FACTORS AND RATE OF GULLY EROSION IN GOMBE TOWN, GOMBE STATE, NIGERIA

Mbaya, L. A.
Department of Geography, Gombe State University, Gombe, Nigeria
E-mail: lazarusambaya@yahoo.com

ABSTRACT

The development of gullies is one of the severe environmental problems in Gombe town. It has threatens urban infrastructure, properties, lives and the physical growth of the town. Knowing the rates of gully development in the last decade helped explain the reasons for current land degradation. This work therefore aimed at assessing gully erosion in Gombe town. Data were derived from field measurements, satellite imageries, and laboratory analysis. Results from the interpretation of Spot 5(1999) and Quick Birds (2009) imageries and field measurements showed that gully variables (length, depth and widths) have significantly increased in the last 10 years. Laboratory analysis of soil particles revealed that the soils are dominated by sand. The values of Atterberg limits (liquid limits; plasticity limit and the plasticity index (PI), shear strength (cohesion and angle of internal friction) and bulk density values were low, soil chemical properties also showed that the soils are moderately acidic, contained low organic matter, and low exchangeable cations, with serious implication on biological methods of erosion control.

Keywords: Gully, erosion, soil properties, Rainfall, Topograhy and Gombe town

INTRODUCTION

The formation of gullies has become one of the greatest environmental disasters facing Gombe town. The town is fast becoming hazardous for human habitation. Hundreds of people are directly affected every year and have to be relocated. Large areas of agricultural land are becoming unsuitable for cultivation as erosion destroys farmlands and lowers agricultural productivity and human settlements. The situation is getting worse annually, since Gombe town assumed the status of Gombe State capital in 1996. The infrastructural development coupled with demographic increase have no doubt heightened the problems of gully erosion in the state capital. People have observed that some small rills, which were crossed with one-footstep have now developed into big gullies and those that have their houses at reasonable distances from such rills some years back are now helplessly observing their houses being collapsed or with exposed foundations. Residents of Gombe town have expressed concern over accelerated erosion rates. These concerns address not only the loss of personal property, but also that gully erosion is causing functional and structural damage to infrastructural facilities such as culvert outlets and roads within the stream channels as well as other public and private structures along the channel. Federal and State Government have attempted to arrest the problem through numerous contracts awarded for gully erosion projects at some key sites in Gombe town. However, the economic practicabilities and engineering control measures have not met people's expectation, owing to lack of adequate information on the topography, soil and geology, rainfall characteristics, catchment areas and landuse patterns of a town experiencing rapid growth. Therefore, solving the gully erosion problem in Gombe town requires concerted research efforts. The main aim of this research was to assess the rate and factors of gully system in the Gombe town.

METHODOLOGY

Gombe town is located between latitudes 10^{o}N to 10^{o}20'N and longitudes 11^{o}01'E and 11^{o}19'E (Fig.1). It shares common boundary with Akko Local Government Area in the South and West; Yamaltu-Deba to the East and Kwami to the North. It is the capital of Gombe State and occupied an area of about 45km^2 (Ministry of Land and Survey, Gombe, 2008). Gombe town is well linked by road to other regional centres like Biu/Maiduguri, Potiskum/Damaturu, Bauchi/Jos and Yola/Jalingo. A single gauge railway line on the Bauchi - Maiduguri route also links the town, in addition to an international airport. The climate of Gombe is characterized by a dry season of six months, alternating with a six months rainy season. As in other parts of the Nigeria Savanna, this precipituos distribution is mainly triggered by a seasonal shift of the Inter -Tropical Convergence Zone (ITCZ). For the years 1977 to 1995, the mean annual precipitation is 835 mm and the mean annual temperature is about 26°C, whereas relative humidity has same pattern being 94% in August and dropping to less than 10% during the harmattan period (Balzerek *et al.*, 2003).

The relief of the town ranges between 650 m in the western part to 370m in eastern parts. Subsequent dissection and stream incision in the area have carved a landscape. The stratigraphy consists of the alluvium, the Kerri Kerri Formation, Gombe Formation, Pindiga Formation, Yolde Formation, Bima Formation and the basement rocks as the oldest (Obaje *et al*, 1999).

Both primary and secondary sources of data were used for this study. Data used in this study were derived from field measurements, satellite imageries (Spot 5 (1999) and Quick Birds (2009) imageries, and laboratory analysis. Three sampled gully profiles were purposively selected for the study. From each gully profiles, a mean of 55 sample points at 100m intervals were delineated for the measurement of gully morphological variables, while soil samples were taking along the gully wall layers (top, middle and bottom) given a total of 36 sample points or 12 samples per gully profiles at 500m interval along the gully profiles. In order to analyze the physical and chemical properties of the soil. GPS Garmin eTtrex H, 30m tape, cone penetrometer and digger were used. Data collected were analyzed using a combination of descriptive and inferential statistical techniques.

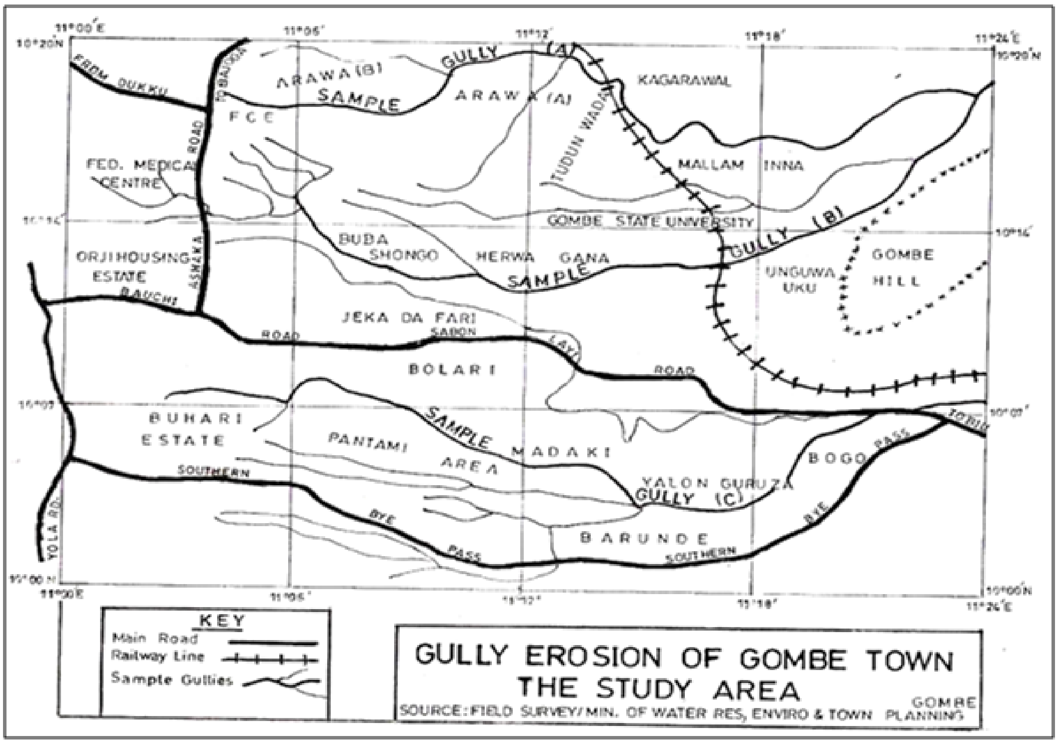


Fig.1: Gully Erosion of the Study Area

RESULTS AND DISCUSSION

Assessing Morphological Characteristics of Gully System of Gombe town: The longitudinal profiles of gully A, B and C are presented in Figure 2 (a, b c). Gully longitudinal profile A and C show that the upstream and the midstream have deeper incisions than the lower stream. This could be due to gradation and catchment sizes of these gully profiles that contribute high volume of runoff into the main gullies and the nature of the soil/geology. Gully longitudinal profile of B shows lower incision. The gully profiles have a flat and steep side walls given it a broad U shaped form (Fig.2a, b, c). This finding agreed with Iorkua (2006) who carried out similar study in Northern Bank of Makurdi, Benue State, Nigeria. The implication of this finding is that gully erosion has deep incision, wide bed and top width that have restricted infrastructural development.

The Spot 5 (1999) and Quick birds (2009) image interpretations and ground truth measurements presented in Fig. 3 and on table 1 revealed significant changes in gully morphological variables. Length of gully profile A, B and C ranges between 4.4km in 1999 to 6.0km in 2009/2010, representing an increase of 0.2km to 0.4km or 4.6% to 7.1% respectively. The changes in bed widths of the ten years period of satellite images (1999 and 2009) interpretation and 2010 ground truth measurement of gully profile A, B and C showed an increase from 6.2m in 1999 to 52.5m in 2009 and 2010, representing an increase of 4.4m to7.9m. Top width for gully profile A, showed an increase of 2.8m or 11% (25.5m in 1999 to 28.3 in 2009); Gully length B, also showed an increase of 4m or 64.5% (7.3m to 10.2m) and gully longitudinal C witnessed an increase of 11.4m or 22.2% (51.4m to 62.8m) respectively. Gully area also witnessed an increase of 2.5km^2 in 1999 to 4.6km^2 in 2009, representing an increase of 2.1km^2 (84%) over the last ten years. This implies a mean annual increase of 210m^2. Slope angle for the three gully profiles were 5^o, 4^o and 6^o respectively with mean value of 5^o. The relatively no variations in slope angle among the sampled sites is attributed to the low topography of the study area. This finding agreed with Iorkua (2006), Rahab (2008) and Ibitoye and Eludoye (2010) in their similar work found severe gully on slope inclined at 30.

Changes in Landuse type between 1999 and 2009: The physical growth of Gombe town can be traced to 1919 when the settlement covered just 8 hectares. In 1999, the built up area reached 31.21km^2 (Table 2 and Figures 4) and in 2009, the town Built-up area reached 41.67km^2, an increased of 10.46km^2. The period between 1999 and 2009 therefore, has witnessed rapid increase in built up area to 10.5km^2 or 33.7% in 10 years, representing an annual increase of 1.1km^2. This high increase could be attributed to influx of civil servants and other migrants when Gombe town became the State capital in 1996. Tarred roads and streets also witnessed increase from 0.8.km^2 in 1999 to 5.8km^2 in 2009 or 600% increased over the 10 years images identifications. On the other hand, undeveloped land and open space witnessed significant declined from 4.9km^2 in 1999 to 1.13.km^2 in 2009 representing an overall decrease of 75.4 percent. The implication of this growth and consequent outward expansion, as well as deforestation of the savanna woodland of Gombe town catchment areas, has increase area of impervious surfaces which generate high runoff than infiltration during rainfall events.

Soils Physical Characteristics: The mean particle size distribution of the soil texture along the three sampled gully profiles (Plate 1) is presented on table 3. Gully profile A have 78.5% sand proportion, 5.5% silt and 16% clay for top layer. Middle layer have 52.5% sand, 11% silt and 36.5% clay. Bottom layer have 21% sand, 7.5% silt and 71.5% clay, with coefficient of variation (C.V) of 1.2%. Gully profile B showed a mean sand proportion of 73.5%, 9.5% silt and 17.0% clay for the top layer respectively. Middle layer have 59.5% sand, 8% silt and 32.5% clay. Bottom layer have 29.5% sand, 15% silt and 55.5% clay respectively. Gully profile C have mean fraction of 74% sand, 7.2% silt and 18.8% clay for the top layer. Middle layer showed 52.7% sand, 11.5% silt and 35.8% clay contents. Bottom layer showed 23.8% sand, 18 2% silt and 58% clay respectively. The overall mean proportion for the three sample gully profiles shows 52% sand, 9.5% silt and 38.5% clay respectively. This findings agree with similar study by Olofin (1992) in Kano, who found that grain size of fine sand to coarse silt ranges up to 50%, while clay alone account for 20 - 30% in the northern savanna of Nigeria.

This implies that the sandstones and shales (Gombe sandstone and Pindiga formations) that dominate Gombe town geology have accelerated gully erosion. This finding agrees with Orazurlike (1987) who found that the Gombe sandstone and Pindiga formation are prone to gully erosion and physical growth of the town, and will continue to increase towards the Kerri - Kerri formation in the western part where it is less susceptible to gully erosion.

Soil Chemical Properties of the Sample Gully Profiles: The average soil pH values of top layer for the three gully profiles were 6.2, 5.7 and 5.6. The middle layer mean values were 4.5, 5.3 and 4.2, while and the bottom layer has mean values of 3.6, 3.3 and 3.5 respectively, with overall mean of 4.6. There was no significant difference among the sampled gully profiles. This implies that the soils are moderately acidic. Table 4 further shows decreases in soil pH mean values from top layer down the soil profiles. The implication of this is that the soil of the study area may not be affected by micro organisms that work on organic matter which might enhance the binding of soils to resists erosivity of rainfall and runoff impact. This also has implication on crop cultivation and growth of *Paniculatu/Pitadeniastrum africanum* to check gully erosion in the study area. The overall pattern of variation of exchangeable Ca, Mg, Na and K on table 4 from top to the bottom of the gully profiles were similar. The mean values of calcium (Ca) for gully profile A, ranges from 5.3% to 7.8%; for gully profile B, 8.3% to 9.7% and for gully profile C ranges from 7.5% to 10.5% respectively. Potassium (K) ranges between 4.7% to 2.6% for gully profile A; 2.2% to 1.0% for gully profile B and 2.1% to 1.4% for gully profile C. Magnesium (Mg) values range between 2.5% to 3.0%; 2.8% to 3.8% and 2.6% to 3.4% for gully profiles A, B and C respectively. There is a general increase in mean values for both soil layers. On the whole the valley bottom soils were more enriched with the basic elements, while the top or middle layer recorded the lowest mean values. This may be explained in terms of the relative steepness of the gully walls, hence, downward of the basic elements and subsequent accumulation at the valley floor.

Exchangeable sodium (Na) on the other hand showed an irregular increase and decreased in mean values from top to the bottom layer of the gully walls. Top layer showed mean values of 0.8 and 1.0% for the three gully profiles. The middle layer mean values are 1.0, 0.9 and 0.9% for gully profile A, B and C respectively, while the mean values for bottom layers are 0.8%, 0.8% and 0.5% for profile A, B and C respectively. These variations might be due to mineral constituent of urban waste and sewage disposal into these gully sites. Jeje and Agu (1990) found that gully erosion affect exchangeable cations and characteristics, by low infiltration rate and very low holding capacity. The implication of this findings to biological control of gully erosion is that increased in Na can have negative effects on the soil fertility and hence retard the growth of plants such as *Paniculatu/Pitadeniastrum africanum* which are regarded as the most effective method of controlling gully erosion because of its affordability, accessibility and adaptability.

The results of soils organic matter content (OMC) on table 6 show the mean value of gully site A, B and C (top, middle and bottom gully wall layers) ranges from 0.6 to 1.3, which is considered low. The overall pattern of variation showed a downward increase in the organic contents. Mills and Fey (2003) also found a linear decrease in erodibility with increasing organic content over a range of 0 to 10%. However, there was significant differences at the top and bottom layers of the gully walls. The possible causes of these differences might be attributed to leaching of the organic matter down the valley floors of the gully site. This finding agrees with similar work by Orazulike (1992), who found that the soils are red and contain nodules of ironstone and marks by deposits of iron oxide pebbles, loose, very permeable and deficient in plant nutrients. The organic content of all the soil samples falls below 2%, which is considered as the threshold below which soils are erodible. Sealing and high surface runoff is also more pronounced in soils with very low organic content. A poor soil structure and low plant nutrient content will cause the soil to be more prone to gully erosion. This might be the reason behind the present distribution of gully erosion in Gombe town. This have implication on tree planted to check gully erosion and on food security, unless more chemical fertilizer is provided.

The results of soil phosphorus test (Table 4) showed downward decreases in mean values from top to the bottom layers of the three sampled gully sites. Gully site A, B and C top layers have mean values of 19, 32 and 20.5%, middle layer for the three sites have 12%, 20% and 18.5% and bottom layer mean values are 11.5%, 11.5% and 15.2% respectively. Analysis of variance showed significant differences in the three layers of the gully profiles. This value is low, and translates low phosphorus in the soil. This finding agreed with Ayuba (1992), who observed that the Nigeria savanna is characterized by low phosphorus. The implication of this finding is that phosphorus is important in plant-soil-water interaction and in the general biogeochemical cycling in natural system.

Geological Properties of the Sample Gully Profiles: The mean soil bulk density for the sampled gully profiles presented on table 5 ranges between 1.9 to 2.2g/cm^3 for gully profile A, B and C respectively. These values are within the range obtained for similar study by Rahab (2008) in Zaria. Moisture contents mean values for the three sampled gully profiles range between 9.8 to 16.7g/cm^3 for gully profile A, B and C respectively. This implies low values. This could have contributed to the long dry season despite the impact of urban waste water that flow into these gully sites. This will have implication on the survival of *Paniculatu/Pitadeniastrum africanum* planted to check gully erosion. The mean values of cohesion for gully profiles A, B and C have the same values of 0.2 kg/cm^3, for the top, middle and bottom sites respectively.

The mean angle of internal friction for gully profiles A, B and C for the top layer were 26.50, 26.60 and 25.50 respectively; middle layer has mean values of 24, 26 and 26 respectively; and bottom layer has mean values of 26, 28 and 26 respectively. The importance of this test is that the force due to runoff and the seepage flux are only resisted by the angle of internal friction when the value is > 400 (Obiefuna et al., 1999). Since the mean angle of internal friction of this study area is below 400 (Table 5), gully erosion in the study area could partly explained due to low shear strength of the soil. The results of this finding will help civil engineers whose activities border gully erosion control, construction of road, drainage and houses.

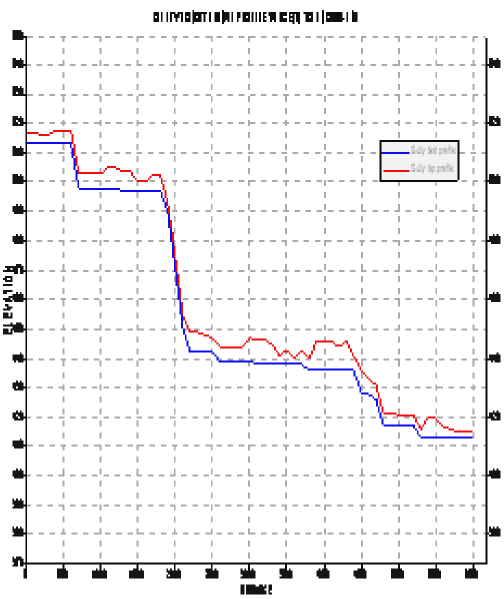
The result of porosity for gully profile A, B and C ranges between 43% and 45.5% at the top layer as the middle layer has 43 to 51% and the bottom layer ranges between 38 to 47.5%. Gully profile A and C are the most porous, probably due to the nature of the soil and degree of sealing surfaces. This finding is within the range of 35-50% and therefore, the soil is porous. A similar result was obtained by Rahab (2008) in Zaria. The implication of this finding is that gully incision and side wall slumping will continue to increase, thereby increasing headward progression of gullies and destruction of more houses.

The results of Atterberg limits (liquid limit, plasticity limit and plasticity index), are presented on table 5. The liquid and plastic limits were measured to obtain the plasticity index, which is a measure of the plasticity of the soil. The liquid limits (LL) for gully profile A; top, middle and bottom layers are 27.4%, 28.2% and 29.6% respectively; Gully profile B has mean values of 26.5%, 27.0% and 26% and gully profile C has mean values of 27.0 for the three layers respectively. The analysis further revealed no significant difference in LL ($P>0.05$) among the sampled gullies. The plasticity limits (PL) for gully profile A, for the top, middle and bottom layers are 22.4%, 22.7% and 24.4% respectively; gully profile B has mean values of 21.5%, 22.5% and 22% and gully profile C has mean values of 22.9%, 22.9% and 22.6% respectively for the top, middle and bottom layers of the sampled soils. Low LL and PL in these soils made the soil to be loose, non-coherent and to slide upon getting in contact with water or even to disintegrate under dry conditions. This finding agrees with similar work carried by Obiefuna et al (1999) and Obiefuna, Oreagbune and David (2010) in Yola town, Nigeria.

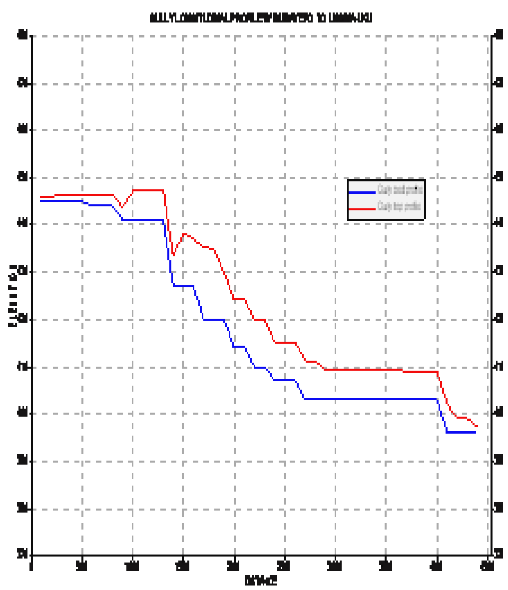
Rainfall Characteristics: Gully erosion is a threshold phenomenon in terms of flow hydraulics and rainfall. Table 6 shows the rainfall variability of the 15 hydrologic years, particularly with regard to annual rainfall. It revealed that of the 15 years period under study, only 4 years (1996, 2001, 2004 and 2010) had total annual rainfall less than the mean annual (800mm), while the 11 years received more than the mean annual total, representing 73.3%. This implies that only 26.7% of the 15 hydrologic years had relatively low rainfall compared with the mean total height of 800mm. However, this amount is high in an urban environment with increasing sealing surfaces.

This finding agrees with Ologe (1987), who found out that stations with mean annual rainfall of 762mm to 1524mm lies within the maximum fluvial erosion. The mean annual rainfall days (Dr) showed 54 days, with a maximum of 63 days (1998), minimum of 34 days (2001) and standard deviation of 6.45. This showed low variation in rainfall days. However, this does not imply that the higher the number of rainy days the higher the amount of rainfall expected as shown on table 6. Rainfall duration of $\leq$ 30min for the year 2008- 2010 showed a mean of 34.2mm with standard deviation of 2.83. This finding agreed with similar work carried by Nyanganji (1997) and Capra, Porto and Sciocolone (2009) who found out that most of erosive rainfall events occurred during the first 15 and 30 minutes of rainfall. The maximum rainfall intensity of $\geq$ I-hr ranges between 39.6mm to 123.7mm and standard deviation of 22.93 respectively. These intense storms with mean of 25mm per hour on exposed surfaces such as the study area accelerate gullies. This finding agreed with Capra *et al.* (2009) who reported that a rainfall event is erosive if the height of rainfall is equal to or more than 13mm per hour or the intensity in 15min is equal to or more than 6mm. The implication of this finding is that every year gully erosion increases due to exceeding rainfall threshold.

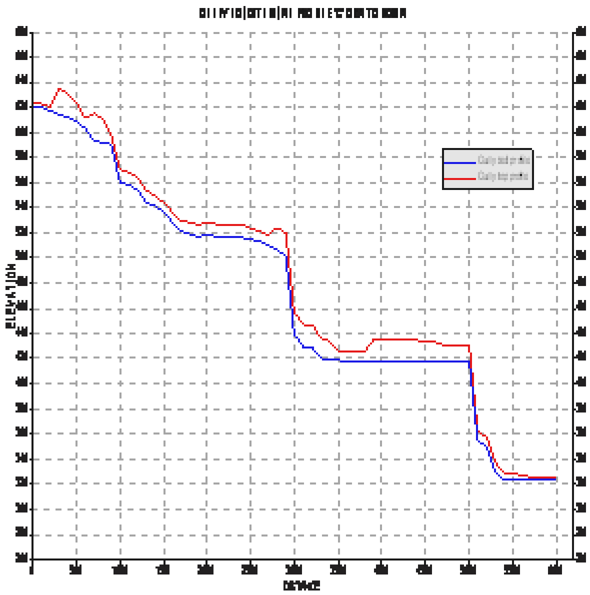
Topography (Slope Length and gradient): A GPS reading taken at Yola/Bauchi junction shows 626.3m a.s.l and at the roundabout (old market) 454.8m a.s.l, representing a height difference of 171.5m through a distance of about 3km. The same GPS reading was taken around PHCN power station along Dukku Road which showed 603.5m representing a difference of 148.7m with that of old market (centre of the town) through a distance of about 3km and mean slope gradient of 50. This is considered high gradient for unprotected surface. The slope length indicates the gravity of low infiltration and high runoff conditions. This finding agrees with similar work by Ebisemiju (1989) who found out that slope gradient alone explains about 63% of the spatial variations in the intensity of gully erosion in Guyana. The implication of this finding is that Gombe town is dominated by active gully erosion and there is the need for holistic approach to watershed management. Ordinarily under vegetal cover, this slope gradient should not have enhanced erosion processes, but due to exposure to direct raindrop impact, human activities and coupled with the poor soil aggregate has accelerated gully erosion.



(a)



(b)



(c)

Fig.2 (A, B C): *Sample Gully Longitudinal Profiles. Elevation and distance are in metres. Vertical scale 1: 10. Horizontal scale 1:250*

Source: Fieldwork, 2010

Table 1: Identified Gully Quantitative Variables derived from Spot 5, and Quick birds Images and Field Measurement of the Study Area

Gully variable	Gully longitudinal profile A					Gully longitudinal profile B					Gully longitudinal profile C					Mean (m)
	'99	'09	Changes	'10	Change between 2009 & 2010	'99	'09	Changes	'10	Change between 2009 & 2010	'99	'09	Changes	'10	Change between 2009 & 2010	
Length (Km)	5.6	6	0.4(7.1)	6	0(0)	4.4	4.6	0.2(4.6)	4.6	0(0)	6	6	0(0)	6	0(0)	5.5
Depth (M)	9.0	10.5	1.5(16.6)	11	0.5(4.8)	6.1	6.7	0.6(9.8)	7	0.3(4.5)	9.0	11.3	2.3(25.6)	13.5	2.2(19.5)	9
Bedwidth (M)	16.4	20.8	4.4(27)	22	1.2(5.8)	6.2	8.7	3.7(23.6)	8.8	0.1(1.2)	44.6	52.5	7.9(17.8)	56	3.5(6.7)	26.2
Topwidth (M)	25.5	28.3	2.8(11)	30	1.7(6.0)	7.3	10.2	4.0(64.5)	11.3	1.1(9.2)	51.4	62.8	11.4(22.2)	65	2.2(3.5)	32.4
Slope angle (0°)	5	5	0	5	0(0)	3.8	4.0	0.2	4	0(0)	5.5	6	0.5(9)	6	0(0)	4.5
BW/D ratio	1.6	2.0	0.4	2.0	0(0)	1.0	1.3	0.3	1.3	0(0)	7.7	8.0	0.3(3.8)	8.1	0.1(1.3)	3.5
TW/BW ratio	1.6	1.3	0.3	1.4	0.1	1.2	1.2	0	1.3	0.1(8.3)	1.2	1.2	0(0)	1.2	0(0)	1.2
Cross sec. Area (M^2)	188.6	257.7	69.1(36.6)	286	28.3(11)	40.2	63.7	23.5(58.5)	70	6.3(10)	542	696	154(28.4)	817	121(17.4)	329.1
Vol. Soil loss (t/ha)	1.2	1.6	0.4(33.31)	1.7	0.1(6.3)	0.3	0.5	0.2(65.6)	0.6	0.1(20)	3.3	4.2	0.9(27.3)	4.9	0.7(16.7)	2.0
*Gully Area (km^2)	2.5															

* - represent the whole town Figures in

parenthesis represent percentage 4.6 2.1(84)

Source: Fieldwork, 2010

10 36 220N 11 36 125E **Plate 1:** Sampled Gully Profile Layers. ***Source:*** Fieldwork, 2010

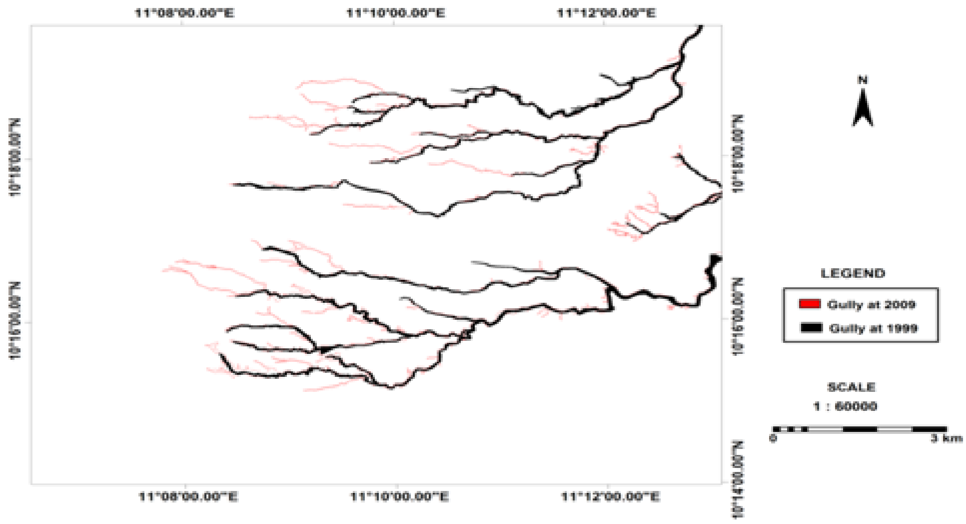


Fig. 3: Identified Gully Density of the Study Area. ***Source:*** Field work/Laboratory Analysis, 2010

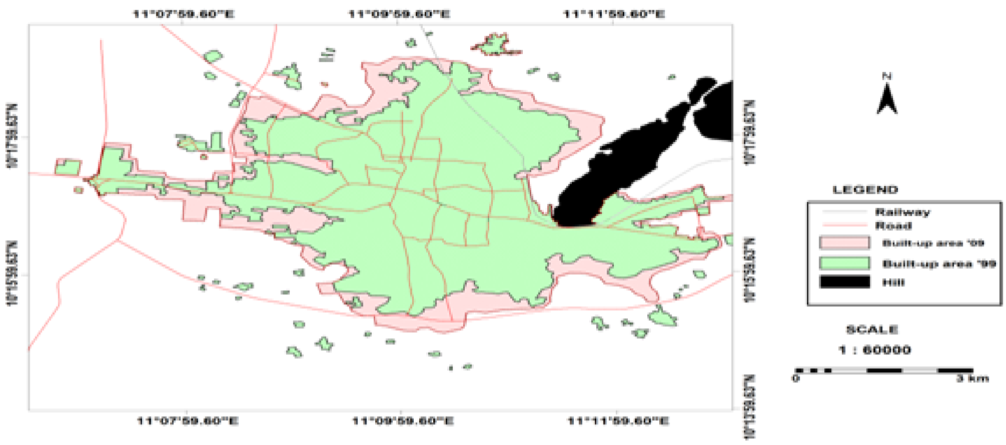


Fig. 4: Identified Landuse changes Gombe Town Between 1999 and 2009

Table 2: Changes in Landuse Type between 1999 and 2009

S/No	Landuse Types	1999	2009	Change km^2	Percentage Change
1	Built up areas (km^2)	31.21	41.7	+ 10.5	33.7
2	Tarred Roads/streets (km^2)	0.8	5.6	+4.8	600
3	Gullies (km^2)	2.54	4.6	+2.06	84
4	Undevelopedland/open space (km^2)	4.6	1.13	-3.47	75.43
5	Vegetation cover (km^2)	6.2	0.6	- 5.6	90.32
6	Total	45.37	53.6	26.5	

Source: Fieldwork, 2010

Table 3: Results of Soil Physical Properties of the Gully Profiles

Soil Property	Soil Depth	Sand (%)			Silt (%)			Clay (%)		TC	F- test	Sig.	
		Mean	SD	C.V	Mean	SD	C.V	Mean	SD	C.V			
Gully Site A	Top	78.5	9.2	1.14	5.5	1.2	4.93	16.0	7.3	4.9	SC	0.20	NS
	Middle	52.5	8.9	1.63	11.0	0.9	2.25	36.5	7.0	1.67	SC	0.24	NS
	Bottom	21.0	9.0	3.33	7.5	0.7	12.2	71.5	4.9	1.31	SL	0.18	NS
Gully Site B	Top	73.5	7.7	1.23	9.5	2.2	13.9	17.0	6.7	4.21	SL	0.21	NS
	Middle	59.5	8.5	1.47	8.0	2.1	9.90	32.5	6.6	2.55	SL	0.29	NS
	Bottom	29.5	7.0	2.78	15.0	2.0	5.88	55.5	6.6	1.61	SCL	0.25	NS
Gully Site C	Top	74.0	4.5	1.27	7.2	2.2	18.5	18.8	6.9	3.89	SC	0.19	NS
	Middle	52.7	7.0	1.67	11.5	3.8	6.54	35.8	4.1	2.51	SCL	0.27	NS
	Bottom	23.8	4.9	3.48	18.2	5.0	6.14	58.0	8.4	1.40	SCL	0.16	NS
Mean	52	7.4	2.0	9.5	2.2	9.2	38.5	6.5	2.7				

TC - Textural Class, SL - Sandy loam, SCL -Sandy clay loam, SC - Sandy clay, NS - Not significant

Source: Field work/Laboratory Analysis, 2010. NS: Not significant

Table 4: Soil Chemical Properties of Sample Gully Profiles

Soil Property	Soil Depth	Gully Site A			Gully Site B			Gully Site C			F- test	Sig.
		Mean	SD	C.V	Mean	SD	C.V	Mean	SD	C.V		
pH	Top	6.2	0.36	60.5	5.7	0.65	15.7	5.6	0.41	16.6	0.134	NS
	Middle	4.5	0.32	20.8	5.3	0.61	16.9	4.2	0.40	22.6	0.662	NS
	Bottom	3.6	0.36	25.3	3.3	0.66	25.3	3.5	0.37	25.8	0.006	NS
OM%	Top	0.8	0.01	123.4	0.8	0.32	89.3	1.3	0.00	76.9	0.001	S
	Middle	0.8	0.01	123.4	0.7	0.01	140.8	0.6	0.00	166	0.313	NS
	Bottom	1.3	0.20	66.6	0.8	0.01	123.4	0.6	0.00	166	0.019	S
ExchCalcium %	Top	5.3	0.34	39.3	8.2	0.20	11.9	9.5	0.21	10.3	0.153	NS
	Middle	5.5	0.32	17.2	9.5	0.44	10.1	10.5	0.40	9.17	0.02	S
	Bottom	7.8	0.43	12.3	9.7	0.52	9.8	7.5	0.35	12.7	0.01	S
NA %	Top	0.8	0.01	123.4	0.8	0.00	125.0	1.0	0.01	99.0	0.008	NS
	Middle	1.0	0.01	99.0	0.9	0.00	111.1	0.9	0.00	111	0.301	NS
	Bottom	0.8	0.01	123.4	0.8	0.01	123.4	0.5	0.00	200	0.571	NS
K %	Top	4.7	0.35	19.8	2.2	0.01	45.2	1.4	0.01	71.3	0.002	S
	Middle	2.6	0.20	35.7	1.0	0.01	99.0	1.5	0.00	66.6	0.016	S
	Bottom	2.8	0.25	32.8	1.0	0.01	99.0	2.1	0.01	47.4	0.005	S
Mg %	Top	2.5	0.24	36.5	2.8	0.25	32.7	2.6	0.22	35.5	0.032	NS
	Middle	3.0	0.31	30.2	3.8	0.24	24.8	3.4	0.31	3.5	0.006	S
	Bottom	3.1	0.32	29.2	3.0	0.01	33.2	3.8	0.34	24.2	0.023	NS
P %	Top	19	1.70	4.80	32	5.99	2.60	20.5	1.2	4.6	0.001	S
	Middle	12	1.67	7.30	20	5.98	3.87	18.5	1.2	3.9	0.002	S
	Bottom	11.5	1.72	7.60	15.2	5.95	4.35	15.2	1.2	6.09	0.005	S

Source: Laboratory Analysis, 2010. OM- Organic matter ,Na - Sodium K - Potassium Mg - Magnesium, P- Phosphorus

Table 5: Atterberg Limits and Geological properties of Soil Samples Gully Profiles

Soil Property	Soil Depth	Gully Site A			Gully Site B	Gully Site C F- test		Sig.				
		Mean	SD	C.V%	Mean	SD	C.V%	Mean	SD	C.V		NS
LL %	Top	27.4	0.8	3.5	26.5	1.1	3.6	27.0	1.0	0.3	0.03	NS
	Middle	28.2	0.7	3.4	27.0	1.0	3.7	27.1	1.0	0.3	0.12	NS
	Bottom	26.9	0.9	3.6	26.0	1.1	3.5	27.0	0.5	0.2	0.12	NS
PL%	Top	22.4	1.4	3.8	21.5	0.6	3.5	22.9	0.8	0.2	0.35	NS
	Middle	22.7	1.3	4.0	22.5	0.5	4.3	22.9	0.7	0.2	0.32	NS
	Bottom	24.4	1.5	3.8	22.0	0.6	4.3	22.6	0.7	0.2	0.03	NS
Cohesion Kg/M^2)	Top	0.2	0.0	500	0.2	0.2	250	0.2	0.0	0.0	0.02	NS
	Middle	0.2	0.0	500	0.2	0.2	250	0.2	0.0	0.0	0.30	NS
	Bottom	0.2	0.0	500	0.3	0.2	200	0.2	0.0	0.02	0.33	NS
AIF (Q0)	Top	26.5	0.6	3.6	26.6	0.17	3.5	25.5	0.06	0.02	0.23	NS
	Middle	24	0.6	4.1	26	0.17	3.6	26	0.06	0.02	0.14	NS
	Bottom	26	0.6	3.8	28	0.15	3.5	26	0.05	0.02	0.21	NS
Porosity(%)	Top	45.5	0.0	2.2	44	0.00	2.2	43.0	1.28	0.5	0.25	NS
	Middle	46.5	0.0	2.2	43	0.00	2.3	51.0	1.26	0.7	0.12	NS
	Bottom	38.5	0.0	2.6	42	0.00	2.3	47.5	1.27	0.6	0.35	NS
Bulk Density (g/cm^3)	Top	2.0	0.2	49.5	1.8	0.2	50.0	1.6	0.3	52.6	0.02	NS
	Middle	2.2	0.3	40.0	2.2	0.3	40.0	2.2	0.2	41.7	0.02	NS
	Bottom	1.9	0.2	47.6	2.9	0.2	32.3	2.3	0.4	2.89	0.13	NS
Moisture Content g/cm^3	Top	10.5	0.6	9.01	10.6	0.6	8.92	9.8	0.6	9.6	0.15	NS
	Middle	11.9	0.7	8.62	13.7	0.5	8.92	10.9	0.7	8.6	0.24	NS
	Bottom	12.8	0.5	8.85	16.7	0.6	8.85	14.5	0.8	8.8	0.14	NS

LL- Liquid limit, PL - Plasticity limit, AIF- Angle of internal friction. Source: Field work/ Laboratory Analysis, 201

Table 6: Main Characteristics of Rainfall Events in the Study Area: total height (Ht), rainy days (Dr), maximum ≤ 30min max intensity, maximum ≥1-h height (H_{max}^{1-h})

Hydrological Year	Ht	Dr	≤ 30min max	≥ I -h_{max}
1996	664.5	51	nm	75.4
1997	986.6	60	nm	54.6
1998	1041.6	63	nm	90.0
1999	965.9	59	nm	89.2
2000	947.5	54	nm	39.6
2001	728.3	34	nm	75.4
2002	851.2	50	nm	54.6
2003	1051.6	53	nm	123.7
2004	796.5	50	nm	42.3
2005	810.0	53	nm	43.7
2006	940.0	60	nm	94.5
2007	881.0	51	nm	62.4
2008	946.0	61	42.3	108.3
2009	846.0	59	32.2	64.6
2010	576.0	55	28.2	86.8
Mean	800	54.1	34.2	73.7
SD	135.35	6.45	2.83	22.93

Nm - not measure, SD -standard deviation. Source: Meteorological Station Gombe (2010)

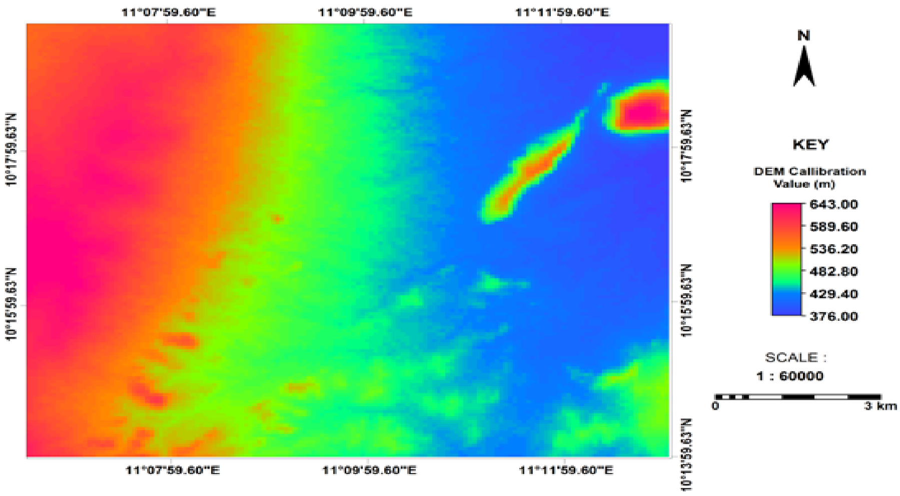


Fig. 5: Digital Elevation Model of the study Area ***Source:*** Field work 2010

CONCLUSION

This study was designed to assess the rate and factors of gully system in Gombe town. Gombe town is facing serious problem of gully erosion causing untold hardships and misery on the lives of the people. Complex interdependent mechanisms between rainfall characteristics, soil erodibility, landuse, topography has reduced infiltration, which caused a higher surface runoff. This has increased deep cutting, take up valuable land, raised the cost of building and the sinking of the ground water table. This chain of cause and effect hits most of the low income groups of the community, where the population density is highest and where the worst damages of gully erosion are found. There is the need to setup phosphorus level in the prone gully sites to meet the demand for phosphorus, more especially when panting *Paniculatu/Pitadeniastrum africanum* in checking gully erosion in the study area.

REFERENCES

Ayuba, H. K. (1992). Effects of Continues Cultivation on the Soil and Vegetation in Konduga L. G. A of Borno State. Unpublished M.Sc Dissertation.

Balzerek H., Werner F., Jürgen H., Klaus-martin M. and **Markus R.** (2003). Man Made Flood Disaster in the Savanna Town of Gombe/NE Nigeria. In Erdkunde 94-109

Capra A., Porto A. and **Sciocolone B.** (2009). Relationship Between Rainfall Characteristics and Ephemeral Gully Erosion in a Cultivated Catchment in Sicily. *www.elsevier.com/locate/still.* Retrieved on 23/2/10

Ebisemiju, F. S. (1989) A morphometric approach to gully analysis. *Geomorphologies,* 33 (3), 307-322

Ibitoye, M. and **Eludoyin, A.** (2010). Urban Growth and Development of Soil erosion in part of Humid of Southwest Nigeria. FIG Congress 2010, Facing the Challenges - Building the Capacity Sydney, Australia, 11 - 16th April 2010

Iorkua, S. A. (2006). A study of inter- relationships among gully elements in North Bank Makurdi. *Journal of Geography and Development,* 1 (1), 32-49

Jeje, L. K. and **Agu, A. N.** (1990). Run-off from Bounded Plots in Alakowe in South Western Nigeria. *Applied Geography,* 10, 63-74.

Mills, A. J. and Fey, M. V. (2003). Declining soil quality in South Africa: effects of land use on soil organic matter and surface crusting. *South African Journal of Science,* 99, 429- 436.

Nyanganji, J. K. (1997). Some Basic Observations on Rainfall and Runoff related Factors on an Artificial Catchment in Maiduguri, NE Nigeria. In: Daura (ed) Issues in Environmental Monitoring in Nigeria, 152-165, Maiduguri

Obaje N. G., Abaa S. I., Najime T. and **Suh C. E.** (1999). Economic geology of Nigerian Coals Resources: A Brief Review. *African Geoscience Review,* 6, 71-82

Obiefuna G.. I., A. Nur A. U. Baba and **Bassey N. E.** (1999). Geological and Geotechnical Assessment of selected Gully Sites, Yola area, Northeast Nigeria. *Journal of Environmental Hydrology,* 7

Obiefuna G. I., Oreagbune I. M. O. and **David C.** (2010). Geotechnical Evaluation of Soils in Numan and its Environs, Northeast Nigeria. *Continental Journal Earth Sciences*, 5 (1), 20 - 31 Wilolud Journals, 2010 *http://www.wiloludjournal.com:* Retrieved March, 2011.

Olofin, E. A. (1992). The Dynamics of Gully Head Recession in a Savanna Environment. Erosion, Transport and Deposition Processes (Proceedings of Jerusalem Workshop), IAHS, NO. 189

Ologe, K. O. (1987). Soil erosion characteristics, processes and extent in the Nigerian savanna. In V. O. Sagua, E. E. Enabor, G. E. K. Ofomata, K. O. Ologe and L. Oyebande (eds) Ecological Disasters in Nigeria. *Soil Erosion,* 26-49

Orazulike, D. M. (1987). Hazardous Earth Processes in parts of Bauchi State, Nigeria: Their Causes and Environmental Implications. *Natural Hazard*, 1, 155-160

Orazulike, D. M. (1992). A Study of Gully Phenomenon in Gombe Town, Bauchi State: Bedrock Geology and Environmental Implications (200-201). Netherlands: Kluwer Academic Publisher.

Rahab, N. O. (2008). Effects of Soil Physical Properties on Gully Morphology in Zaria, Northern Nigeria. A paper presented at the 48th Annual Conference of Association of Nigerian Geographers, held at the Department of Geography, University of Calabar, October 2008.