

Geotechnical Investigation of Gully Sites in Bagadaza and Surrounding, Gombe North, North-East Nigeria

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Abstract

Despite the seriousness of soil erosion and gully formation problems prevalent in Bagadaza area, limited investigation and research have been carried out. This research is aimed at investigating the geotechnical properties of soils that contribute to the formation of gully and provides mitigation measures. In order to attain the objectives, different journals, books, previous studies, and papers related to soil investigation and index properties of soils has been reviewed. During field work, visual identification of soils, test pitting, logging, disturbed and undisturbed soil sampling were done. Laboratory test results show that the gully soils are dominated on average by 3.26% Sand, 3.43% Silt and 93.31% Clay. The Liquid Limit varies from 32.5 to 76.6%, and Plasticity Index from 10.54 to 40.06%. The Shrinkage Limits varies from 5.71 to 21.43% and the Free Swell from 40 to 80. The Unified Soil Classification System shows that the gully soils are composed of 11.8% Silt, 17.6% Elastic Silts, 23.5% Fat Clays and 47.1% Lean Clays. The Specific Gravity of the soil samples varies from 2.50 to 2.59, the optimum Moisture Content ranges from 23.1% to 23.2%, while the Maximum Dry Density ranges from 1.16g/cm³ to 1.57g/cm³. The Over Consolidation Ratio of the top soil is greater than 1. The results obtained in this investigation, especially from the Atterberg limit, sieve analysis, compaction test and specific gravity tests, show that the soils are cohesive soils with low dry densities and low specific gravity which mainly contributes the initiation of erosion gully formations in the study area. Of all the preventive and mitigation measures, vegetation is the simple and most effective way of keeping the soil stable. However, a combination of effective structures coupled with vegetation will give rise to a very productive way of combating erosion and gully hazard in the study area.

KEYWORDS: Soil erosion, Gully formation, Bagadaza, Geotechnical properties, Mitigation measures

INTRODUCTION

Gully erosion is an episode that is devastating the scenery of southeastern Nigeria and one of the most threatening global environmental hazards. The gully started in the middle of the nineteenth century, about 170 years ago with the

initiation and propagation of narrow channels which rapidly widened by erosion into major gullies, gorges, and canyon proportions (Egboka and Nwankwo, 1985; Ankidawa *et al.*, 2020). The rate of gully growth in southeastern Nigeria is estimated at 20–50 m/year (Egboka and Nwankwo, 1985, Abdulfatai

et al., 2014). Gully erosion involves detachment and transport of soil particles by natural agents such as gravity, running water, ice mass, wind, freeze–thaw, and anthropogenic from the upland topmost units (Fernandez *et al.*, 2003; Geleta, 2011; Ashiagbor *et al.*, 2013; Okengwo *et al.*, 2015). This results in sediment deposit at the river networks leading to river morphological changes and reservoir sedimentation problems such as the reduction of water storing capacity of the reservoirs by blocking the porosity of the rock reservoirs (Fernandez *et al.*, 2003; Geleta, 2011; Ashiagbor *et al.*, 2013; Okengwo *et al.*, 2015). Based on the studies by Brice (1966) and Abdulfatai *et al.* (2014), gully erosion has been extended to include a drainage channel that transmits transient flow, steep side, steeply sloping or vertical head muffler with a width greater than 0.3m and a depth greater than 0.6m. Gully development in the Moldavian Plateau of Romania was studied using the Caesium 137 technique, and it was discovered that 57% of the gullying occurred during the cold season and 43% occurred during the warm season (Ionita, 2006). A gully erosion susceptibility assessment and management hazard-prone area was investigated in India using multivariate additive regression splines, flexible discriminate analysis. Random forest and support vector machine as well as field surveys. They built a gully erosion susceptibility model, which is useful for land managers and policymakers, as they initiate remedial measures and erosion hazard mitigation in prioritized areas (Gayen and Bai, 2019). Geotechnical assessment of soil in erosion prone zone was carried out in the kkumalai Mountain foot, Kanyakumari District Tamilnadu to identifying the geotechnical parameters that influence soil erodibility, such that suitable soil stabilization can be ascertained (Subash *et al.*, 2016). Geotechnical investigation and assessment of earthquake factors were

carried out at Hurghada City, Red Sea, Egypt (Ismaiel, 2018) and it was discovered that the allowable bearing capacity of the investigated soils ranged from 1.5 to 2.5kg/cm², and therefore recommended deep pile foundations in the region. Soil erosion models at Densu River Basin in Ghana using revised universal soil loss equation (RUSLE) and geographic information system (GIS) tools were developed to estimate the annual loss and found out that 88% of the basin has low erosion risk, and 6% moderate erosion risk. They further stated that erosion risk is high at 3% and severe at 3% of the basin (Ashiagbor *et al.*, 2013). Rainfall-runoff slope length and steepness and land cover management have been used for soil erosion modelling in southeastern Nigeria (Egboka *et al.*, 2019). They described slope length as the distance from the source of runoff to the point where either deposition begins, or runoff enters a well-defined channel that may be part of a drainage network. The geologic setting, tectonic and upliftment, geotechnical properties of soil, mining activities, farming, deforestation, and overgrazing operations have been widely reported to be the major causes of gully erosion in southeastern Nigeria (Igwe and Orji, 2019; Ankidawa *et al.*, 2020). Onwuemesi (1990) investigated the hydrogeophysical and geotechnical properties of soils in Nsukka and its environs and discovered that the areas were prone to gully erosion due to low plasticity and very loose compactness of the soils. The characteristics and erodibility potentials of soils from different geologic formations in Anambra State, southeastern Nigeria has been investigated (Igwe and Egbueri, 2018). The causes, consequences, and control measures of gully erosion in southeastern Nigeria have been revealed (Egboka *et al.*, 2019). The dangers posed by gully erosion which include loss of farmland and vegetation, isolation of villages and towns as well as barren and infertile land have

been well published by many scholars in scientific journals such as (Igwe, 2012; Igwe and Egueri, 2018; Egboka *et al.*, 2019) but the proper understanding of its genesis and continued expansion is relatively lacking. Also, few studies on gully erosion have been conducted at a large spatial scale because of its time demanding and challenges encountered during the studies. The differences in susceptibility to gully erosion within the sedimentary formations have not been adequately studied. The adopted methods for controlling gully erosion in southeastern Nigeria are inappropriate. This is because gully erosion continues to originate and expand in southeastern Nigeria. These necessitated the field campaigns and mechanical soil laboratory analyses of sediments in the study areas to provide detail geological and geotechnical information on the origin and continued expansion of the erosion gully. Once gullies are initiated, the soil properties become responsible for their rapid propagation (Okagbue and Ezechi, 1988). Both natural attributes (rainfall, topography, engineering-geological properties of soils, slope of the land surface) and associated human activities contribute to initiation and propagation of gullies. Osadebe and Akpokodje (2007) concluded that impermeable nature of the cohesive top soil assist in initiating the gully process by encouraging overland flows that lead to the formation of rills and eventual gullies. In addition, the soil erodibility index is influenced by both physical and chemical properties of soil (Osadebe and Akpokodje, 2007). More so, one of the factors that endanger water and soil is soil erosion. The major cause of land degradation around the world is soil erosion by gully erosion (Nampak *et al.*, 2018; Rizeei *et al.*, 2016). Gully erosion is defined as a deep channel that is formed by concentrated water flow, which in the process removes surface soils and materials. The aim of this research is to investigate the geological and

geotechnical properties of soils contributing to the formation, development and expansion of gully erosion in Bagadaza area and to provide appropriate mitigation measures that could effectively be implemented.

The Study Area

The study area lies within the Gongola arm of the Upper Benue Trough of northeastern Nigeria. It forms an integral part of Gombe (sheet 172 NW) and lies within longitude 11°06' and 11°15'E and latitude 10°25'30" and 10°16'30" N (Figure 1). The study area is located on a spur with gully developed from narrow valleys which could have provided pathways for runoffs over time. Furthermore, these valleys developed into active and complex gully that presently pose serious threat to lives and property, house and agricultural lands. The formation of gullies has become one of the greatest environmental disasters facing the study area (Bagadaza and its environs). The environment 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 destroy farmlands and lowers agricultural productivity and human settlements. The situation is getting worse annually. 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 Collapsing or with exposed foundations. Residents of Bagadaza community 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. Therefore, solving the gully erosion problem in Bagadaza community requires concerted research efforts. It was this exigency that prompted this study which is aimed at determining the geological and geotechnical factors leading to the formation, development and expansion of gully sites In Bagadaza area of Northeast Nigeria with a view of recommending appropriate control measures. The area is characterized by wet and dry seasons, having a mean annual

rainfall and temperature of 850mm and 32°C respectively. Rainfall within the study area occurs mostly between June and September. Precipitation is associated with a storm of high intensity, especially in July and August. The vegetation of the study area can be described as Sudan savannah with open grassland and shrubs which dries up during the dry season, the vegetation comprises of scattered shrubs and trees.

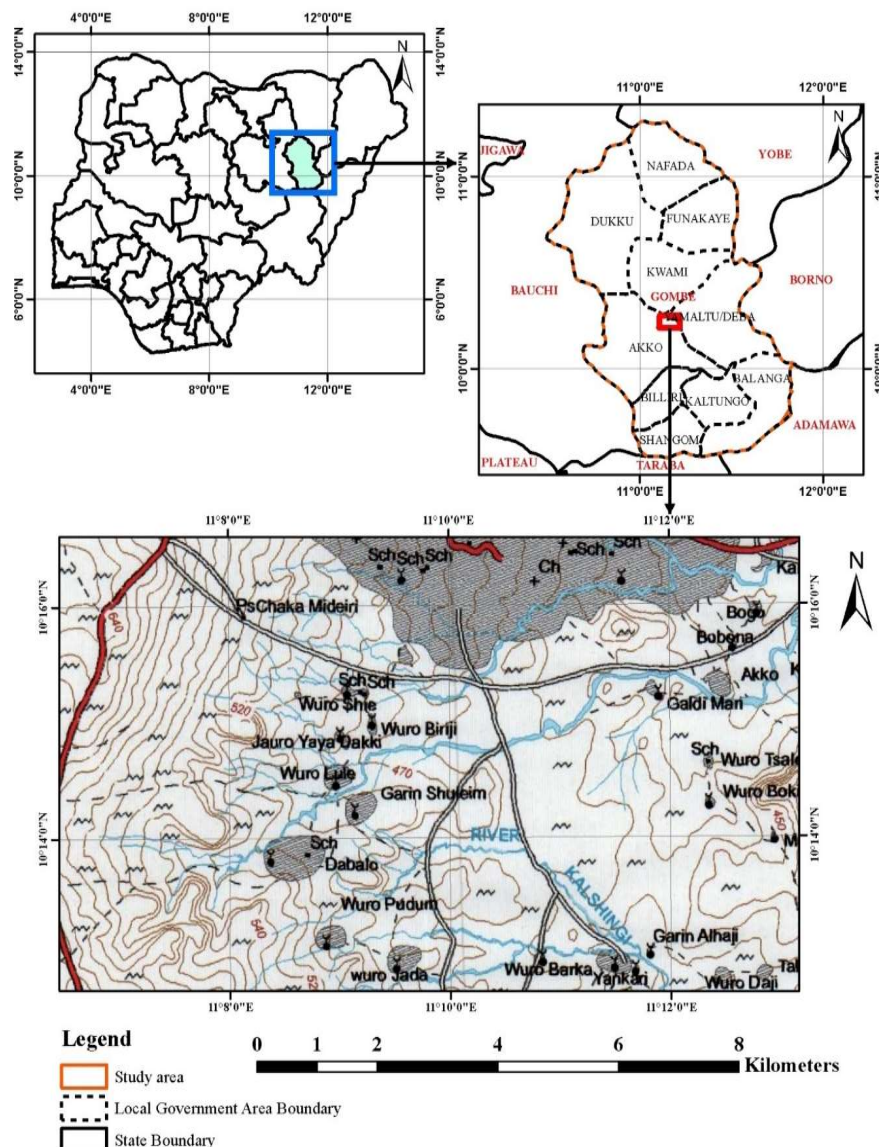


Figure 1: Topographical map showing the study area

Geology of the study Area

The study area is underlain by four geologic Formations, they include Yolde

Formation, Pindiga Formation, Gombe Sandstone, and Kerri-Kerri Formation. The Yolde Formation is Cenomanian in age, deposited in continental to the marine environment it comprises of sandstone and shale at the base while the top consists of sandstones, shales, and calcareous sandstone (Carter *et al.*, 1965; Dupreez and Barber, 1965; Abubakar *et al.*, 2008). The Cenomanian-Santonian marine Pindiga Formation, consisting of thick marine shale, with some limestone beds toward the base (Zaborski *et al.*, 1997). while the Gombe Sandstone is the last Cretaceous deposit in the Gongola arm of the Upper Benue Trough. It is underlain by the marine Pindiga Formation and overlain by the Kerri-Kerri Formation. The lacustrine to deltaic Gombe Formation consists of well-bedded fine to medium-grained friable, ferruginous sandstone, siltstone, and

shale with ironstone (Carter *et al.*, 1965; Dupreez and Barber, 1965). Three major lithofacies characterize this formation, they include the basal transitional portion, bedded facies, and red sandstone facies. At its base, it comprises intercalation of silty shale occasionally, with plant remains (Zaborski *et al.*, 1997). The continental Kerri-Kerri Formation ended sediment deposition in the Upper Benue Trough; it consists of sandstones, siltstones, and shales. The complex geologic crystalline bedrock formed the base on which the relief of the study area was established. The elevation of the study area is within 330 m to 721 m. The flat-topped to conical hills characterized the landscape; this landscape is the outcome of dissection and stream incision in the area after the deposition of sedimentary formation during the late Cretaceous period.

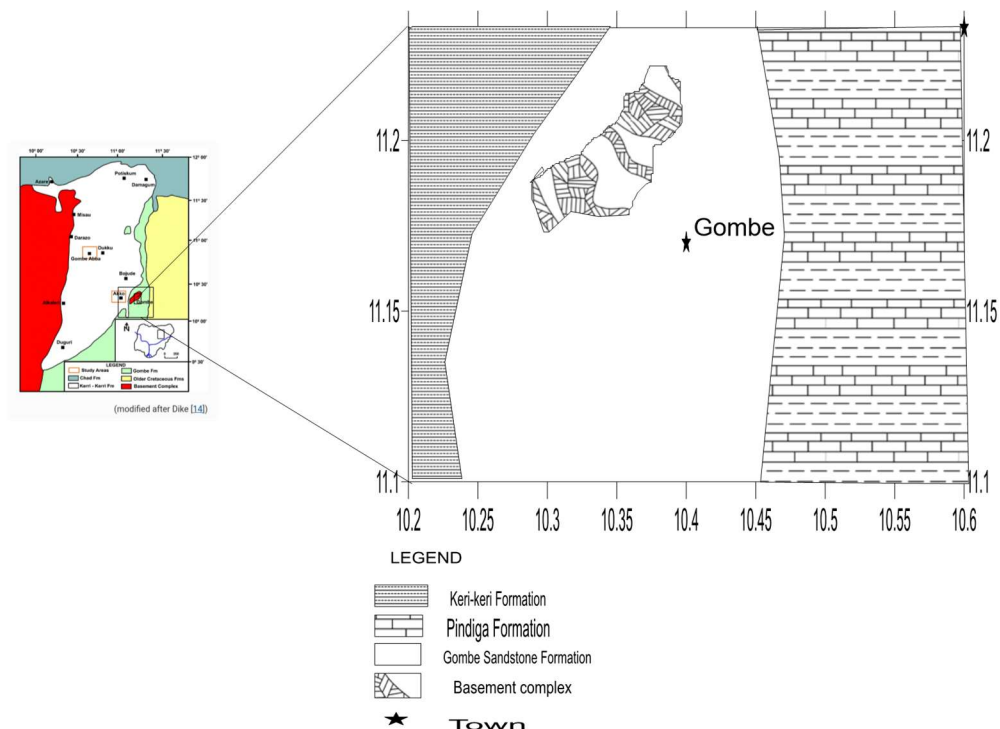


Figure 2: Superficial geologic map of the study area

METHODOLOGY

A reconnaissance survey and detailed mapping of the study area was carried out

to identify gully sites, geological conditions, and the effect of length and steepness of slope, land cover management, and human activities to delineate the origin and continued expansion of gully erosion in the study areas. Field equipment used for the study and sampling include a map of the study area, Sampling bags, Global Position System (GPS), Camera, measuring tape, Twain Masking tape, Markers, Field note book, Pen, Pencil, Geological hammer, Shovels, Diggers and compass clinometers. The length and slope steepness (angle of slopes) were measured using the measuring tape and inclinometer respectively. The depth, width, and lateral extent of the gullies were measured using the measuring tape to determine the gully intensities. The use of the Global Position System (GPS) aided the assessment of land use and land cover change as well as the elevation in the study area. Soil samples were collected from the gully walls at various depths ranging from 5.0 meters to 19.0 meters. The techniques for sample collection follow those of Spangler and Handy (1973). Thirty (30) gully wall Profiles in fifteen (15) gully locations were examined and a total of thirty (30) soil samples were collected and packaged in polythene bags for laboratory analysis to determine the index properties of the soils. A detailed geological field mapping which entailed ground traversing, description of the rock types, delineation of formational boundaries and dip and strike measurements are recorded on a base map. Representative samples are taken from Libya (Central part of the study area), Riyal (Northeastern part), Hammadukafi (Southeastern part), Mettako and Masina. Madina quarters, Duniya dam, Bye pass, Wuro daji, Wurojuli, Wuroshie, as shown in Figure 3.

The soil samples were subjected to laboratory testing for natural water content, grain size distribution (sieve analysis), Atterberg's Limit Test (Liquid limit, Plasticity index and Plastic limit test), California Bearing Ratio, Standard compaction Test. The plastic limit of the sediments was determined by rolling out a thread of the fine portion of soil on a flat, non-porous surface. The test was performed in accordance with procedures specified by the American Society for Testing Materials (ASTM Standard D 4318) (British standard, 1990; Ishaque *et al.*, 2010) and the British Standard Method for Testing Soils (B.S 1377–1990) (Adeleye and Fayose, 1978) for civil engineering purposes. The liquid limit was measured using the Casagrande method and the procedure described by ASTM Standard 4318 (British standard, 1990). The Atterberg tests were done to determine the behaviour of the soils. The grain size analysis of the sediments was carried out using the hydrometer method. This is to determine the particle size distribution of the soils. The compaction test which shows the optimum moisture content (OMC), and the maximum dry density (MDD) was carried using a proctor soil compactor. The purpose is to understand the compaction characteristics of different soils with the change in moisture content. Permeability of the sediments was determined using the falling head permeability technique described by Munch and Douglas (1985). The purpose is to determine the hydraulic conductivity of the soils. The shear strength of the sediment was determined using a vane shear apparatus as described. The purpose is to determine the shear properties of discontinuities in soils of the study area.

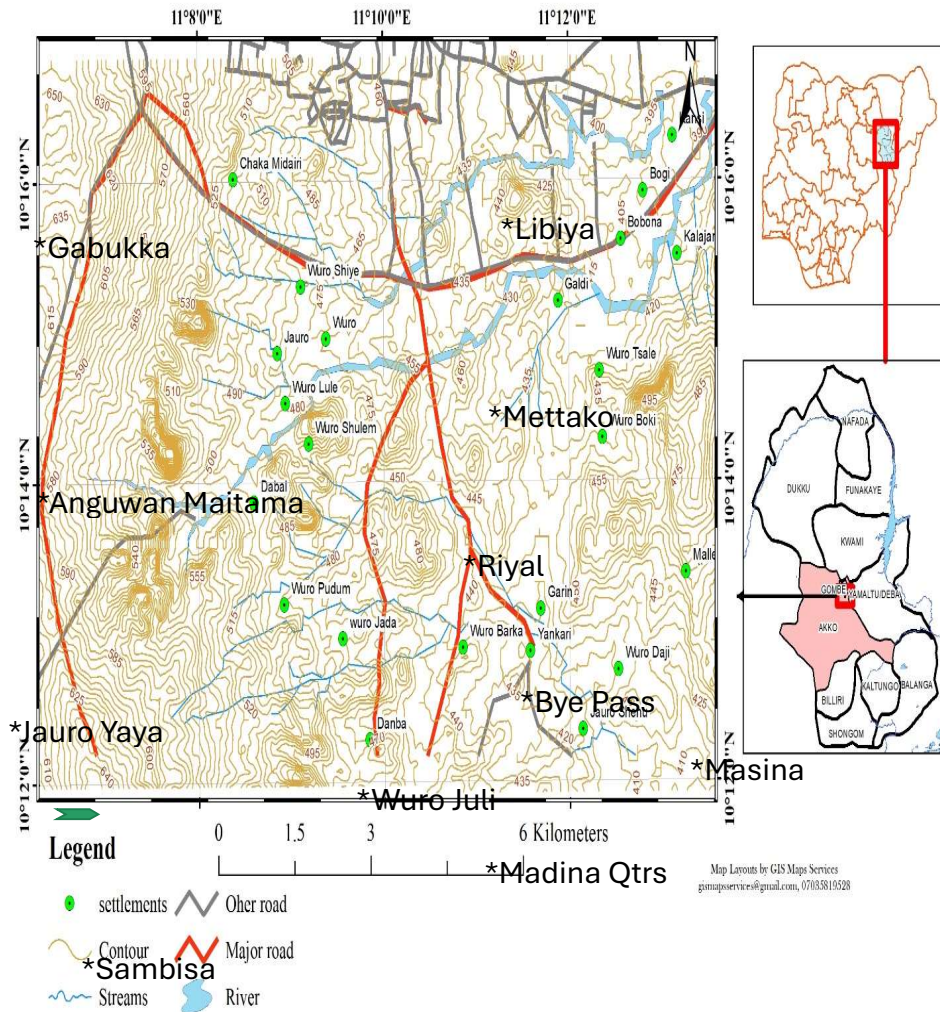


Figure 3: Map of the study area showing sampling locations

RESULTS AND DISCUSSION

Table 1 shows the results of slope steepness (angle of a slope) and the gully intensities in the study area. The slope is the gradient or land inclination. The standard slope descriptors, a slope value $< 0.3^\circ$ indicate flat level slope, $0.3 < 1.1^\circ$ depict nearly level, $1.1 < 3^\circ$ indicate very gentle slope, $3 < 5^\circ$ indicate gentle slope, $5 < 8.5^\circ$ indicate moderate slope, $8.5 < 16.5^\circ$ indicate strong slope, $16.5 < 24.0^\circ$ depict very strong slope, $24 < 35.0^\circ$ indicate extreme slope, $35 < 45.0^\circ$ indicate steep slope, $> 45.0^\circ$ indicate a very steep slope. Based on the results obtained compared with the standard slope descriptors, the degree of steepness of the gullies in the study area ranges from

strong slopes to a very steep slope. It depicts that gully erosion is more pronounced in areas with high steepness. This finding agrees with the finding of Igwe (2015) and Ankidawa *et al.* (2020) who found that gullies with steeper slopes have higher erodibility potentials than flat ones. A reconnaissance and intensive field surveys of the study areas reveals the long length and steepness of the slope, the gully intensities which vary from low to a very high degree of erosion the elevation of the study areas which ranges from < 250 to ≥ 450 m. The generated land cover/ land use maps from New map-30 m, which includes water resources, built-up, road network, gully area, vegetation/derived savannah and farmland contributed to the origin and continued expansion of gully

erosion in the study areas. It was also observed that some of the areas have a long hilly slope which increases the amount of cumulative runoff and the steepness of the slope. This increases the velocities of the runoff and exposes surface pores of the land which eventually enhances the initiation and propagation of gully erosion. The prevalence of gully erosion in the study areas also includes human activities such as bush burning, agricultural, overgrazing, deforestation, and deliberate refusal to plant/replanting of trees, faulty road constructions and drainage systems as well as nonchalant attitude of the affected community people. The Bima Sandstone comprising of sequences ranging from unconsolidated to poorly consolidated sands (310m thick), thin intercalation of clay stone and siltstone bands, lenses, and poorly sorted and medium to coarse-grained. These units are interbedded by shale and fine sand layers (25cm thick) in a few of the gully sites. The Pindiga Formation comprising of predominantly medium to coarse, thickly friable, very poorly sorted to poorly sorted, and poorly cemented sandstones with some fine sand at the base. The topmost part of the Pindiga Formation consists of reddish sands.

Table 1: Result of soil analysis on the sample from gully sites of study area

Location of the gully	Liquid limit %	Plastic limit %	Plasticity index %	Compaction O.M.C mg/m ³	MDD mg/m ³	Permeability cm/s	Shear strength kg/cm ²	Sand %	Sill %	Sediment description
Gabukka	4.00	12.8	8.8	6.40	1.70	2.11X10 ⁻³	26.0031	100.00	0.0	sand
Mettako	46.12	5.5	40.6	10.30	1.80	3.61x10 ⁻³	28.0024	98.0	0.12	Sill
Libiya A	6.42	8.9	2.48	7.80	2.40	3.23x10 ⁻³	24.00.36	93.024	2.4	Sill
Libiya B	5.97	7.8	1.83	7.50	1.60	2.58x10 ⁻³	29.00.41	96.013	1.3	Sill
Wuro biriji	4.62	21.1	5.52	8.20	2.80	3.4x10 ⁻³	23.00,38	93.2.6	2.6	Sill
Wuro juli	6.29	6.3	0.41	10.70	2.50	2.46x10 ⁻³	18.00.20	100	0.0	Sand
Wuro daji	5.10	10.8	4.51	6.80	1.30	2.17x10 ⁻³	30.00.23	97.0	1.1	Sand/sill
Wuro shiye	7.83	8.6	1.50	7.20	1.10	3.18x10 ⁻³	27.00.32	98.0	1.3	Sand/sill
Bypass	16.14	18.1	5.27	9.60	1.70	2.01x10 ⁻³	18.00.23	100.00	0.0	Sand
Maddina	32.50	7.9	8.24	6.40	1.10	2.16x10 ⁻³	26.00,29	100.00	0.0	Sand
Riyal	14.30	8.1	4.00	10.70	2.70	2.31x10 ⁻³	19.00.32	98.0	2.4	Sill
Hammadu kafi	18.45	18.6	0.7	8.47	2.50	3.47x10 ⁻³	24.00,33	94.52	1.6	Sill
Massina	8.00	21.9	8.45	7.48	1.40	3.56x10 ⁻³	28.00.27	98.0	1.2	Sand/sill
Duniya dam A	14.47	19.8	11.12	9.74	1.70	2.16x10 ⁻³	18.00.32	97.3	1.3	Sand/sill
Duniya dam B	16.56	10.6	4.6	8.69	1.50	2.17X10 ⁻³	19.26	100.00	0.0	sand
Range										
Mean	13.78	12.45	7.20	8.39	1.85	0.038	23.8	97.54	1.02	

Result of the geotechnical analyses

Table 1 reveals the results of soil analysis carried out on soil samples from gully sites of the study area. The liquid limit (LL) ranges from 32.5. to 46.1% with a mean value of 9.79%, plastic limit (PL) ranges from 5.5 to 21.1% with a mean value of 13.41%. The plasticity index (PI) which is a measure of the plasticity of the soil is determined by the difference between the liquid limit and the plastic limit and the value ranges from 0.4 to 11.12% with a mean value of 7.33%. The sands and silts content range from 86.0 to 96.0% with a mean value of 90.9% and 1.0 to 5.0% with a mean value of 3.0% respectively which coincides with the research work by Obiadi *et al.* (2014) and Igwe and Egbueri (2018). The compaction which shows optimum moisture content (OMC) and the maximum dry density (MDD) ranges from 6.40 to 10.70mg/m with a mean value of 10.62 and 1.40 to 2.00 mg/m with a mean value of 1.68. The shear strength of the soil is the result of friction and interlocking of particles and possibly cementation or bonding at the particles (Surendra and Sajeev, 2017). The shear strength parameters are the cohesion and the friction angle. The cohesion value obtained varies from 0.23 to 0.43kg/cm² with a mean value of 0.30kg/cm². The shear angle of internal friction ranges from 24.0° to 32.0° with an average value of 24.7°. The shear strength enhances the initiation of gully erosion by encouraging overland flows. According to Surendra and Sajeev (2017), plasticity index (PI)=0 indicate sand, non-plastic, and non-cohesive, >0 <7 indicate sand/silt, low plastic and partly cohesive, 7 to 17 indicate silt/clay, medium plastic, and cohesive and >17 indicate clay, high plastic and cohesive. The angle of shearing resistance <28° indicates very loose compaction, 28 to 30° indicates loose, 30 to 36° suggests medium compaction, 36 to 41° indicates dense compaction, and >41° indicates very dense compaction (Surendra and Sajeev, 2017;

Ankidawa *et al.*, 2020). The soils in the gully sites of the study area are low plastic which signifies poor cementing and insufficient binding materials suggesting a high susceptibility to gully erosion and high instability. The low moisture content indicates a high capacity for water retention during rainfall. The low value of cohesion and angle of internal friction results in soil cracking. Highly sandy with low silt content and very loose compaction reveals a very loose lithology. The values obtained for hydraulic conductivity ranges from (2.1 to 3.2) × 10⁻³cm/s with a mean value of 2.67 × 10⁻³ cm/s suggesting high permeability. Based on the U.S. Bureau of Reclamation and revealed by (Surendra and Sajeev, 2017), soils are classified as (i) Impervious: k (Coefficient of permeability) less than 10⁻⁶cm/s, (ii) Semi-pervious: k between 10⁻⁶ and 10⁻⁴cm/s and (iii) Pervious: k greater than 10⁻⁴cm/s. From the values obtained, it shows that the soils are highly permeable suggesting high infiltration rates thereby giving rise to high flow velocities, high seepage pressure, and high internal erosion potentials (Okengo *et al.*, 2015). The results of soil samples from Mettako, Massina, Riyal, Libiya and Wuroshiye: liquid limit (LL) ranges from 21.40 to 27.10% with a mean value of 24.09%, plastic limit (PL) ranges from 20.80 to 30.30% with a mean value of 26.79%. The plasticity index (PI) ranges from 0.00 to 5.40% with a mean value of 2.70%. The optimum moisture content (OMC) and the maximum dry density (MDD) ranges from 6.40 to 10.70mg/m with a mean value of 8.47 mg/m and 1.10 to 2.80mg/m with a mean value of 1.9mg/m. The cohesion value obtained varies from 0.20 to 0.41kg/cm² with a mean value of 0.30kg/cm². The shear angle of internal friction ranges from 18.0° to 30.0° with an average value of 25.3°. The values obtained for hydraulic conductivity range from (2.01 to 3.61) × 10⁻³cm/s with a mean value of 2.70 × 10⁻³ cm/s suggesting high permeability. The sand and silt contents

range from 87.0 to 100.0% with a mean value of 95.10% and 0.00 to 2.60% with a mean value of 1.43%. The shear strength of the soil is the maximum internal resistance of the soil to the motion of its particles by sliding or slipping. The forces that withstand shear are mainly the inter-granular friction and the cohesion force. The soils formation exhibits low plasticity, highly sandy with low silt content, low cohesion, very loose compactness, and high permeability. According to Coulomb's law, as described by (Onwuemesi, 1990), the shear strength is given by the equation $S = C + \tan \theta P$ where S = Shear strength, C = Cohesion, P = Effective pressure, $\tan \theta$ = Coefficient of friction, and θ = Angle of internal friction. The vital roleplayed by shear strength is that the friction force due to run-off and the seepage flux is only opposed by the angle of internal friction because of the very low cohesion to cohesion-less and very permeable nature of the sandy formations. Several researchers including (Onwuemesi, 1990; Ankidawa *et al.*, 2020) have recorded detailed reports on permeability blueprints of soil samples. Permeability is a measure of the capacity of soil to permit the passage of fluids such as water and it has the dimension of velocity (Onwuemesi, 1990). The environmental framework of these study areas which includes ridges and domes impede the infiltration of the rainwater. This rainwater then flows as runoff and loses the soil particles as a result of the very low shear strength of the soil. The lithological and geotechnical characterization of the sedimentary lithologies of Bima and Pindiga formations shows that the landscape contributed to the initiation of gully erosion disaster in the study areas.

Genesis and continued expansion of gully erosion in the study area

Different parts of the study areas where the two main sedimentary formations (Bima and Pindiga formations) cropped

out have continued to witness incipient gullies in recent times. The genesis and continued expansion of gully erosion in the area is mainly linked to the geology, topography, human activities that are poorly planned, and geotechnical properties of the soils. The soil surface is also accessible to rainfall and run-off due to scanty vegetation/plant cover in the areas of study. The geotechnical properties of these areas determine their susceptibility to gully erosion (gorges) which are advancing into canyon proportions. Detailed mapping, plastic limits, low liquid limit, low plasticity, the high proportion of sands, high permeability, the shear strength, and the very loose compactness of soils from Massina, Mettako, Riyal, Wuroshiye and Gabukka shows that the geological conditions and geotechnical composition of the soils were responsible for the initiation and propagation of the gully erosion in the study areas. This is in line with the considerable study by Igwe and Egbueri (2018). Based on the independent studies by Egboka *et al.* (2019), Egboka and Nwankwo (1985), Igwe and Egbueri (2018) and confirmed by this study, such interbedded shale formed a dry thick layer during the dry season causing contraction of clay and eventually led to soil fracture which is also conveyed to the sandy units. The shale is soaked with water after rainfall; the clay minerals swell up and establish a susceptibility to slide. The thick layers of sand underlain by the plastic shale usually slide down-dip in the gully with the shale acting as a lubricator. The characteristics of the soil formation, rainfall-runoff, long hilly and steepness of the slope, poor land cover, low plasticity, a high proportion of sands, high permeability, the shear strength, loose compactness of soils, and human activities enhanced the initiation and continued expansion of gully erosion in the study area. These features led to carving, piping, and landslide resulting in a step-like gully cross-section that is displayed in the

majority of the affected areas where the Formation outcropped. Different colours of the soils ranging from light grey, white, pink in the study area shows different heat-releasing and heat-absorbing capacity of the soils. These reveal the non-co-existence of expansion and contraction of the soils leading to structural damages of the study area. The friability of the soil, loose structure, low degree of diagenesis, poorly bonded mechanism, low compressive strength, the rapid disintegration of soil during rainfall and run-off, low soil fertilization, long hilly and steepness of the slope, poor land cover, and faulty land usage, low plasticity, a high proportion of sands, high permeability, the shear strength, the very loose compactness of soils, and human activities contributed to initiation and continued gully erosion expansion. These features result in slumping and sliding movements in the affected areas. The danger of this badland degradation was found in all the gully sites where

gorges are about 3.2m. The potential implications of these gully erosion include damaging of buildings, residential houses, bridges, and roads, loss of farmland and vegetation, isolation of villages and towns, increased migration of inhabitants as well as degradation of agricultural fertile land. The grain size analysis (both sieve and hydrometer analysis) result in Table 2 shows that the erosion gully sites contain very high proportion of fine materials. Generally, from the analysis, it is observed that the gully sites have similar grading and percentage compositions of particle sizes, and are mainly dominated by on average 3.15% Sand, 3.34% Silt and 93.51% Clay. Soil texture (proportion of clays, silts and sands) influences the infiltration capacity of the soil. When rainfall infiltrates rapidly, runoff will be minimal. Moreover, particles vary their ease of detachments. Silt particles are most easily detached due to their small nature of the particles and do not easily form aggregates (Ankidawa *et al.*, 2020).

Table 2: Summary of Grain Size Analysis and Composition in Gully Sites

Sample location	Depth (m)	Gravel >4.75 mm	Coarse Sand 4.75 - 2.00 mm	Medium sand 2.00 - 0.425 mm	Fine Sand 0.425-0.075 mm	Silt 0.075-0.02 mm	Clay <0.002mm
A1	7.2	0.00%	2.04%	0.30%	1.14%	2.26%	92.60%
B1	1.3	0.00%	2.16%	0.28%	1.65%	2.47%	92.40%
C	11.2	0.00%	1.25%	0.33%	1.89%	4.33%	93.46%
D	8.42	0.00%	2.37%	0.64%	0.46%	4.44%	93.50%
E	1.48	0.00%	1.49%	0.76%	0.33%	3.48%	93.60%
F	9.00	0.00%	0.42%	0.56%	0.78%	4.40%	94.40%
G1	3.76	0.00%	0.26%	0.89%	1.93%	4.35%	93.50%
H1	18.45	0.00%	0.67%	1.20%	1.89%	4.48%	93.60%
I1	0.60	0.00%	0.45%	0.46%	1.98%	2.32%	92.40%
J1	4.36	0.00%	0.00%	0.76%	1.68%	1.48%	92.60%
K	0.7	0.00%	0.00%	0.98%	1.97%	1.33%	93.40%
L1	6.40	0.00%	0.00%	3.08%	0.99%	4.44%	94.60%
M	0.42	0.00%	0.00%	2.34%	0.79%	3.49%	93.60%
N1	5.48	0.00%	0.00%	1.46%	1.69%	3.34%	95.50%
P1	14.57	0.00%	0.00%	1.35%	1.94%	3.49%	93.50%
Average			0.74%	1.00%	1.41%	3.34%	93.51%

Classification

Soil classification is used to specify a certain soil type that is best suitable for a given application. Of the several classification schemes available, the most common use for engineering purposes is the Unified Soil Classification System

[ASTM D 2487-93] which is used for virtually all geotechnical work and AASHTO classification system [AASHTO M 14587] which is used in highway and road construction. Both systems use the results of grain-size analysis and determinations of Atterberg

limits to determine a soil's classification. The AASHTO classification system is mostly used to characterize subgrade soils in road construction. For the present research work, classification was done on both methods, but the Unified Soil Classification System is found best suited due to the vast application areas and meets

the intended works. In the Unified Soil Classification System fine-grained soils are classified based on plasticity and compressibility rather than grain size distribution, that is, the relationship between the liquid limit and plasticity index (Table 3).

Table 3: Summary of laboratory Test result

Samples	Water content (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	CBR (%)
A	13.60	4.00	12.8	8.8	24.00
B	28.60	46.12	5.5	40.6	19.00
C	20.80	6.42	8.9	2.48	26.00
D	16.5	5.97	7.8	1.83	24.2
E	4.68	26.62	21.1	5.52	24.00
F	12.36	5.89	6.3	0.41	19.00
G	6.96	6.29	10.8	4.51	22.00
H	17.27	7.10	8.6	1.50	25.00
I	18.27	7.83	13.1	5.27	39.00
J	20.26	16.14	7.9	8.24	36.00
K	8.81	12.10	8.1	4.400	24.00
L	10.49	14.30	13.6	0.7	27.00
M	9.03	13.45	21.9	8.45	26.00
N	9.21	8.00	19.12	11.12	24.4
O	15.43	14.47	19.8	4.65	28.00
P	14.60	8.12	17.4	9.28	19.00
Range	4.6-28.6	4.0-46.1	5.5-21.1	0.4-40.6	19-39
Average	17.2	9.79	13.41	7.33	25.41

Measurement of Gully Morphology

The depth, width and length of gully sections in the study area were measured using measuring tape in order to calculate the quantity of soil lost to gully erosion. The data obtained were used to estimate the volume of soils lost, gully density, gully to plot area ratio as well as gully texture (Table 4). The shortest gully occurred in Jauro Yaya with a length of 1.54m whereas the longest gully is found around Mettako (H1) with a length of about 70.62m, the total volume of soils lost from the fifteen selected gully sites in the study area is about 123,369cm with the Masina gully site being the worse hit with a total of about 1263.54m of soils lost whereas 9.198m of soils were lost at

Jauro yaya gully site. The relatively low soils volume lost at Jauro gully site indicate that the gully site is still at its early stage of development whereas relatively high value of soil at M gully site indicate a rapidly increasing gully site. The gully density varies from 1.54m/ha at Riyal (L1) gully site to 58.66m/ha Riyal gully site with a mean value of 15.126m/ha could be categorized as largely low degraded (Pathak *et al.*, 2005). The total surface area devastated by gullies varies from 1.20m in Libiya (P1) gully site to 137.318m in Masina gully site with a mean value of 32.95m. This indicate that the total surface areas damaged by gullies is least in Libiya gully site and quite significant in Masina gully.

Table 4: Description of Sample Location, Geometry and Characteristics of Gully Sites in Bagadaza Area

S/N	Location	Longitude	Latitude	Altitude (m)	Length (m)	Width (m)	Depth (m)	Volume of Soil Lost (m ³)	Gully Density M/Ha	Gully to Plot Area Rated M ² /Ha	Gully Texture (m ²)	General Trend (Degrees)
1.	Masina A	11° 30'06E	10°20'06N	181	14.6	12.02	7.2	1263.54	12.1	137.318	175.492	28
2.	Masina A ₂											
3.	Gabukka B	11° 36'08E	10° 11'05N	274	5.4	3.23	1.31	22.849	4.46	14.426	17.442	74
4.	Gabukka B ₂											
5.	Wuroshie C	10° 23'00E	9° 15'03N	295	7.53	6.45	11.2	543,96	6.22	40.172	48.568	181
6.	Wuroshie C ₂											
7.	Wuroshie C ₃											
8.	Bye Pass D	10° 26'04E	9° 30'06N	310	9.84	7.34	8.42	608.139	9.84	59.739	72.225	267
9.	Madina Quarters E	9° 52'08E	9° 28'07N	246	4.56	3.21	1.48	21.66	3.77	12.107	14.637	275
10.	Anguwan Maitama F	12° 15'07E	11° 16'00N	398	3.48	3.04	9	95.212	2.87	8.75	10.579	210
11.	Sambisa G ₁	12° 30'06E	11° 15'08N	410	2.33	1.32	3.76	11.56	1.92	2.543	3.075	245
12.	Sambisa G ₂											
13.	Mettako H ₁	11° 30'08E	11° 18'06N	345	70.62	30.62	18.45	39,895	58.41	1.788	2.162	375
14.	Mettako H ₂											
15.	Mettako H ₃											
16.	Duniya Dam I ₁	12° 18'07E	11° 15'04N	367	6.41	5.92	0.6	22.76	5.3	31.387	37.947	182
17.	Duniya Dam I ₂											
18.	Wuro Biriji J ₁	13° 15'06E	11° 16'08N	284	5.81	4.83	4.36	122.35	4.8	23.211	28.062	194
19.	Wuro Biriji J ₂											
20.	Wuro Jule K ₁	13° 12'09E	12° 30'09N	364	3.64	1.22	0.7	23.1	3.64	3.673	444.8	184
21.	Wuro Jule K ₂											
22.	Riyal L ₁	12° 16'00E	11° 28'07N	279	70.92	30.47	6.4	13,829	58.66	1.787	2,160	320
23.	Riyal L ₂											
24.	Wuro Daji M	11° 30'02E	10° 15'06N	418	4.44	3.5	0.42	6.526	3.67	12.853	15.54	312
25.	Jauro Yaya N ₁	13° 17'05E	12° 18'08N	426	1.54	1.09	5.48	9.198	1.54	1.388	1.678	186
26.	Jauro Yaya N ₂											
27.	Libiya P ₁	13° 15'08E	13° 26'03N	369	60.08	20.54	14.57	17.98	49.69	1.02	1,234	285
28.	Libiya P ₂											
29.	Libiya P ₃											
30.	Libiya P ₄											
	TOTAL				271.2	134.8	93.35	123,369	226.89	4,942.50	6,250.60	2,249
	MEAN				18.08	8.98	6.22	8,224.60	180.5	329.5	416.703	1,959.60

Mitigation Measures

Once the gully has formed, it is very difficult to restore it back. There is an old saying “prevention is better than cure”. That is to say that preventing the formation of a gully is much easier than controlling it. In addition, the fact that those gullies are not stabilized, they become larger, deeper and longer. The rate of growth depends on several factors including the climatic condition of the area, the topography, soil types, geology and many more factors. Under certain climatic and geological conditions, vertical gully banks can easily become as high as 20 meters (Pathak *et al.*, 2005). Therefore, such types of gullies will be dangerous due to the huge landslides which occur on gully banks after heavy rains if proper stabilization on those gullies is not done. Table 5 Summaries the mitigation measures in the study area.

Table 5: Summary of applicability of mitigation measures in the study area

Mitigation type	Reasoning to use	Applicability condition	Cost	Reliability	Applicability in the study area	Remark
Reshaping and Filling	In order to restore the desired shape	In gullies where water flow is minimal	cost effective only if the land can be reclaimed	Long term	Gully A1&2, C, D, E, and H	Only reshaping Gully #a, b1 & 2 and 9,
Rock/Sand Bag Check dams	Where there are concentrated flows causing erosion in large rills or small gullies	In areas with insufficient supply of stones	Low-cost	Short term	Gully A, B, C, D, E, and G	They are not suitable for the treatment of large gullies
Brushwood check dams	Hold fine material carried by flowing water	Small gully heads, no deeper than one meter	Low-cost	Short-term Temporary structures	Gully A, B, C, D, E, F and G	Used in rills and small gullies developed on the banks of the gullies
Log check dam	Hold fine and coarse material carried by flowing water	To stabilize incipient, small and branch gullies generally not longer than 100 meters	Low-cost	The structures are substantially stronger	Gully A1, B, C and D	
Wooden Check Dams	To hold fine material in the gully	To stabilize gullies with moderate slopes (< 10%) and small drainage areas that do not have flood flows which carry rocks and boulders	Low-cost	Short-term	Gully A1 & 2, B, C, D and F	
Loose Rock /Wire-Bound Loose Rock	To control channel erosion along the gully bed and to stop waterfall erosion by stabilizing gully heads	to stabilize the incipient and small gullies and the branch gullies of a continuous gully or gully network	Low-cost	Short-term but stable	Gully a, b, c, d, e, f, g	Wire-Bound loose Rock has the flexibility to permit adjustments in the structural shape
Gabion	Used gully treatment, roadside protection, dam construction, river training, retaining wall, etc.	Tough and long lasting provided that the wire has been well galvanized	Costly than others	Usually not higher than 1.5 m spillway height	Gully a, b, c d, f, f, h, K.	Flexible and can be installed where the surface is uneven Since water is continuously flows in Gully E and F gabion is applicable only for bank protection

CONCLUSIONS

This study treated the gully erosion problem, which constitutes a serious threat to several communities in southeastern Nigeria. It is also caused by poorly planned anthropic activities. The lithological and geotechnical characterization of the geologic formations revealed that the gully erosions were developed on steep slopes and non-vegetated areas. Field surveys and

laboratory analyses revealed that the genesis and continued expansion of gullies in the study area was facilitated by the cohesionless and very permeable nature of the sandy formation. Agronomic and engineering techniques have been proposed which can play mitigating roles in the formations as well as the continued expansion of gully erosion hazard in the study area.

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