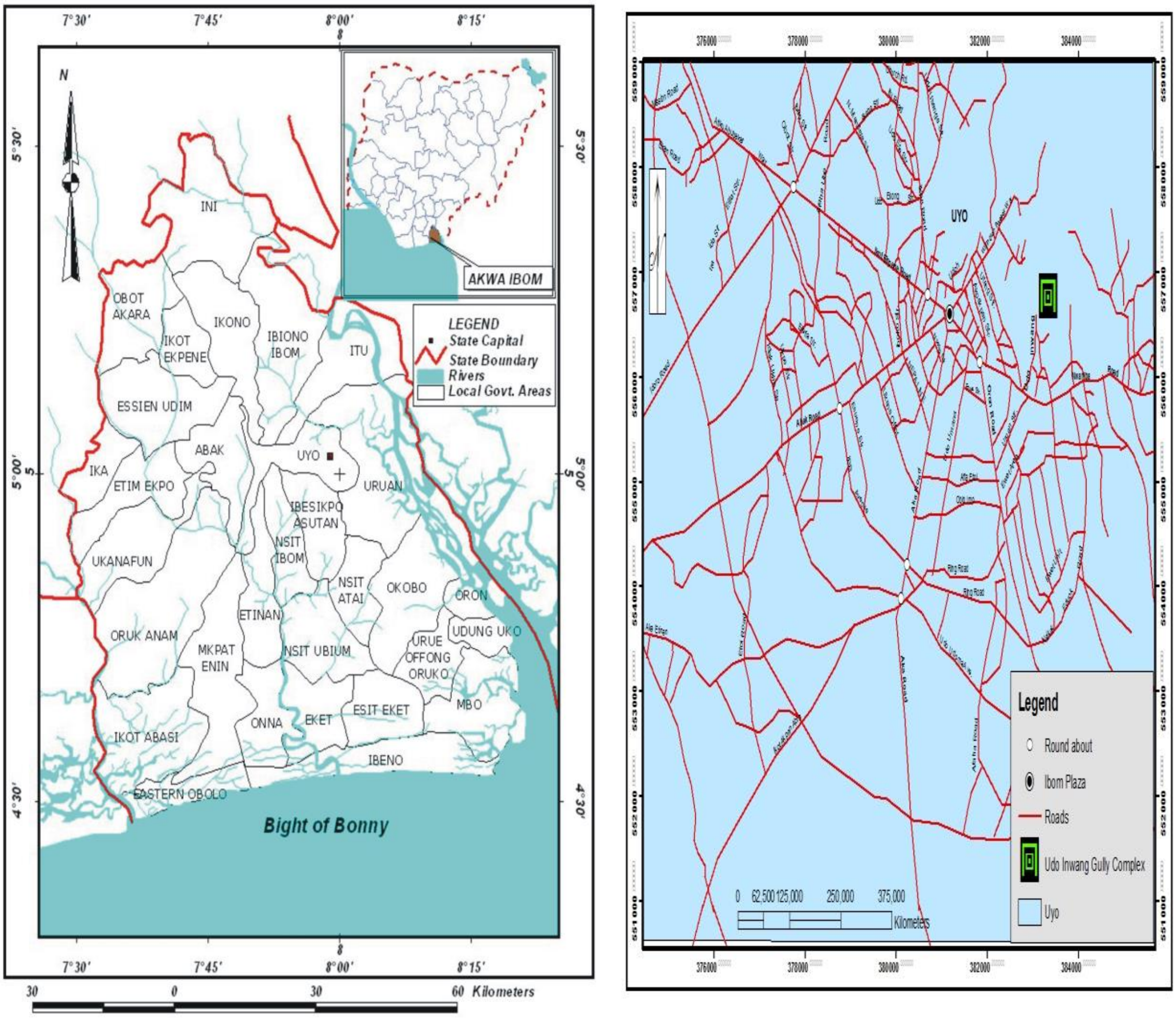

Fig. 1: Location of Udo Inwang gully Complex in Uyo, Akwa Ibom State

MATERIALS AND METHODS

Field surveys Measurements of gully morphology and hydraulic variables were carried out in April 2021. In the field, the DGNSS was set over one of the existing controls BM 2, temporary adjustments were carried out, then the following procedures in their order of execution were carried out;

I. The Base GNSS was switched on, and was made to track the satellite for a period of about 45 minutes using its antenna.

II. The data logger was used to interface the Rover GNSS with the Base GNSS.

III. After all setups and configurations were completed, the Rover was ready to be used for collecting points. Random spot heights were acquired across the entire gully area.

The capture was done first along the gully shoulders before descending into the gully bed to continue acquiring spot heights for the full description of the gully section. A total of 254 points were captured to describe in finer detail the Udo Inwang gully channel up to a length of 421m for the open section, the full length spanning a total distance of about 860m along the open section.

The data from the field work was processed (after filtering for outliers in excel) in a 3D modelling environment (Golden surfer package) to yield a fine-grained digital terrain model of the gully section by IDW (Inverse Distance Weighing) interpolation. A 3D surface was also developed from the result to simulate the 3d morphology of the gully section (see below) Along the gully, 20 cross sections were individuated. The cross sections were monitored using the survey instrument. Each field survey allowed the reconstruction of the geometric characteristics of 20 cross-sections by measuring width w, depth h, cross-sectional area High Resolution satellite imagery from google earth was also incorporated in to the mapping procedure in ArcGIS. This allowed us to examine the distribution of the spot heights on the ground and understand where profile cross-sections are to be ran in order to characterize the gully morphology. The imagery provided a base to map other ancillary data such as roads and critical infrastructure in the vicinity of the study area by vectorization and map compilation in the ArcGIS environment.

Calculation of Volume of Soil loss. In order to calculate the volume of soil loss from the surveyed gully channel, Field Office Technical Guide/ FOTG (2002) formula of soil loss estimation was used as stated in the equations 1&2 below;

V = L x {Wt +Wh}/2 x Df ……….. Equation (1)

Where L = the total length in meter
Wt = the average top width in meter
Wb = the average bottom width in meter
Df = the average depth measured in meter
V = the displaced volume in cubic meter

To convert this calculated volume to a weight of soil lost over time ones/year) equation 2 was used.

E = {V x W/1000}x Y x N ………… Equation [2]

Where E = the soil loss in tons per year
V = the volume in cubic meter calculated above
W = the average weight of soil in kilogram per cubic meter (Bulk density)
1000 = the weight in kilogram per tone
Y = the numbers of years the gully has been active
N = the number of similar classic gullies

The other important element on gully dynamics assessment is the soil bulk density, which was obtained from earlier work in the watersheds. According to Udosen (2008) the average soil bulk density of soil of the study watersheds is 0.98g/ cm3.

Data Analyses: The statistical tool SPSS was employed to; [i] establish relationships between gully morphometric properties viz; gully depth, shoulder or top width, bottom width, width/depth ratio etc. [ii] compute correlation matrix and [iii] run a bivariate regression model and validate the regression model.

RESULTS AND DISCUSSION

The entire Udo Inwang and its environs is drained by a first order stream, which is itself a minor tributary of Ikpa River and the morphometric properties of the receiving stream is presented in Table 1.0. The stream is 1.8 km long, 2-6m wide and flows on a fairly steep order-1 stream channel of 3 degrees with a basin/local relief of 79m. It is known locally as Idim Ewet or Idim Ndom. The average velocity of the stream flow was calculated as 1.34 cubic metres/sec. The depth of the stream channel ranges from less than 1.2m to over 3.5m. The stream water is mildly polluted, as indicated by dirty colour of stream water

Table 1: MORPHOMETRIC PROPERTIES OF THE STREAM DRAINING UDO INWANG AND ENVIRONS

STREAM ORDER	STREAM LENGTH (km)	BASIN RELIEF (m)	RELIEF RATIO	STREAM CHANNEL SLOPE (1o}
1st order	1.6 km	79m	0.0494	3o

SOURCE: Computed from Uyo Sheet 1995/1-4. Scale 1:2500

As revealed by satellite image interpretation the gully headscarp is fringed by a hotel, Cardinal Ekanem School and oil palm plantation (Fig.2).

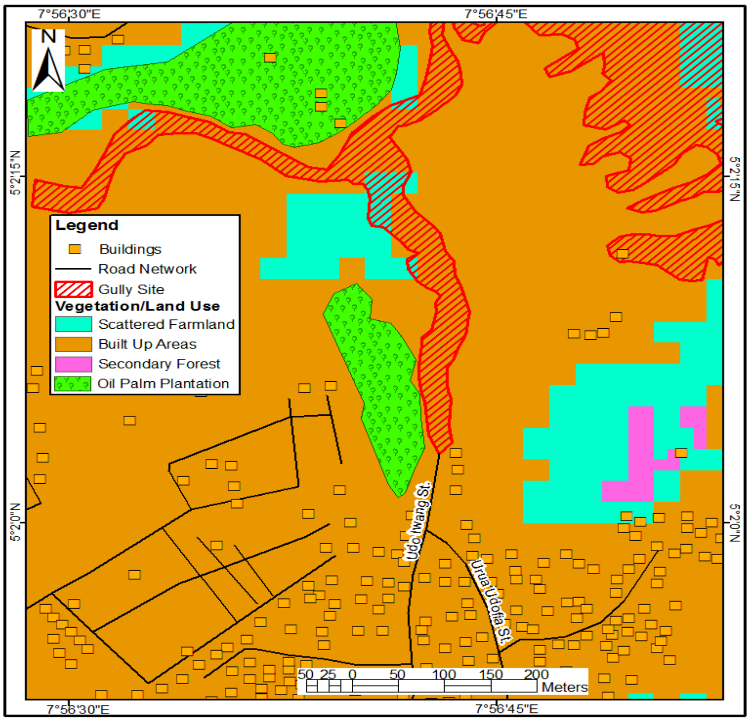

Fig. 2: Facilities around the gully headrim

Gully Morphometry and soil loss

Knowledge on gully morphology is essential to explain the reasons for current erosion and to carry out effective gully stabilization measure (Pathak et al. 2005). Morphological characteristics of gully erosion such as gully depth, shoulder width, bed width, volume of soil loss, shoulder width-depth ratio (cross sectional area) and shoulder width/bedwidth ratio in the watershed are presented in Table 1. The processes of gully expansion at Udo Inwang is through headscarp collapse caused by plunge erosion, side collapse mainly from translational landslides, slumping, sloughing etc (Fig. 3).

Fig. 3 Translational landslides on gully side slopes

The total length of Udo Inwang gully complex as at 2003 was estimated to be 860m, while the surveyed section during field measurement in April 2021 was 421m(Fig.6). Therefore, the annual average growth rate of the gully length was 22m/year. According to (ul Rasool et al. 2011) the gully length growth rate >10m yr-1 is considered as catastrophic type of gully development. Hence, the average growth rate of gullies in the study watershed with 22 m/ year-1 lies under catastrophic or destructive type of gully erosion.

For this study the amount of soil loss was estimated with the formula given by FOTG. According to the FOTG (2002) formula for soil loss estimation (V = L x [(Wt +Wb)/2] x Df) the total volume of soil lost from the watersheds is 480,376.26m3, which translates to 18,593.64 tons/ha and the average rate of soil loss has appeared to be 476.76 ton/ ha /year.

The broadly-loped gully head scarp is barely 30m from Udo Inwang street (Fig.4).

3D SURFACE MODEL OF UDO INWANG GULLY EROSION SITE

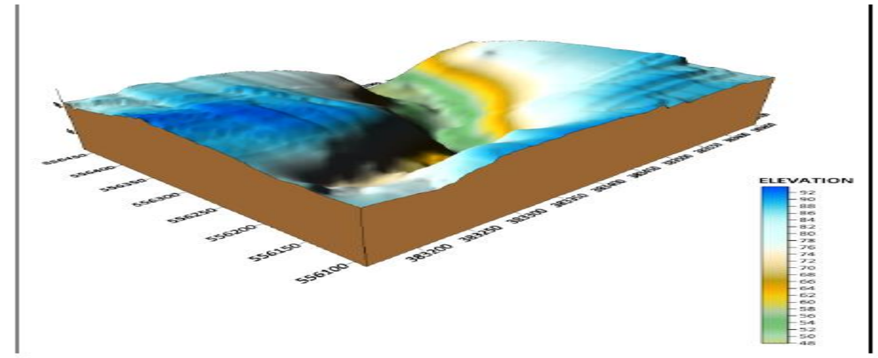

Fig. 4: DEM of Udo Inwang Gully headrim

Most valley slopes in Ewet stream sub-watershed are rectilinear in the middle section, often characterized by upper convexity and a narrow concave segment close to the thalweg line. Exposure of these slopes to direct raindrop impacts following deforestation causes concentration of runoff in the concave segment downslope, which may provoke rapid mass movement of soils and gully retreat upslope. It is known that by removing vegetation cover on the steep valley slopes of Ewet stream, the pattern of runoff generation is drastically changed and this in turn can lead to accelerated erosion manifesting in gullying. Thus, throughflow, interflow and baseflow which probably constituted the major drainage and erosional processes when the slopes were forested prior to unplanned urbanization may be superseded by overland flow, sheet wash and rilling/gullying on these valley-side slopes. As it is now, Udo Inwang gully system has cut down to the water table and is now sustaining stream flow especially during the wet season. It is rapidly extending laterally and headwards through basal sapping related to ground water seepage and channel bank collapse.

Fig. 5: Royal Garden Hotel fringing steep gully edge

One direct consequence of higher sediment delivery ratio is the reported case of dried streams, eg Afaha Oku stream (Udosen, 2000 and 2012).

Gully Morphometry and Cross sections

The geographic coordinates and dimensions of surveyed gully cross-sectional profiles are shown in Fig.6 and Table 2. Measured gully depth varies from 1.1m at profiles no. 10 to 29m at profile no.5, while the shoulder or top width ranges from 26m to 98m. It is worth noting that the bed width is typically narrow ranging from 4m to just 33m wide. the cross sectional profiles ranges from 39 m2 to 2842m2, the widest cross section is barely 120m from the headrim

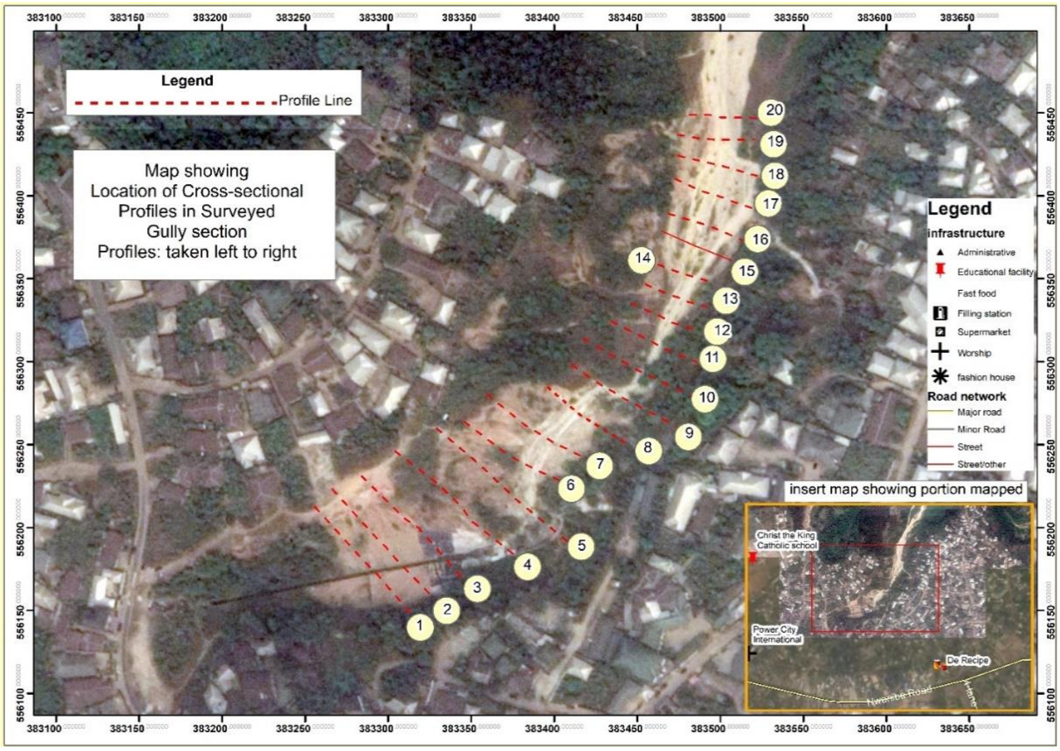

Fig.6: Location of Cross sectional profiles of Udo Inwang gully complex

TABLE 2: MORPHOMETRY OF UDO INWANG GULLY CHANNEL

Latitudes	Longitudes	Depth(m)	Shoulder Width (m)	Bed Width (m)	Shoulder width/ Depth ratio	Shoulder Width/Bed Width Ratio	Cross sectional area (m^2)
5° 1' 52.264" N	7° 56' 49.330" E	17	70	26	4.12	2.69	1190
5° 1' 52.355" N	7° 56' 50.249" E	11.8	65	33	5.5	0.78	767
5° 1' 52.512" N	7° 56' 50.981" E	25	70	10	2.8	7	1750
5° 1' 52.721" N	7° 56' 51.793" E	27	70	23	2.59	3.04	1890
5° 1' 53.044" N	7° 56' 52.453" E	29	98	20	3.37	4.9	2842
5° 1' 53.451" N	7° 56' 52.989" E	22	67	23	3.05	2.91	1474
5° 1' 53.960" N	7° 56' 53.534" E	21	78	14	3.71	5.57	1638
5° 1' 54.487" N	7° 56' 54.010" E	2.2	40	17	18.18	2.35	88
5° 1' 54.724" N	7° 56' 54.717" E	1.4	71	5	59.16	14.2	85.2
5° 1' 54.987" N	7° 56' 55.052" E	1.1	46	8	41.8	5.75	50.6
5° 1' 55.533" N	7° 56' 55.392" E	1.2	34.2	8	28.5	4.27	41.04
5° 1' 55.977" N	7° 56' 55.620" E	1.5	26	7	17.33	3.71	39
5° 1' 56.432" N	7° 56' 55.824" E	2.2	34	4	15.45	8.5	74.8
5° 1' 56.764" N	7° 56' 55.979" E	2	40	18	20	2.22	80
5° 1' 57.248" N	7° 56' 56.160" E	1.5	44.5	34	29.66	1.17	66.75
5° 1' 57.638" N	7° 56' 56.353" E	2.4	50	30	20.83	1.66	120
5° 1' 58.302" N	7° 56' 56.586" E	5	51	23	10.2	2.21	255
5° 1' 58.984" N	7° 56' 56.813" E	1.6	46	14	28.75	3.28	73.6
5° 1' 59.634" N	7° 56' 56.767" E	2	41	20	20.5	2.05	82

SOURCE: Extracted from Field Survey, April, 2021

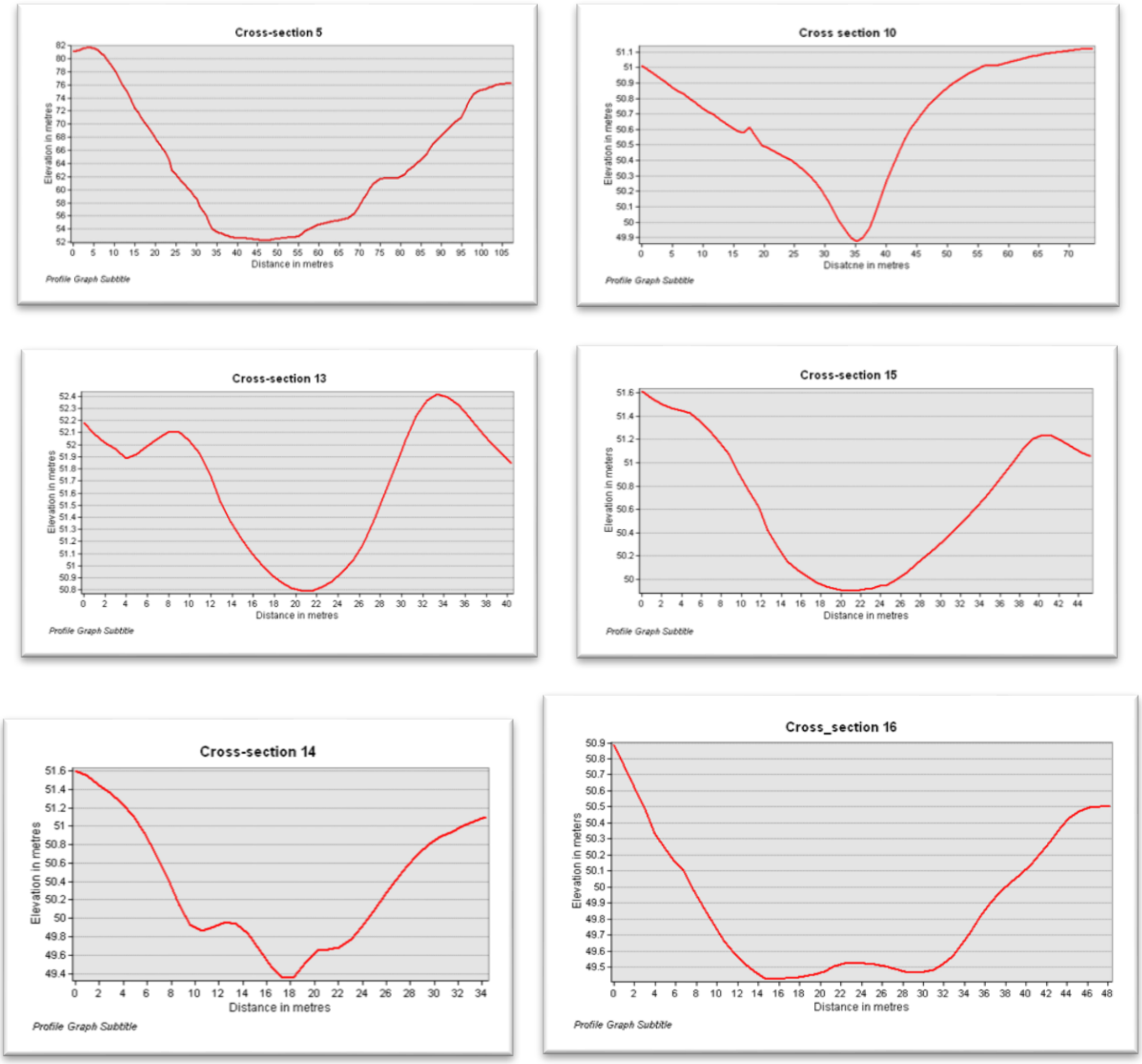

Fig.7: Cross-sectional profiles of the gully channel

The cross-sectional profiles are indicative of V-shape to U- shape, all with very narrow bed width and steeply sloping gully sides, which is feature of gullies developed on very loose and incoherent soils that slumps/collapses on exposure (Fig. 7).

CORRELATION MATRIX

It is evident from Table 3 that out of fifteen possible correlation coefficients, 46.7% are significant at 95% confidence level. the strongest relationship is between gully depth and cross- sectional area (0.98} and is significant at 99% confidence level. The conclusion that can be drawn from the relationship is that the retreat of gully sides take place at rates proportional to the rate of gully deepening (as deep gullies channels in the study area are characterized by translational landslides on exposed gully sides (Figs. 3 and 5). This explains why cross-sectional area also correlates strongly with shoulder width {0.87). However, the relationship between cross sectional area and the adjustments between shoulder width and depth is negative (-0.68) as gully deepening is mainly caused by basal undercutting at headscarp due to plunge pulling effects, while gully sides widening are caused mainly by mass wasting processes. Other significant relationships are between shoulder width/depth ratio and depth (-0.74); shoulder width and depth (0.84); shoulder width/bed width ratio and bed width (-0.74) and shoulder width bed width ratio and the adjustment between top-width and gully depth (0.48).

Table 3; Correlation matrix of Gully morphometric properties

Correlations						
	Depth	SW	BW	SW/D_RATIO	SW/BW_RATIO	CSA
Depth	1	.836**	0.208	-.724**	-0.004	.981**
SW		1	0.243	-0.373	0.217	.870**
BW			1	-0.391	-.739**	0.183
SW/D_RATIO				1	.484*	-.676**
SW/BW_RATIO					1	0.026
CSA						1
**. Correlation is significant at the 0.01 level (2-tailed).						
*. Correlation is significant at the 0.05 level (2-tailed).						

Sequel to the already established strong positive relationships between the gully depth and cross-sectional area, a regression model was employed to validate the strength of the relationships. The regression model, **Y= 80.9 x – 89.705 or Y = X89** (where y and x are gully cross sectional area and gully depths respectively) indicates that gully depth alone accounts for 89% of variance in gully cross-sectional area. in the study area (Fig.8).

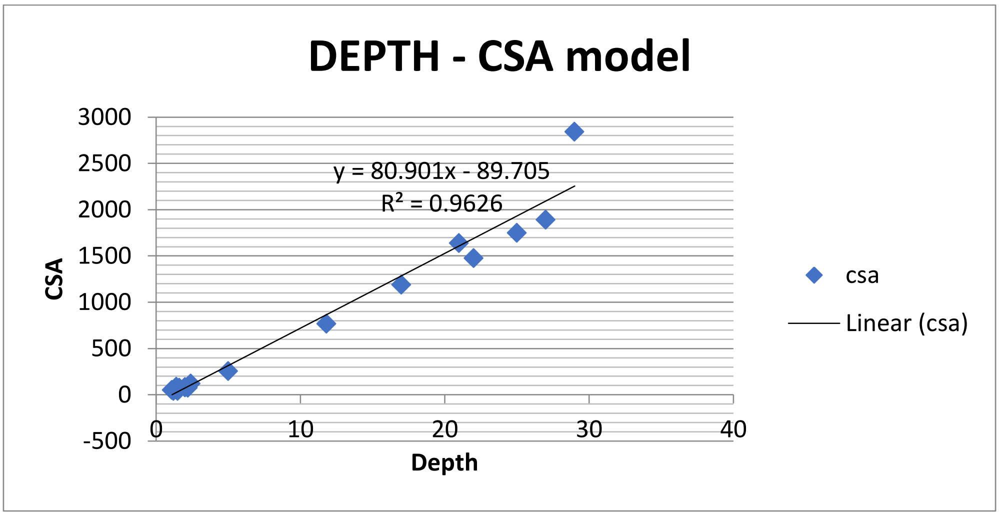

Fig.8: Relationship between gully depth and Cross -sectional area of gully profiles.

CONCLUSION

According to the results, measured gully depth varies from 1.1m at profiles no. 10 to 29m at profile no.5, while the shoulder or top width ranges from 26m to 98m. The bed width is typically narrow ranging from 4m to 33m wide. the cross sectional profiles ranges from 39 m2 to 2842m2, the cross-sectional profiles are indicative of V-shape to U- shape, all with very narrow bedwidth and steeply sloping gully sides, which are features of gullies developed on very loose and incoherent soils that slump/collapse on exposure. The total volume of soil lost from the watersheds is 480,376.26m3, which translates to 18,593.64 tons/ha and the average rate of soil loss appears to be 476.76 ton/ ha /year. The annual average growth rate of the gully length was 22m/year. Hence, the average growth rate of gullies in the study watershed with 22 m/ year-1 lies under catastrophic or destructive type of gully erosion. The correlation between the gully depth and cross- sectional area (0.98} and is significant at 99% confidence level. Hence, the retreat of gully sides take place at rates proportional to the rate of gully deepening (as deep gullies channels enhance the process of translational landslides on exposed gully sides). This explains why cross-sectional area also correlates strongly with shoulder width {0.87). But it can be assumed that this correlation is just a result of an empirical study, which is not applicable to other regions with diverse climate, geology and soils We have proven this fact only for a fluvially dissected landscape in the humid tropical environment of Africa underlain by sedimentary rocks and similar studies is recommended for other regions riddled with gullies.

REFERENCES

Frankl A., 2012. Gully development and its spatio-temporal variability since the late 19th century in the northern Ethiopian highlands. Afrika Focus 25(2)

FOTG 2002. Estimating soil loss from gully erosion. Section1, USA Department of Agriculture Natural Resource Conservation Services. Retrieved from https://efotg.sc.egov.usda.gov/references/public/MO/gully-ephemeral erosion

Moges, A., Holden, N. M., 2008. Estimating the rate and consequences of gully development, a case study of Umbulo catchment in southern Ethiopia. Land Degrad. Dev. 19, 574–586. http://dx.doi.org/10.1002/ldr.871.

Poesen, J., Nachtergaele, J., Verstraeten, G., Valentin, C., 2003. Gully erosion and environmental change: importance and research needs. Catena 50, 91–133. http://dx.doi.org/10.1016/S0341-8162(02)00143-1.

Pathak P, Wani S. P, Sudi R., 2005. Gully control in SAT watersheds. Global theme on agroecosystems report no 15

Udosen, C. E., 2000. “Thresholds of Gully Erosion in the Coastal Plains Sands of Eastern Nigeria: A Case Study of Ikpa River Basin”. Unpublished Ph.D. Dissertation, Department of Geography, University of Ibadan, Oct., 2000.

Udosen C. E., 2008. Gully Erosion in Ikpa River Basin: a threshold phenomenon. Published by Time Communications. Lagos, Nigeria. Pp. 295.

Udosen, C. E., 2012. ‘Digital elevation models as a tool for monitoring and evaluating gully development in a humid tropical environment. ’Online Journal of Earth Sciences, Vol. 6 [2-6] pp6-14 Medwell Journals, Pakistan

Udosen C. E., 2017. ‘’Rainfall Trends in a Humid Tropical Environment. Published by AniHap Resources, Uyo, Nigeria. Pp. 243

ul Rasool I, Khera KL, Gul F., 2011. Proliferation of gully erosion in the submontane Punjab, India Asian J Sci Res 4:287–301

Vijith H, Dodge-Wan D., 2019. Modelling terrain erosion susceptibility of logged and regenerated forested region in northern Borneo through the analytical hierarchy process (AHP) and GIS techniques. Geoenviron Disasters 6(1):8

APPENDIX

Multiple regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.989a	.978	.969	150.60918	.978	114.980	5	13	.000

a. Predictors: (Constant), SW_BW_Ratio, Depth, Bed_width, SW_D_Ratio, Shoulder_width

ANOVAa

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	13040514.614	5	2608102.923	114.980	.000b
	Residual	294880.637	13	22683.126		
	Total	13335395.251	18			

a. Dependent Variable: Cross_Sectional_Area

b. Predictors: (Constant), SW_BW_Ratio, Depth, Bed_width, SW_D_Ratio, Shoulder_width

Coefficientsa

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Correlations		
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part
1	(Constant)	-248.634	168.602		-1.475	.164	-612.877	115.608			
	Depth	59.841	12.097	.726	4.947	.000	33.707	85.975	.981	.808	.204
	Shoulder_width	16.032	5.920	.346	2.708	.018	3.243	28.820	.870	.601	.112
	Bed_width	-17.608	8.554	-.190	-2.058	.060	-36.088	.873	.183	-.496	-.085
	SW_D_Ratio	-.358	5.500	-.006	-.065	.949	-12.241	11.525	-.676	-.018	-.003
	SW_BW_Ratio	-49.847	28.289	-.183	-1.762	.102	-110.961	11.267	.026	-.439	-.073

a. Dependent Variable: Cross_Sectional_Area