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Morphometric Characterization and Agricultural Implications of Gully Erosion in Gashala Area, Hong LGA, Adamawa State, Nigeria.

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Abstract

An impact assessment of gully erosion hazards on food security was carried out in ten (10) locations of arable lands in Gashala environs, in the year 2023. The study comprised of measurement of the physical characteristics which include texture, bulk density, porosity, length, depth and the width of each gully site. The gully volumes were also measured and classified according to Shahrivar and Christopher. (2012). The result of the physical properties indicated higher sand content relative to Silt and Clay. The particle size analysis revealed that the average values for Sand, Silt and Clay were 52%, 27% and 20% respectively; giving a textural class that is predominantly sandy loam. Due to larger macro-pores and fewer micro-pore spaces in sand, the bulk density tends to be high (1.74 g/cm^3). This bulk density value of the soil surface was high enough to generate surface runoff that favored soil erosion. The results of gully measurements revealed that Milendi was highest in volume (1,020 m^3), Pavu has the longest gully (152 m), Contarabi 3 was deeper in size (5.2 m) and highest area covered by gully erosion (19.2 m^2), Contarabi 2 has the lowest gully volume of 128 m^3, the shallowest depth (1 m) and the least covered area (3.2 m^2). The shortest gully was Contarabi 1 (19 m), the gully was widest at Naiwa (6.2 m). These variations in sizes of length, depth, width, area and volume indicated the impact of several factors of erosion active at the erosion sites. The rate of soil loss ranged from 100.8 t/ha/yr to 561.84 t/ha/yr across the locations, with the highest rate recorded at Pavu. The effects of this soil loss on food security were dual; On-site productivity (loss of crop yield, top soil, nutrient and decline in soil quality) and Off-site effects (seedling burial, chemical effects, burial of top soil and alteration in soil-water regime and water-table). Several factors for gully erosion, including climatic, anthropogenic, topographic, edaphic, and vegetative are evident. Possible biological and engineering measures are also reported which might be beneficial. Biological measures of erosion control are basically adopted when the land slopes are smaller than 2% in general, and erosion problems are not severe. But when the land slopes are more than 2%, engineering measures may be necessary.

Keywords: Arable, Anthropogenic, Topographic, Edaphic and Engineering, Physical Characteristics

1.0 Introduction

Soil erosion leads to the removal of soil nutrient and degradation of soil structure, is considered to be a major environmental and geomorphological issues affecting agricultural sustainability. (Singh & Panda, 2017). It is considered the most conspicuous and widespread agent of soil/land degradation ever known (Lal, 2015; Kumar & Ramachandra, 2003). It is estimated that 1/6 of global soils has already been degraded by erosion due to water and wind, resulting in a reduced ability of society to produce sufficient food (agriculture) (Wang *et al.*, 2020). The productive power of some lands (worldwide) has declined by half due to the effect of erosion and desertification (Eswaran et al., 2001). Annually, 75 billion tons of soils are lost from farmlands, and 12 million hectares of cropping land which means approximately 1% of the total area is no longer fit for farming, leading to the degradation of 38% of global cropland since World War II (Dahl, 2013). Soil loss also leads to several other farm challenges, and as these problems increase, there comes a point at which the farm is abandoned (Anthoni, 2000).

Gullies are defined as a channel resulting from erosion and caused by the concentrated but intermittent flow of water usually during and immediately following heavy rains; deep enough to interfere with, and not to be obliterated by, normal tillage operations (Tarekegn, 2012). Gullies are one of the most destructive forms of erosion, damaging farmland and difficult to reverse (Billi and Dramis, 2003; Moges and Holden, 2009). Gully erosion, especially in semi-arid areas is a burning problem as it leads to degradation of agricultural land (Kropacek *et al.,* 2016). Additionally, gullies tend to evolve head ward thus, increasing the drainage density and accelerate desertification processes in the semi-arid zones (Valentin et al., 2005). It was also shown that gully erosion is often a major contributor in reservoirs sedimentation, which is a serious problem especially in semi-arid areas with pronounced seasonality in precipitation such as Ethiopia and Nigeria (Hamed *et al.*, 2002; Haregeweyn *et al.*, 2006; and Tamene *et al.*, 2006). Usually, gully erosion is triggered or accelerated by land use change and/or by extreme climatic events (Valentin *et al.*, 2005). By the end of 21st century, 40 to 50 percent of all undernourished are expected to live in sub-Saharan Africa (Tekwa *et al.,* 2021)

Soil attrition can be devastating to agricultural development and food security (Ighodaro, *et al.,* 2016). It leads to productivity or overall farm yield losses, especially because of decreased fertility of the soil due to loss in soil nutrients. It diminishes the quality of soil through the loss of water, soil organic matter, nutrients, biota, and depth of soil, thus reducing the productivity of natural, agricultural and forest ecosystems (Gundiri, 2023). Further, eroded sediment contains a considerably higher measure of organic matter and nutrients than that of the topsoil from where it is derived (Vahyala *et al.,* 2018). Thus, to attain food security and improvements in livelihoods, especially in the rural areas of Nigeria, soil erosion is no doubt one of the agricultural problems that need to be addressed.

Much of the natural covering for the rangelands has been degraded and indigenous vegetation depleted (through charcoal burning and firewood harvesting) thus leaving ground cover in some areas badly depleted (Vahyala *et al.,* 2018). Approximately 70% of all energy consumed in rural areas are generated from wood fuel thus accelerating the pace of devegetation and land degradation (Gundiri *et al.,* 2023).

The problem of land degradation is widespread within Gashala, which also faces poverty and repeated natural disasters, such as droughts and floods, sediment fills up man-made reservoirs, bleeds agricultural lands from its fertility, erodes away the agricultural lands completely, continuous cultivation under the increased population pressure, roads cut off, economic downturns and generally low agricultural productivity which can only be maintained with artificial fertilizers that in many cases are too expensive and also can be harmful to humans. No matter where they result from-natural or human-induced-climate changes, climate variations affect the resilience of diverse ecosystems and sustain the livelihoods of people living in these zones. Among the problems contributing to land degradation are a lack of knowledge about the nature, extent and severity of the condition, and an inadequacy of tools and methods for assessing, monitoring and managing the situation (Gundiri, 2023).

Although loss of net primary productivity (NPP) is sometimes understood to indicate degradation, losses such as these also result in a corresponding loss of human capital and community breakdown in rural communities, as well as poverty-related social costs and a reduction in ability to invest in preventing degradation.

In this regard, assessment of land degradation at basin level is of pressing importance for policy informed decisions concerning food and water security, environmental integrity, and sub-national as well as national strategies for economic development and resource conservation. This study is aimed at measuring the loss of agricultural activities and capital development due to soil erosion hazards in Gashala area, Hong LG, Adamawa State, Nigeria

2.0 Material and Methods

2.1 Location and Size

Gashala is a small village settlement in Hildi District, Northeast of Hong LG headquarters, where so much farming, business and educational activities are going on. Hong is located between latitudes 10°00'00''N and 10°35'00''N and longitudes 12°35'00''E and 13°20'00''E. It has a total land area 2,419.11 km^2 (Bashir and Raji, 1999). Hong local government is sandwiched between six Local Government Areas namely; Gombi, Song, Mubi-North and South, Maiha, and Michika. It is also bounded by Borno State to the North. The Local Government Area is predominantly made up of Kilba people, followed by Marghi. Other tribes in small numbers are Fulani, Hausa, Higgi, Fali, Njenyi among others (Adebayo *et al.,* 2020).

2.2 Climatic Characteristics

The climate of Hong LG is the Tropical Continental type which is characterised by dry and wet seasons; summer and winter (Adebayo, 1999; Ezekiel *et al.* 2024). According to Adebayo *et al.* (2020) and data from NBS (2018), Hong has a mean annual rainfall ranging between 800-1200 mm with onset usually 10th – 20th May and cessation between 26th September and 26th October.

2.3 Geology and Hydrology

The Geology of Hong LGA according to Nigerian Geological Survey Agency [NGSA] (2006) is characterized by a mixture of rock types and minerals as presented on. Most of the area (Hong LGA) is underlain by Magmatite and some Porphyritic Granite especially in the North-Eastern (NE) and Eastern part of the Local Government area. Some medium to coarse granite biotite are also found. The hydrology of the area is dependent on the rainfall pattern and the underground reservoir mostly in areas underlain by sedimentary rock formations. According to Adebayo (1999), the water resources available in the State (Adamawa) including Hong LGA are adequate if utilized properly. The rivers in the area are seasonal in nature. The major streams according to Akosun *et al. (*2020) are *Kwaleta* and *Dugwaba* streams.

2.4 Relief and Drainage

The relief of Hong LGA comprises flat, relatively flat and rugged terrain with hills and mountains spread across all the districts. The drainage of the area is a function of the existing relief condition as the streams and rivers originates from the highland areas. The parent materials are heterogonous and comprised predominantly loamy sand, clay and sandy clay of a range of colors (Vahyala, *et al.,* 2018). Which are also predominantly alfisols, luvisols, regosols, leptosols, cambisols, vertisols, and lithosols having lithic and paralithic which was similar to that of Girei area, based on their variations (Gundiri, 2023).

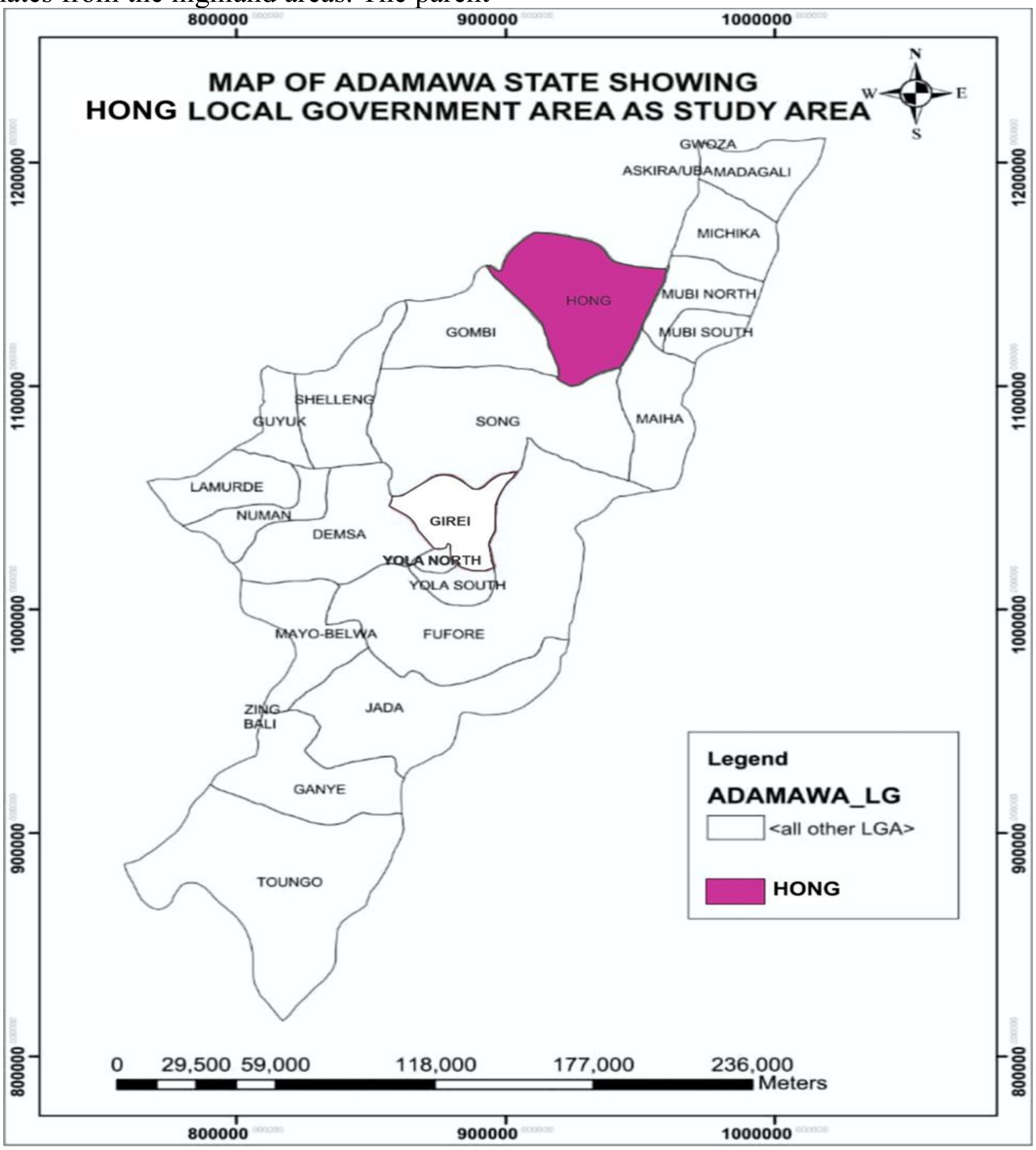

Figure 1: Adamawa State showing the location of Hong LGA (study area)

2.5 Site elevation and topography

A semi-detailed survey of selected gully erosion sites were conducted in the field in A global positioning system (GPS) was used to obtain elevation above sea level of each gully system as suggested by Vandekerckhove *et al.* (1998), Nachtergaele *et al.* (2001), and Nasri *et al.* (2008). The study area has a relatively high altitude with the highest reaching 560 m above sea level.

2.6 Determination of gully erosion parameters (length, depth, and width)

The following measurements were carried out in the selected gullies: (1) the head-cut retreat (longitudinal growth) and gully widening (or lateral retreat) down-slope from the head-cut, and (2) the gully expansion rates and associated amount of soil loss along the total gully length. To estimate gully expansion and the amount of soil loss from total gully reach, average gully width, depth and lengths were measured using measuring tape at the beginning and end of the rainy season. To determine the soil loss in the various sites were then computed using the measured length (l), width (w), and depth (d) of each gully feature. Thus, actual soil loss estimates were determined using mathematical expressions relating gully length, width, and depth as follows:

Width = (W)

Average width $\frac{(WT+WM+WB)}{3}$ -- -- -- -- --- (1)

Where: TW= Top width, MW = Middle width and BW = Bottom width

Depth = (D)

Average depth $=\sum\left(\frac{(d1+d2+d3+d4+d5+--\mp d)}{n}\right)$ -- -- -- (2)

Length = (L)

Where Li is the length of considered gully segment (m)

Cross-sectional area (A)= Average depth(D)*Average width(W) , Gully Volume= $(A) * L$--(3)

The gully volume was estimated using the formula: V= $\sum Ll$ Ai -- -- -- (4)

Where Li is the length of considered gully segment (m) and Ai is the representative cross-sectional area of the gully segment (m^2).

Also, after determining all considered factors, the gullies were classified based on gully volume in four groups including big gully (>200 cubic metre), medium gully (volume=100-200 cubic metre), small gully (50-100 cubic metre) and very small gully (volume<50 cubic metre). In addition to this classification, the gullies were also classified based on soil texture as contained in Shahrivar and Christopher. (2012).

2.6.1 Area of soil loss (ASL)

Cross-sectional area (A) = Average width * Average depth

Area of gully = wd -- -- -- -- -- (5)

Net area of gully = wd_2 - wd_1 -- -- (6)

Where: w = width of gully channel, d = depth og gully channel , w_1 = width of gully channel before seasonal rainfall event, d_1 = depth of gully channel before seasonal rainfall event, w_2 = width of gully channel after seasonal rainfall event, d_2 = depth of gully channel after seasonal rainfall event. The total ASL =Net

2.6.2 Volume of soil loss(VSL)

Gully Volume = Cross-sectional area (A) * Length (L)

The gully volume was estimated using the formula: $V = \sum Li\, Ai$ -- -- (7)

Where Li is the length of considered gully segment (m) and Ai is the representative cross-sectional area of the gully segment (m^2)

2.6.3 Mass of soil loss

The mass of the soil loss was calculated by multiplying the soil loss volume for each subsection by the measured average bulk density of the soils which was an expression described by Wolf and Snyder (2003):

Mass of soil loss = Total volume of soil loss (VSL) × Soil δ_b -- -- (8)

Where: δ_b = Soil bulk density

2.6. 4 Determination of Rate of Soil loss*:*

Long- and short-term erosion rates were estimated using AGERTIM (Assessment of Gully Erosion Rates through Interviews and Measurements) developed by Nyssen, *et al.*, (2006) was chosen allowing us to understand the historic context of the gully development (Nyssen *et al.*, 2006).

Long-term gully erosion rates **(RL)** in tone $ha^{-1}\ yr^{-1}$ were calculated using the equation:

$$RL = \frac{VBd}{TC} \quad (9)$$

Where, V= estimated current volume of the gully (m^3), Bd= average bulk density of soils in the watershed, T= Time span of gully development in years, C= the watershed area in hectares.

Short-term erosion rates **(Rs)** in t $ha^{-1}\ yr^{-1}$ were determined to estimate the erosion rate in the study period.

$$Rs = (V - V_0)\frac{Bd}{TC} \quad (10)$$

Where V= Gully volume at the end of study period, VO=Initial gully volume at the beginning of the study period. T= Time span of gully development in years, C= the watershed area in hectares.

Erosion per unit gully surface (RP), in tone m^{-2} was determined by the formula:

$$Rp = \frac{VBd}{Ap} \quad (11)$$

Where V= the current volume of the gully, AP= Plane area of the gully (m^2).

2.6.3 Determination of some selected physical soil properties of the study area

Soil texture (particle-size analysis)

The soil texture was determined using the Bouyoucos hydrometer method as described by Jaiswal (2003). Forty grams of oven-dried, sieved soil were mixed with 50 mL of Calgon solution (i.e., 10% sodium hexametaphosphate), diluted to 500 ml with distilled water and then allowed to soak for at least 10 min. After soaking, the solution was mixed with a motorized mixer for 5 min, added to a 1-L sedimentation cylinder, and further diluted with distilled water to the 1000-mL final volume. Once this process was completed, the samples were left overnight to equilibrate to a constant temperature. Hydrometer readings were recorded at 40 s and 2 h after plunging ceased. The hydrometer readings were corrected based on readings from a soil-less blank as was previously described for the standard method. The following equations were used to determine percentages of total sand and clay from the abbreviated method,

$$\% \text{ Silt} + \% \text{ Clay} = \frac{(R\ 40\ sec - R\ Blank)}{(oven-dried\ soil\ weight\ in\ g) * 100} \quad \text{-- -- -- --} \quad (12)$$

$$\% \text{ Clay} = \frac{(R\ 2hr - R\ Bank}{(oven-dried\ soil\ weight\ in\ g) * 100} \quad \text{-- -- -- -- --} \quad (13)$$

$$\% \text{ Sand} = 100 - (\% \text{ Silt} + \% \text{ Clay}). \quad \text{-- -- -- -- --} \quad (14)$$

The bulk density

The soil bulk density was determined by collecting undisturbed soil sample using soil core sampler, the collected sample was oven dried at 105 °C for 24 hours to a constant weight. The volume of the soil core was determined from the internal radius and the height of the core. The mass of the oven dry soil was divided by its volume to obtain the bulk density of the soil in g/cm^3 (Jaiswal, 2003) in general, bulk densities greater than 1.6g/cm^3 tend to restrict root growth. Sandy soils usually have higher bulk densities (1.7 g/cm^3) because they have larger macro-pores and fewer micro-pore spaces.

$$Bd = \frac{ODM}{V} \quad \text{- - - -- -- -- --} \quad (15)$$

$$V = \frac{(\pi D^2 h)}{4} \quad \text{-- - -- -- -- -- --} \quad (16)$$

Where: ODM= Oven dried mass of sample

V= effective internal volume of container

D= diameter of the container

h= the height of the container

Soil porosity

The porosity of the soil was determined as described by Jaiswal (2003). A particle density of 2.65 g cm^{-3} was assumed. It was estimated by subtracting % solid space from 100. The ratio of bulk density to particle density was a measure of solid space in the soil.

$$\%Porosity = 1 - \left(\frac{Bd}{Pd}\right) * 100 \quad \text{-- -- -- -- --} \quad (17)$$

Where: Bd= bulk density

Pd= Particle density

Assessment of Residential and Farmland hazards Implication of Study Area

As part of this method the watershed area was visited with interviewees as a group and on an individual basis. The field visit allowed the interviewees to recall the changes in the area when they were young. Also, the assessment of financial loss was equally conducted by both interview and assumption based on yearly harvests obtained on the farmland and also cost of construction materials incurred, all converted using normal scientific conversions then it was converted to current monetary value, and measurement using AGERTIM (Assessment of Gully Erosion Rates through Interviews and Measurements) developed by Nyssen, *et al.*, (2006) Reconnaissance survey of the areas affected by gully erosion as well as Field measurements involving morphological parameters of the gully such as length, width and depth were carried out and recorded manually.

Statistical Analysis

Coefficient of variability (CV)

A CV test was carried out to test the degree of variability of the soil properties.

$CV = \frac{SD}{M}(100)$, Where; SD= standard deviation, M=mean -- - -- (18)

3.0 Results and Discussion

Predominant values of the bulk density across the various locations indicated high figures with the mean value of 1.64 g/cm^3 and CV value of 2.9002 % which revealed no variation of Bd across the locations. since any value above 1.6g/cm^3 was termed high and can reduce water infiltration into the soil effectively and subsequently initiated and aggravated erosion as a result of overland ponding and flow. This high mean value of Bd might be attributed to the fact that the sand content was higher relative to the silt and clay counterpart. Also, The results of the particle size analysis, Table 1, of the study area indicated high amount of sand relative to silt and clay, with corresponding mean values of 51.64%, 27.66% and 20.66% respectively, while their CV values were; 11.31%, 23.03% and 22.48% respectively, indicating moderate variability across the locations except for % sand which indicated slight variability of 11 .31 % across the locations. This result made it predominantly sandy loam across the study locations, with exception of few places like; Naiwa 1, Contarabi 2 & 3 which exhibited clay and sandy clay character. With the characteristics of the soil surface and other factors such as; high rate of deep tillage, overgrazing and facilitated by steeply sloping terrain, different types of soil, combined most have influenced erosion inn the area. This argument was supported by Egbuna *et al.* (2024) who reported a similar scenario, that the most common cause of erosion is the relatively uniform loss of the soil surface by excess runoff, which is facilitated by steeply sloping terrain, different types of soil and rocks, the removal of vegetative cover, and shoddy construction work.

However, the resulted high compaction of the soils surfaces in most areas, which might be attributed to the presence of sand concretions that often curtail gully incision at depth of their occurrence might have reduced the rate of erosion in some of the locations, this observation agrees with the reports of Heckman and Vericate (2018) who stated that soils with higher Bd were responsible for low rate of gully incision. . While the compaction of soils of other location might be the reason of the expansion of those gullies, since compacted sites can cause heavy infiltration reduction creating favorable condition for ponding and subsequently runoff, and runoff continues rills are formed and later converts to gullies. Even as also reported by Francisca *et al.* (2023), that sheets concentrates over time, creating rills and channels, and if left unchecked, it may spread into the enormous gullies. This was also observed by Gundiri (2023), who reported that Soils compacted sites, such as animal trails, footpaths, and unpaved roads, can concentrate storm run-off into small areas, thus contributing to gully erosion.

The result for particle density and %porosity, with their CV values, indicated low variability across the locations, since the values were 2.74% and 4.41% respectively. The natures of soil in these areas might have contributed to the erosion of these soils, because soils predominantly sand and sandy loam are mostly prone to washing away due to lack of cohesion, This finding was supported by Githinji *et al,* (2023), who stated that soils predominantly sandy and silty are easily washed away even by low velocity sheet erosion.

On the other hand, soils containing clay minerals tend to resist moving water, due to its ability to withstand water pressure. which also indicated high level of compaction and resistance to erosion, as displayed by sandy clay soil at Naiwa 1 and Contarabi 2. This observation was also in line with the findings of Nwankwoala and Igbokwe (2019), that soils found to be predominantly clayey and sandy clay with high Bd could resist breakage even with high velocity runoff.

As observed in Table 3, all the gully locations were located at the category of the gentle slope position (2 – 6%) except for Naiwa 1 which was termed, moderate sloping position (6-13%) category. The slope played a vital role in surface water runoff. For instance, places with moderate slope position (6 -13%) have high runoff rate and higher erosion characteristics and soil loss values of (293.71 Kg/ha, 556.72 Kg/ha and 602.67 Kg/ha) for Naiwa 1, Contarabi 3 and Milendi respectively, were recorded at higher altitude areas of Gashala. On the other hand, the lowest values of (195.37 Kg/ha, 87.35 Kg/ha and 71.49 Kg/ha) for Mugau 3, Contrabi 1 and Contarabi 2 respectively, were found at low altitude areas especially where the terrain assumed an almost flat nature, such as Naiwa 1 as suggested by Gundiri (2023) and Egbuna et. al. (2024), that high altitudes tends to generate high amount of runoff due to slope length and slope angle. Furthermore, according to the report of Otim *et al*. (2019) and Idowu *et al.* (2013), both runoff volumes and rates increases as watershed size increases; however, both rates and volume per unit of basin area decreases as the runoff area increases, which was similar to this study. Watershed size may determine the season at which high runoff may be expected to occur (Table 3). Due to the nature of the slope rate, gully activities were able to accelerate, because most human activities were carried out at the lower slope, while the streams and rivers originated from the highland areas. The resultant flood had succeeded in opening up a large gully volume of about 1020.0 m^3 at Milendi, area of 19.2 m^2 at Contarabi III, and length of 152 m long at Pavu (Table 2) resulting in loss of soil fertility as well as a rapid declined of agricultural productivity, at least 71.5 kg/ha/year mass of soil losses was observed from the gully, it does posed a potential threat to the inhabitants. Similar observation was also recorded by Mansur (2014), who reported that the expansion of the gully signify a major geomorphic progression in a varieties of broad environments. However, according to Idowu *et al.* (2013), overland flow was the upper reaches of the hydraulic length, shallow flow begins where overland flow converges to form gullies while channel flow as available man-made drains. Similarly, Githinji *et al,* (2023) stated, that as slope are widened, erosion occurs as water flows faster. As a result of this, soil loss increases proportionately to slope length and slope inclination. Furthermore, because, the slope length and slope incline combined gave a good estimate of soil erosion rate, erosion were caused by surface runoff towards the direction of slope. However, in terms of slope percentage which was the key driver of soil erosion, most areas got a lower percentage hence less susceptible to soil erosion. Consequently, the erosion present were attributed to other factors that causes gully erosion; such as over flooding and human factors such as blockage of drainage and indiscriminate cultivation activities. Furthermore, this attribution was also inn support of the work of Christoher *et al.* (2021) that Cultivation or over-grazing soils that are susceptible to gully erosion are always venerable to erosion when exposed to several disturbance.

The result of the length, width depth, area, volume, R.S.L, and M.S.L indicated high variability across locations with the exception of elevation which had low variability of 4.23% across the study area. It was noticed that little variation existed among the altitude of most region within Mugau area. The entire area had a low gradient especially on the lower sides, places like; Mugau, Contarabi 1, Pavu and Naiwa area has got high gradient. This clearly indicated there were some siltation on lower areas. This low level of slope might be attributed to the impact of soil deposition when washed from the high and sleep location. As a result of the act of deposition by moving water, gullies are mostly filled with soil deposit, thereby reducing impact of gully activities in such locations. This argument was supported by the findings of Gundiri *et al.* (2025), who reported that erosion was at minimal level when moving towards the down stream due to reduction in runoff velocity, which was in agreement with this study.

Places were no any practical runoff and erosion reducing factors exist, the amount of water and the rate at which its runs off, tend to be more prone to erosion since they were not subjected to soil erosion preventive measures, places such as Naiwa 2, Mugau and Contarabi.

The erosion per unit gully surface rate (RP) for the 10 gully locations for one year were presented in Table 2. The highest rate was recorded at Pavu with the value of 561.79-ton ha^{-1} yr^{-1}, followed by Milendi with the value of 525.60-ton ha^{-1} yr^{-1} it was evident by the CV value of 62.49% that there were high variation of rate of soil loss across the study locations which might be attributed to the topography, soil type, anthropogenic activities even as concluded by Cynthia et al. (2025) who stated that activities of man combined with other natural factors such as climatic and geomorphological, aggravates erosion when left unchecked. On the other hand, the lowest rate was recorded at Contarabi1, with value of 64.75-ton ha^{-1} yr^{-1} followed by Naiwa 1 with the value of 100.80-ton ha^{-1} yr^{-1}. The difference in rate of soil loss might be as a result of prevailing factors which were higher in other locations more than others. The higher the predictors the higher the rate of erosion in such areas. Furthermore, the more the vulnerability to factors of erosion, the higher the rate also. Contarabi 1 was a growing gully with little contributing variables than Pavu which was a sand mining site. This observation was also studied by Akubo *et al.* (2024) who reported that erosions were mostly responding to natural and artificial factors.

The pattern of soil loss progress exhibited both increasing and decreasing paths in the various locations for that particular year. The results showed that the rate of soil loss in Gashala areas were highest at Pavu and less at Contarabi1. These increasing and decreasing pattern might be as a result of control and management by the farmers and residents of the area, together with the watershed characteristics, as reported by Capra *et al.* (2004) and supported by Ezekiel *et al.*. (2024) which their findings were in line with this study. While, the decreasing pattern were perhaps due to the relative conservation practices such as; vegetative barriers, soil deposition and sand-bag lines, diversion by the water ways to other channels leaving the original flow channel and ridging across the slope direction, as reported by Hailu *et al.* (2015) that the major soil conservation strategies are broad-based terraces and cover cropping of bare soils. Therefore, conservation practices that address these parameters might be most effective even as reported by Zegeye *et al. (*2016), Sadiq and Ardo (2020), and Ezekiel *et al.* (2024) who stated that conservation and management practices that could inhibits erosion prevalence are most recommended for curtailing aggravating problems to avoid catastrophic effects on both agricultural, residential and economic variables.

Table 1: Some Soil Physical Characteristics of Gully in different Locations

S/N	LOCATION	COORDINATE WGS84: UTM	%SAND	%SILT	%CLAY	TC	BD (g/cm^3)	PD (g/cm3)	%Porosity
1	NAIWA 1	0294559 1141437	53.2	20.0	26.8	Sandy Clay	1.6	2.6	39.4
2	NAIWA 2	0294536 1141397	53.9	25.3	20.8	Sandy Loam	1.6	2.6	38.3
3	MUGAU 1	0293749 1143194	61.7	21.0	17.3	Sandy Loam	1.7	2.6	41.5
4	MUGAU 2	0293701 1143226	41.2	40.0	18.4	Silty Loam	1.6	2.6	43.6
5	MUGAU 3	0290701 1143226	47.3	32\.0	20.8	Sandy Loam	1.7	2.6	41.6
6	CONTARABI 1	0293707 1143215	50.5	26.7	22.8	Loamy	1.6	2.6	39.9
7	CONTARABI 2	0291650 1141958	48.2	25.0	26.8	Sandy Clay	1.6	2.5	40.2
8	CONTARABI 3	0291677 1141977	47.9	31.3	20.8	Sandy Clay Loam	1.6	2.7	43.6
9	MILENDI	0293463 1145662	56.7	22.0	21.3	Sandy Loam	1.7	2.7	43.1
10	PAVU	0292937 1145918	55.9	33.3	10.8	Sandy Loam	1.7	2.6	41.6
Mean			51.6	27.7	20.7		1.7	2.6	41.3
SD			5.8	6.4	4.7		0.1	0.1	1.8
CV			11.3	23.0	22.5		2.9	2.5	4.4

Key: Textural Class = TC, Bulk density = BD and Particle density = PD

Table 2: Characteristics of The Gully Channel Parameters across the Study Areas

S/N	Location & Coord (WGS84: UTM)	Length(m)	Width(m)	Depth(m)	Area (m^2)	Vol(m^3)	R S L (t /ha/yr)	M S L (Kg/ha)	Vol class	Elev(m)
1	NAIWA 1 0294559 1141437	30	6.2	2.0	12.4	372.0	100.8	210.8	Big Vol	545
2	NAIWA 2 0294536 1141397	90	2.8	2.0	5.6	504.0	311.0	293.7	Big Vol	550
3	MUGAU 1 0293749 1143194	95	3.0	1.2	3.6	342.0	339.7	206.2	Big Vol	535
4	MUGAU 2 0293701 1143226	60	5.5	1.7	9.4	561.0	205.9	324.7	Big Vol	501
5	MUGAU 3 0290701 1143226	90	2.4	1.5	3.6	324.0	321.8	195.4	Big Vol	501
6	CONTARABI 1 0293707 1143215	19	2.0	4.0	8.0	152.0	64.8	87.4	Med Vol	547
7	CONTARABI 2 0291650 1141958	40	3.2	1.0	3.2	128.0	132.5	71.5	Med Vol	560
8	CONTARABI 3 0291677 1141977	50	3.7	5.2	19.2	962.0	171.6	556.7	Big Vol	555
9	MILENDI 0293463 1145662	150	3.4	2.0	6.8	1020.0	525.6	602.7	Big Vol	543
10	PAVU 0292937 1145918	152	3.7	1.3	4.8	731.0	561.8	455.7	Big Vol	508
Mean		77.6	3.6	2.2	7.7	509.6	273.6	300.5		534.5
SD		46.6	1.3	1.3	5.0	311.2	171.0	184.9		22.6
CV		60.1	36.7	61.5	65.3	61.1	62.5	61.5		4.2

Key:UTM = Universal Transverse Mercator, Vol = Volume, RSL = Rate of soil loss, MSL = Mass of soil loss, Elev = Elevation and Coord = Coordinate

Table 3: Some Site and watershed characteristics of the Study Area

S/N	LOCATION	COORDINATE WGS84: UTM	Slope	Vegetation	Land use	Probable causes of gully erosion
1	NAIWA 1	0294559 1141437	Moderately sloping (6-13%)	Few grasses & trees	Corn and groundnut	Excessive cultivation, runoff/steep slope
2	NAIWA 2	0294536 1141397	Gently Sloping (2-6%)	Trees, shrubs & grasses	Not cultivated	Landforms
3	MUGAU 1	0293749 1143194	Gently Sloping (2-6%)	Few grasses & trees	Not cultivated	Overgrazing/cattle route
4	MUGAU 2	0293701 1143226	Gently Sloping (2-6%)	Trees, shrubs & grasses	Not cultivated	Indiscriminate road construction
5	MUGAU 3	0290701 1143226	Gently Sloping (2-6%)	Trees, shrubs & grasses	Rice and corn	Excessive land use
6	CONTARABI 1	0293707 1143215	Gently Sloping (2-6%)	Trees, shrubs & grasses	Rice, corn and maize	Excessive cultivation, runoff
7	CONTARABI 2	0291650 1141958	Gently Sloping (2-6%)	Trees, shrubs & grasses	Rice and maize	Excessive land use
8	CONTARABI 3	0291677 1141977	Gently Sloping (2-6%)	Trees, shrubs & grasses	Not cultivated	Excessive land use, runoff
9	MILENDI	0293463 1145662	Gently Sloping (2-6%)	Few grasses & trees	Not cultivated	Minor footpath, runoff
10	PAVU	0292937 1145918	Gently Sloping (2-6%)	Few grasses & trees	Not cultivated	Laterite excavation or Sand mining

Key: UTM = Universal Transverse Mercator

Hazards Assessment

Gully erosion had caused considerable damage to infrastructure like roads, residential buildings, schools and farmlands in Gashala area, and it's still posing serious challenge to arable lands around the region (Plates 1, 2 and 3). Though, the damages caused by this singular phenomenon cannot be easily quantified, but properties worth millions of naira have been destroyed, animals and human lives has lost to gully erosion in the study area even as supported by Egbuna *et al.* (2024) who reported that, . The monster has continued to elude efforts to stop it from spreading and damaging more valuable land and properties, as well as occasionally human lives, making it extremely difficult to control the growth of gullies in the southeastern part of Nigeria. Furthermore, Ezekiel *et al.* (2024) also observed a similar scenario at Northern Adamawa State, where he argued that the problem of the gully erosion has aggravated the loss of socio-economic value such as income, amount and kind of education ethnic origin and religious background which was in line with this findings.

However, from the result of study conducted by both interview and measurement (AGERTIM) it was observed that 30% of inhabitants of the area have their houses under threat by erosion, while 70% of farmlands in the area are affected by erosion at different stages of development (Table 4) An estimated average decline of 35% in farm productivity was observed right from the time the land was put under cultivation to date due to decline in soil fertility, volume of soil loss and rate of soil loss. The rate at which erosion was going in the area was really alarming. Farms cultivated by my father were no longer cultivated, my own inherited farmland at Contarabi had been abandoned, because it was no longer fertile and productive due to erosion. The little farmlands available to us had to be sheared, by shearing, means putting pressure on the little portion of land left, with increasing population, feeding had become a problem because of limited productive lands that can sustain a family needs, as such there was high rate of food insecurity in the region.due to increasing population and hunger. These series of factors have reduced our agricultural income by at least 30%. this devastating effects of erosion was also found to be common in the southeast according to Christopher *et al.* (2021). These effects range from loss of farmlands, loss of vegetation, effects on properties, a threat to lives, effects on infrastructure, soil loss and sedimentation, creation of badlands to other multiplier effects. Loss of farmland: Large areas of farmlands have been destroyed or virtually lost due to rampaging gullies.

Other farmers are equally facing the same scenario of losing farmland to erosion, putting pressure on the little left, in so doing, family crises erupt due to lack of land, even to the extent of losing lives, farmers and herders' crises etc. So many lives and properties have been lost due to this singular reason, 'erosion' in Gashala, directly or indirectly.

Management Strategies

Lack of sensitization programs was one of the key concerns at Gashala, because people were not sensitized about the implication and importance of soil erosion. However, lack of funds to conduct sensitization programs and lack of personnel was also a major hindrance. This clearly indicated that the government and other stakeholders needed to increase allocation on soil conservation measures. It was also realized that 30 percent of the sampled population were trained on suitable farming methods while 70 percent were not trained. Suitable farming methods are the key factors to curb soil erosion. Some of the key factors that lead to soil erosion in sandy preferential areas were sand mining or laterite excavation, Indiscriminate construction projects especially roads and overgrazing/cattle route. Gashala is one of the major areas where sand mining and some of these activities were carried out excessively, especially during the rainy season. Majority of sampled population in the area portrayed a zone where sand mining was not regulated. This was a phenomenon emphasized by Christopher *et al.* (2021) supported by Egwuonwu *et al.* (2019) that Poor road construction aided by increased runoff generation due to urbanization cum more corrugated roof that lead to an abrupt build-up of concentrated flow. By this, it becomes clear that land-use change might impact gullies more than climate change. Man's action or animal burrows along channels susceptible to gully erosion could trigger it if a waterfall-like feature is created by such action where water plunges to scour the area with a renewed vigor. This argument was in support of this study.

This is a call for intervention from the government to regulate sand mining. Farms should always be encouraged to be managed properly.

Understanding the controlling factors of gully head mi-gration and lateral expansion of gullies was crucial to design appropriate gully control measures. Retreat rates depended most strongly on the stability of the top soil and the volume of runoff flowing down from the high hill. The longitudinal retreat for deep gullies contributes the most to the volumetric gully erosion in the area. Therefore, regrading the gully head and bank slopes could reduce the occurrence of gravity-induced bank collapse for deep gullies. This was in accordance with the study of Liu, Zhang, Zhu and Hu (2022) that, Simple grouting and stabilization can arrest the progress of gullies, especially when applied at a very early stage of development, excess runoff can be channelled to a local base-level stream or river by the construction of drainage. These drainages must get to the local base stream or river level; otherwise, they form triggers at their discharge points. Materials to be used for the construction work should be acid-resistant, especially where hydro-geochemical analysis of the surface and groundwater in the vicinity of the gully shows acidity. Groundwater level influences the development and growth of gullies; therefore, controlling groundwater level through the installation of wells and dewatering facilities at strategic locations is necessary to check this. The pumped water can be put to other domestic and industrial uses. Similarly, afforestation campaign can also help in curtailing erosion, by advocating and practicing tree planting exercise. This practice was in line with the report of Ocheli, Ogbe, & Aigbadon (2021) who observed that, an extensive afforestation program can be very effective in controlling gully erosion, especially when well applied. This helps to protect the soil from the direct impact of raindrops and runoff, as well as maintain the moisture content of the soil at a responsible level during the dry season.

Plate 1: Typical farmland been abandoned as a result of gully erosion at Mugau

Plate 2: Road nearly cut off by a gully erosion at Mugau 2

Plate 3: Another scenario of farmland abandoned as a result of gully erosion at Contarabi 3

Plate 4: Gully erosion at early stage of development at Contarabi 1

Plate 5: A typical example of gully hazard where a bridge is about to collapse at Mugau 2

Plate 6: A farmland left uncultivated due to gully erosion menace; this is also a grazing area. Naiwa

Plate 7: A typical example of a deep gully >200cm^3 that made a farmland unproductive at Contarabi

Plate 8: A gully erosion site that can no longer be used, as can be seen of cowpea been destroyed at Contarabi 3.

Conclusion

The problem of land degradation is widespread within Gashala, which also faces poverty and repeated natural disasters, such as droughts and floods, sediment fills up manmade reservoirs, bleeds agricultural lands from its fertility, erodes away the agricultural lands completely, continuous cultivation under the increased population pressure, roads cut off, economic downturns and generally low agricultural productivity which can only be maintained with artificial fertilizers that in many cases are too expensive and also can be harmful to humans. No matter where they result from-natural or human-induced-climate changes, climate variations affect the resilience of diverse ecosystems and sustain the livelihoods of people living in these zones. Among the problems contributing to land degradation are a lack of knowledge about the nature, extent and severity of the condition, and an inadequacy of tools and methods for assessing, monitoring and managing the situation. Minimum soil loss was experienced at Contarabi 1 &2. However, Higher rates of soil loss were experienced at Contarabi 3, Mugau, Milendi and Pavu. This can be attributed to several other factors emanating from environment. Most of the soil loss was experienced within agriculturally productive regions thus showing evidence of the fact that agriculture within Gashala area basically contributes to soil loss. This can be attributed to farmers not professionally managing their land.

As such, a more comprehensive soil conservation method will involve the application of certain hydrological or bioenvironmental processes so as to control the overland flow and excessive runoff. Therefore, to prevent, control or reduce all the damages due to soil erosion, the best way to combat in each area, identification of the factors which affect soil erosion as the first measure

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