GEOLOGICAL AND GEOTECHNICAL ASSESSMENT OF SELECTED GULLY SITES IN SANGERE LOKO AREA NE NIGERIA

Gabriel Ike Obiefuna, Aliyu Musa Dukurma and Isa Danlami

Department of Geology, Modibbo Adama University of Technology Yola Nigeria

ABSTRACT

An assessment of geological and geotechnical parameters of selected gully sites in Sangere Loko Area of northeastern Nigeria is presented. Field geological study revealed that the area is underlain by basement rocks consisting of granites and granite gneiss which has been intruded by the Tertiary basaltic rocks. The soils in the area are product of insitu weathering of the underlying basement rocks giving rise to clays, silts, laterites and sand deposites occurring more than 3 meters in depth. Results of sieve analysis indicate that soils at the gully sites have sorting values ranging from 0.204 to 1.434 showing well to poorly sorted soils. Furthermore the mean hydraulic conductivity values of 4.89 x 10^{-3} cm/s and mean transmissivity value of 1.24 x 10^{-4} cm^2/s indicate relatively moderately permeability, seepage fluxes and pore pressures which will likely reduce the shear strength of the soils. The plastic limits of the soils vary from 13.15% to 21.90 % whereas the plasticity index varies from 12 % to 21.30 % revealing soils of low to moderate plasticity as well as friable, poorly cohesive soils that are susceptible to gully erosion. The compaction test display maximum dry density values of 1.78 kg/m^3 to 2.21 kg/m^3 with an optimum moisture content values of 6.10 % to 10.20 % revealing generally loose soils that are susceptible to gully erosion. The results of the study were used to infer the surface and subsurface processes that contribute to the formation and expansion of gullies as well as recommendations on how to control the menace of gully erosion in the area were made.

Keywords; Geological and geotechnical parameters, basement rocks, insitu weathering, Sangere Loko Area, Northeastern Nigeria

INTRODUCTION

Gully erosion is simply defined as the erosion of the soil by flowing water in well-defined channel. It is directly observable in the field due to its striking morphology on the landscape. It is an environmental hazard that is ravaging the landscape of parts of Song and environs. The dangers of gully erosion have been discussed by many workers in standard textbooks and scientific journals but few people understand its real impact on the agricultural infrastructural and socio – economic aspects of both rural and urban development in Adamawa State especially Song area (Onwuemesi 1990).

It was in the light of the above consideration that geological and geotechnical assessment were done in the area with a view of providing geological and geotechnical information on the genesis and expansion of gullies in Song and its environs. The information from this study will help suggest appropriate measures to control gully development and expansion in the area.

Study Area.

The study area is located at the South-West of Song Local Government Area which lies within longitude $12^{o}\,30^{'}$ E and $12^{0}\,36^{'}$ E and latitude $09^{0}\,45^{'}$ N and $09^{0}49^{'}$ N covering an areal extent of about 80.37 km^{2}. (Figure 1). The area is accessible as it lies along Girei-Song Highway, it is also traversed by several footpaths linking the villages to the town.

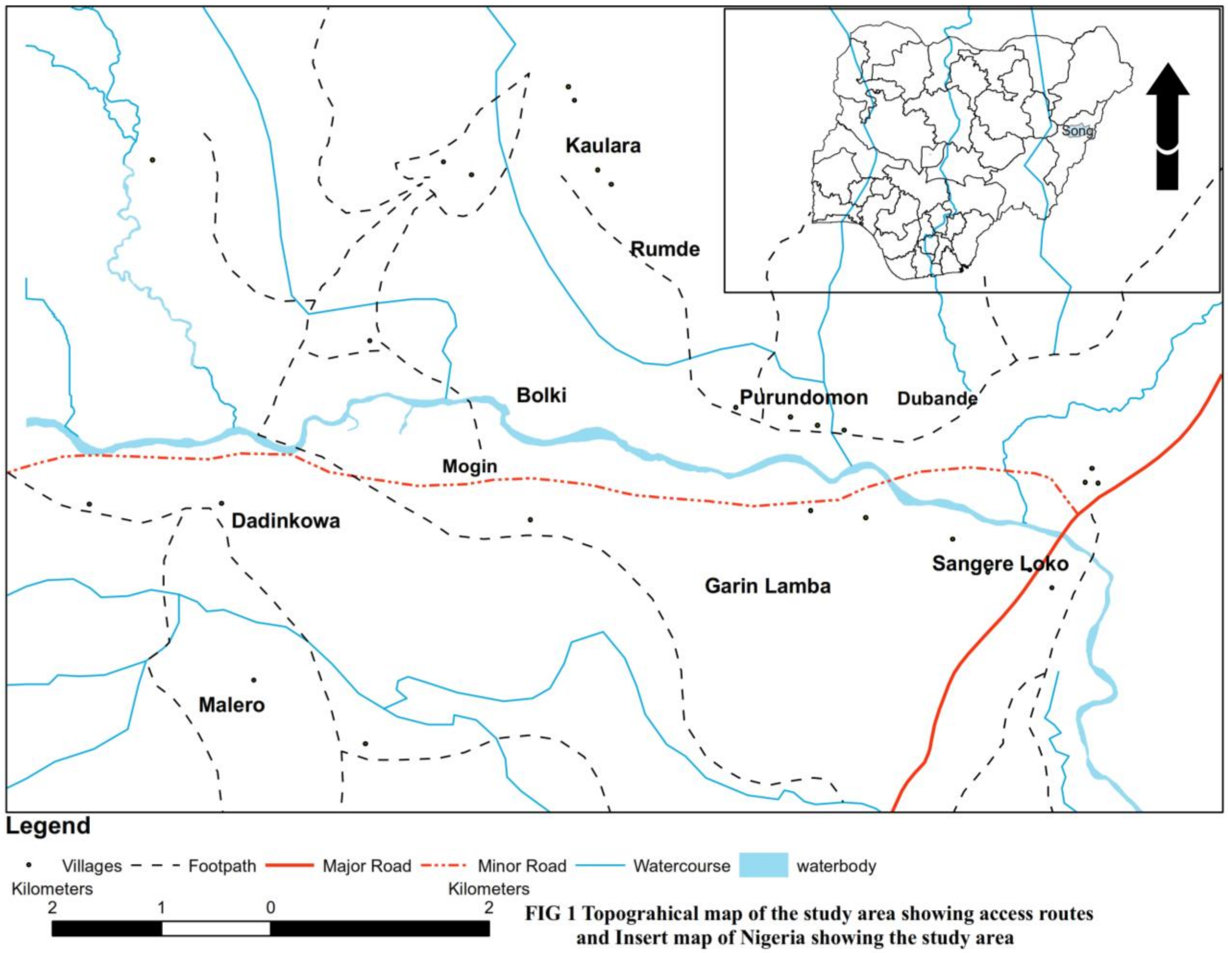

Fig: 1 Topographical map of the study area

The study area is characterized by highlands and flat topography. The low lying areas are characterized by patches of granite outcrops while the entire southern part are characterized by chains of mountains with elevation ranging from 3100 feet (940 meters) to 3800 feet (1150 meters) above sea level

The temperature in this area remains high in most part of the year as a result of its proximity to the equator which is characterized by mean maximum daily temperature ranging from 43°C to 46°C between the months of March and June (Adamawa State Government Diary, 2005). It is also cold with temperature ranging between 27°C and 32°C during which air temperature is often low due to the influence of the dusty harmmatan windstorm. Climatically, the area belongs to the tropical hinterland and falls within the Northern Guinea climatologically zone characterized by short and scattered trees and grasses.

The prevalent vegetation in the study area is savanna and it is characterized by tall grasses which are thinly distributed, and the trees are medium to short and interspersed with grasses. The study area has two distinct seasons; a dry season which lasts from November to March, and a wet season which lasts from April to October (UBRBDA, 1987 – 1994 Year Book). Thus the rainfall is seasonal and it is at maximum in the month of August with greatest number of rainy days.

The area is drained by network of streams, which take their source from the mountainous area and flow to join several rivers in the northeastern low plain areas. Most of the rivers are seasonal and they exhibit trellis and dentritic drainage patterns which are characteristics of areas with homogeneous resistant rock (Oyawoye, 1970).

Most of the previous works in the area are mostly regional (Carter et al 1963; Du Preeze and Barber 1965 and Kiser 1968) described the geology and chemical quality of groundwater in northeastern Nigeria. From the reviewed literature of Ekweme, (1993), the Adamawa Massif like other basement areas of Nigeria has experienced a polyphase thermo-tectonic events. The last and most penetrating is being the Pan African orogeny. Ekwueme (1993) gave some details of the basement works of Northeastern Nigeria in which he classified the rocks as consisting of migmatite gneisses, diorite, porphyritic granites, volcanic rocks and alluvial deposits. Related structural geological mapping and interpretations of Landsat and aeromagnetic data over Hawal Basement Complex NE Nigeria were carried out by Bassey (2007) whereas Bassey et al (2006) gave some details on magnetic anomaly and structure of rocks of Precambrian Massif NE Nigeria.

Gullies are widespread throughout Nigeria especially in the Southeastern part where the problem is well pronounced. However, the intensity of gully varies from place to place and based on the predominant erosion mechanism Uma and Onuoha (1987) classified the active gully spots into three. The first group is called the classical gully erosion due to its accelerated nature whereas the second group involved mass wasting, landslides, slumping and soil creep (Table1). The third group are those that cut deep into bedrock and have groundwater seepage at various levels of their banks. The process going on in them involved certain movement of large masses of earth material through landslides and slumping. This constitutes the most serious threat to lives and properties.

The classical types are often shallow and surficial and are seldom more than 10m deep (Grove 1951) and may or may not be related to stream channels. The bank erosion on the other hand is usually associated with semi or mature stage of river development and is commonly due to under cutting. Grove, (1951) defined erosion as the progressive removal of surface sediment from the parent mass by wind and water and often followed by localized intense erosion producing gullies. Ogbukagu, (1976) defined erosion as the process of acquisition or detachment of material as well as its transportation by wind, water and ice with the menace by gully erosion being more pronounced in the south eastern Nigerian (Grove, 1951). Floyd, (1965) attributed the original and growth of complex gullies of the south eastern Nigeria to the effect of agricultural and human activities. Floyd (1965); Ofomota (1965); Ogbukagu (1976) emphasized the role of geological processes in the development of gully complex in south-eastern Nigeria. Recent and related works has been carried out in adjoining areas of Hawal Massif include (Obiefuna et al 1999; Obiefuna and David 2010 and Obiefuna et al 2018).
The main objectives of this research work are as follows:

(1) To carry out a detailed geological mapping of Sangere Loko and Environs with a view of among other things delineating rock types, geological boundaries and the gully sites.
(2) To carry out the geological and geotechnical assessment of some selected gully sites in Sangere Loko area

The result of the soil test analysis such as compaction test, Atterberg limit test, CBR and geological assessment such as petrographic analysis was interpreted and used in assessing and recommending proper solution that will assist in arresting the menace of gully erosion in the area.

Geology of the Study Area

Geologic History

The study area is underlain by the rocks of the hard crystalline craton basement which are the ancient Precambrian rocks formed from series of Orogenic circles within the mobile belt of Central Africa. The various radiometric dating revealed the existence of Liberian (2500 ±200 million years), Eburnean (1800±200 million years) and Kibarian (1200±200 million years) Orogenic events (Ogezi 1977). However many of the structural traces were obliterated by the late Proterozoic and Pan African thermotectonic events that spanned from 750 to 500 million years (Rahaman 1988). During the Pan African Orogeny there was structural development which resulted in fracturing towards the NW-SE and SW-SS direction. The Pan-African Orogeny was followed by Post Metamorphic epirogenic uplift, cooling, fracturing, and faulting causing high level of magmatic activity in the study area. The end of Pan-African Orogeny was terminated by the emplacement of diabase (Rahaman 1988).

Rocks of the Crystalline Precambriam Basement Complex of Nigeria underlying the study area which include granites, gneisses basalt and migmatites have undergone tectonism leading to fracturing such as joints, faults and intrusive bodies such as pegmatites, macro granites, dykes and quartz veins. These underlying rocks have experienced partial to complete weathering leading to the occurrence of 1 to 10 meters of residual soils consisting of silts, clays, fine grained sands and shales.

Major Lithologic Units in the Study Area

Residual Soils

The residual soils are formed by the physical and chemical disintegration of the underlying basement rocks. The disintegrated or weathered materials which may either be formed deposited at its place of origin is called in-situ soil or elluvium or may be transported by agents of denudation such as water, wind or ice before being deposited as transported or drift soil or alluvium. The elluvium are genetically or compositionally related to the underlying basement rocks since they are derived from them. They are infertile due to their having undergone leaching with their thickness varying in places depending on physical or chemical homogeneities of the underling parent rocks (Obiefuna et al 2018)

The alluvium are transported, stratified and unrelated compositionally to the underlying basement rocks. They are of uniform thickness and by virtue of their mode of formation are quite fertile and are found along river channels and include glacial, aeolion or alluvial deposites. The soil of the study area are mostly residual elluvium derived from the physical and chemical weathering of the underlying basement rocks

They are very fine deposits of weathered materials and are composed mainly of silts, lateritic soils, clays, fine grained sands, clayey soils and shales. They are light to yellowish in colour. The alluvium consist essentially of gravels and sands which are very good aquifers and have given very high yields to well. The processes in the formation of deep weathering lead to the development of lateritic profiles as the overburden forms the elluvium. The parent materials such as granites and granite-gneisses are cut through by pegmatite, aplite and quartz veins which are weathered to varying degrees with depth. They occur almost althrough constituting more than 90 % of the study area.

Granite Gneiss

The granite gneiss forms a very small proportion of the study area just at the northeastern part showing a gradational contact with the surrounding fine grained granite and the basalt of the Hawal Massif.. The granite gneiss consists of the fine grained granoblastic aggregate of quartz and feldspar with biotite which appears grayish in colour. It is banded with light and dark coloured bands. The light coloured band consists of quartz and feldspar while the dark coloured band consist of biotite and hornblende minerals. They are found around the northeastern part of the study area.

Granite

These are discordant rocks occurring as small irregular bodies rarely exceeding 180 cm in extent and 27 m in width. There is little variation in colour and appearance. They are generally pale brown grey equigranular fine grained rock. Foliation is defined by parallel alignment in mica. They resemble the syntectonic granite through the felspartization of the fine grained granite and is believed to have taken place during the later granitization (Falconer 1911).

The granite in the study area is found in the eastern part of the study area between the granite gneiss and the basalt. The basement complex rocks are found in the north eastern part of the study area and is composed of the pre-Cambrian crystalline rocks of the north eastern Nigeria which belongs to the Pan-African orogeny. The granite in the study area is coarse grained and the minerals consists of quartz, feldspar and biotite. The rock is pinkish in colour.

Basalt

The basalts of the study area are fine grained, vesicular and consist essentially of phenocrysts of nodular olivine set in a groundmass of pyroxene, plagioclase feldspar, biotite and magnetite. The olivine partially alters to iddingsite whereas secondary minerals such as zeolites and carbonate minerals sometimes occupy the vesicles or amygdaloidal cavities in places (Islam and Baba1990). The basaltic rocks are found in the southern part of the study area and occur as boulders, ridges and enscarpment of different sizes and shapes. The basalts appear dark grey in colour and range from 10 cm to about 2.5 meters in size and are also found largely in the northeastern part.

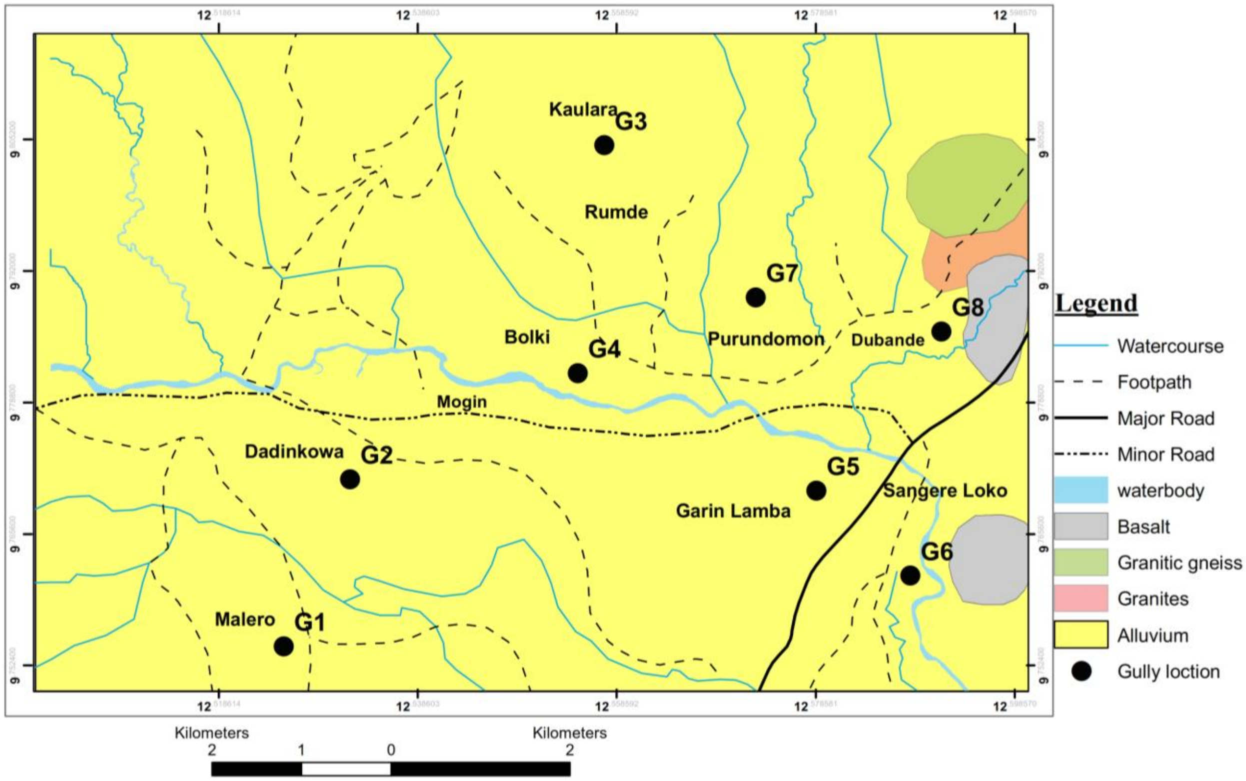

Figure: 2 Geological map of the study area showing the Gully Sites

MATERIALS AND METHOD

The research was carried out in three stages. The first stage involved the use of topographic map in the identification and demarcation of the study area. The second stage involved a reconnaissance survey and subsequently a detailed geological mapping was carried out using geological tools such as hammer, chisel, tape, GPS, compass clinometer and field map. The third stage in the data acquisition involved the laboratory analyses of the samples that was collected in the field. The samples (both soil and rock) was collected at 8 places randomly and was subjected to a number of laboratory tests such as grain size distribution (Sieve analyses), petrographic analyses, compaction test and atterberg limit or consistency limit test (liquid and plastic limit).

Laboratory Procedures

Eight (8) samples were collected from the field which were closely examined. Their colour, texture and other physical properties was also determined while others were subjected to petrographic analyses.

Particle size distribution analyses

This was done with the aim of finding the distribution of grain sizes within the soil samples that was collected. The result was used in determining the sorting characteristics of the soil. The materials used for the analyses includes British standard sieve, a heavy duty balance, a wire gauze, rubber hammer, electric oven, large metal tray, sample containers of known weight, trowel and water.

Procedure: The samples were oven dried to expel any moisture contents. After this, 300g samples are taken in a container of known weight and labeled. To the sample water was added and then allowed to stand for 24 hours.

This was aimed at disintegrating all the soil material. The soaked sample was then washed over 20 mm sieve until the water was free of fine particles. The washed sample was oven dried for 24 hours and the weight of the sample and the container was determined.

The weight of oven dried sample was obtained by subtracting the weight of the container. The weight of the fine materials washed off from the original samples was obtained by subtracting the weight of the washed oven dried sample from that of the original sample. The sieves were arranged in a stack with the larger aperture sieve at the top with the smaller aperture at the bottom. The samples were run through the sieves and the weight retained on each sieve was determined using the heavy duty balance. The result was recorded in a laboratory reporting sheet and analyzed.

Petrographic Analyses

Thin section preparation:

Thin section or slides of rocks was used for the petrographic study of the rock samples. The thin sections were obtained by cutting thin slides from a specimen using diamond saw. One side of the sample was then polished to a perfectly smooth flat surface using super glue as an adhesive and heated in an electric oven or heating plate to harden it. It was then mounted on rock cutting machine where the specimen are further reduced in thickness by rotary grinding blades. Then the specimen was made very thin and almost transparent and removed from the machine and polished to the correct thickness (0.03 mm) using carborum-dum powder. The surface of the specimen was then covered with a thin glass over slip using Canada balsam and heated to harden. After producing the slides it was then subjected to microscopic examination using the petrographic (polarizing) microscope to determine the different mineral constituents and their relative composition.

Microscopic examination of the rock samples: Microscopic examination of the rock samples were carried out to determine the different minerals contained in the rocks in the study area. The instrument used is the petrographic (polarizing) microscope with a magnification of x 10. The different minerals in the slide were determined.

Atterberg or Consistency Limit Test: The Atterberg or Consistency limit test includes liquid limit test and plastic limit test. The liquid limit has been defined as a moisture content at which a standard groove cut on a remoulded soil material closes at twenty five blows of the liquid limit apparatus. In order words, it is that moisture content at which the soil will flow under its own weight. Plastic limit is the percentage moisture content at which a soil can be rolled without breaking into threads three (3mm) millimeters in diameter (Bell, 1983). The numerical difference between the liquid limit (LL) and plastic limit (PL) is called the plasticity index (PI), it is the change in moisture content of a soil giving rise to a one hundred fold change in the strength of the soil.

Equipment Used: The materials and equipment used for the test include the ; liquid limit (Cassagande) apparatus, mortar and pistle, an electric oven, BS NO 425 sieve BS (1967), a grooving tool, glass platen, a balance for weighing water and some numbered specimen containers.

Liquid limit test: A portion of the plate was remolded on a glass platen and laced in the liquid limit apparatus and grooved using a standard grooving tool while preventing air trapped. The handle of the Cassagrande apparatus was then rotated which caused the bowl to be jarred against the base plate. The number of blows required to close the groove was recorded. A sample of the material was then taken in a specimen container, weighed and placed in the oven for 24 hours and weighed again to determine the moisture content. The above procedure was repeated three more times, each time adding little quantity of water. The results were presented in a laboratory reporting sheet and plotted on a graph paper (moisture content % against number of blows) and the best straight line drawn between the points. The moisture content at 25 blows defines the liquid limit.

Plastic Limit: The plastic limit has a similar procedure like the liquid limit test, except for the absence of the liquid limit apparatus. The soil paste at different moisture contents was rolled with the palm on a glass plates into threads. The threads were put into containers like those in the limit test and weighed. They were then placed in the oven for 24 hours after which they were reweighed and the weight difference gave the plastic limit. The results of the two tests were analyzed and the plasticity index (PI) was obtained as the numerical difference between the liquid limit (LL) and the plastic limit (PL) as PI= LL-PL.

Compaction Test: Compaction tests are carried out with the aim of determining the moisture density relationships of soils. A number of methods has been developed for this purpose. These include the standard compaction method (also called proctor method), the modified AASTHO method and the vibrating hammer methods. The method adopted for this work is the standard method due to its availability. This method was introduced by Proctor 1933 and has become the most widely used method of compaction test in the world (BS 1377, Test II).

Materials used for the Test: Materials used for the test include the following ; Riffle box, heavy duty balance (up to 25kg with sensitivity of 1 – 5g), large metal tray, rubber hammer, measuring cylinder, scoop and spatula, an oven (105 – 110^{0}c) small numbered specimen containers, the BS CBR mould, steel tamping rod, Cee – spanners and water.

Test procedure: A sample of 6000g weight of air dried soil was thoroughly mixed with 120 mm of quantities of water and compacted in five layers into a mould with an extension attached, each layer compacted using a steel tamping rod at 25 blows for 5 layers. The surface of each layer was roughened in order to obtain a better bond between them. After compaction the mould and its contents were weighed and a representative sample was taken and used in the determination of moisture content. The specimen was oven dried for 24 hours and the moisture content obtained by determining the weight difference. The procedure was done four more times on each sample until there is a reduction in weight of sample. The results were then analyzed to determine the optimum moisture contents and the corresponding maximum dry density.

RESULTS AND DISCUSSION

Geotechnical assessment of gully sites

Incipient gullies were observed in different parts of Sangere Loco and its Environs. The locations of the gully sites are shown in Table 1 and Figure 2 and the photographs of the gully sites are shown in plates 1 to 8. The depth of incision of these gullies varies from 1.30 m to 6.00 m with a mean value of 2.75 m whereas the width ranges from 9.50 m to 65 m with a mean value of 34.96 m. They generally trend in the SE-NW, NE-SW and NS direction with the SE-NW direction dominating and consist essentially of loose fine to very coarse grained sands. They are very much in their early stage of development (Floyd 1965). It has been observed that it is the geological and geotechnical properties of these soils that determine their susceptibility to gully erosion (Onwuemesi 1990, Obiefuna et al 1999, Okunlola et al 2014, Amagu et al 2018 and Obiefuna et al 2018). The liquid limit and plastic limit were used to obtain the plasticity index which is the difference between the liquid limit and the plastic limit (PL-LL) and were used to measure the plasticity of the soil (Figure 3 to 10). These measurement indicate that the plastic limits varies from 13.15 % to 21.90 % with a mean value of 17.18 % whereas the plasticity index varies from 12 % to 21.30 % with a mean value of 15.33 % revealing soils of low to moderate plasticity as well as friable, poorly cohesive soils that are susceptible to gully erosion (Bell 1983, Onwuemesi 1990 and Obiefuna et al 2018)

The compaction test shows that the soil has a maximum dry density values ranging from 1.78 kg/m^3 to 2.21 kg/m^3 with a mean value of 1.95 m^3/kg with an optimum moisture content ranging from 6.10 % to 10.20 % with a mean value of 8.86 % (Tables 2, 3 and 4 and Figures 11 to 18). They are generally low signifying loose soils that are susceptible to erosion.

Table 1: Geometry of the gully sites

S/N	Location	Depth (m)	Width (m)	General Trend
1	Malero	3.2	65	125°
2	Dadinkowa	4.0	60	120°
3	Kaulara	1.3	17.5	100°
4	Bolki	2.0	9.9	280°
5	GarinLamba	1.5	9.5	150°
6	SangereLoko	2.0	42	180°
7	Purudomon	6.0	46	254°
8	Dubande	2.0	30	250°
	Total	22	279.7	
	Mean	2.75	34.96	

Plate 1: Location1: Malero, Depth of 3.2m Medium to Coarse Sand.

Plate 2: Location 2: Dadinkowa, depth of Gully 4.0m Medium to Coarse Sand

Plate 3: Location 3: Kaulara depth of Gully: 1.3m Medium tp Coarse sand

Plate 4: Location 4: Bolki depth of gully: 2.0 m Midium to Coarse sand

Plate 5: Location 5: Garinlamba depth of gully:1.5m Medium to Coarse sand

Plate 6: Location 6: Sangereloko depth of gully 2.0m Medium to Coarse sand

Plate 7: Location 7: Purudomon depth of gully: 6m Medium to Coarse sand

Plate 8: Location 8: Dubande depth of gully: 2m Medium to Coarse sand

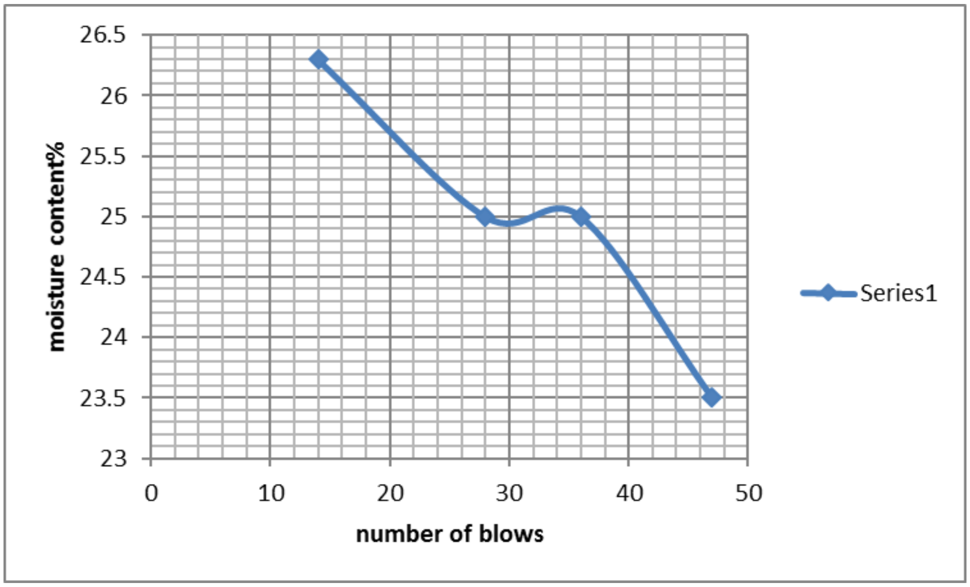

Figure 3 Plot of Plastic and Liquid limit Data for Malero Gully Site

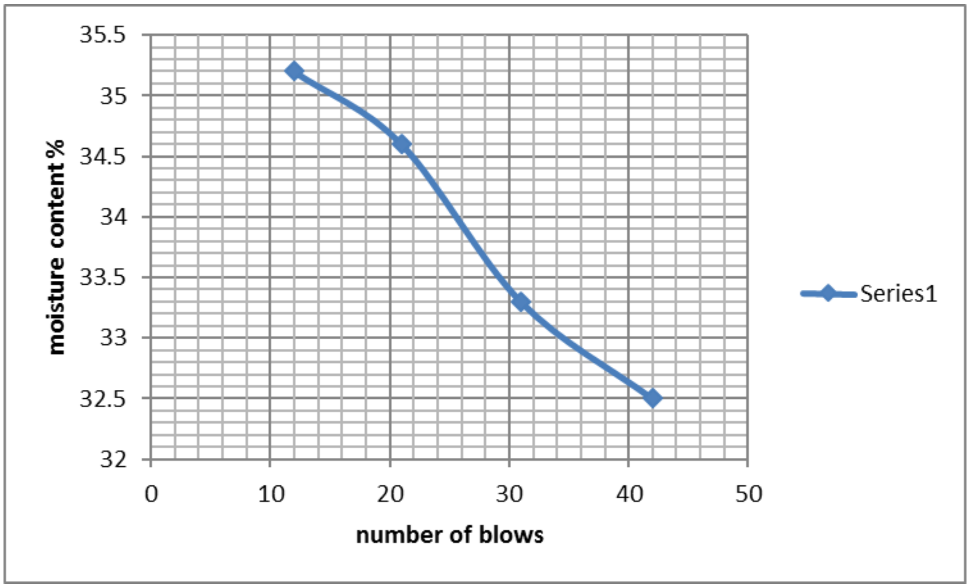

Figure 4 Plot of Plastic and Liquid limit Data for Dadinkowa Gully Site

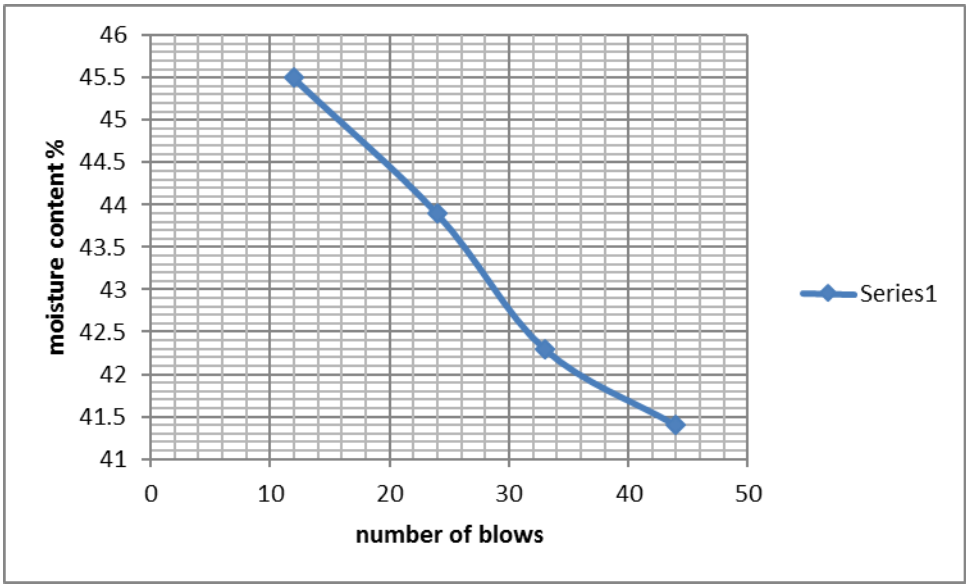

Figure 5 Plot of Plastic and Liquid limit Data for Kaulara Gully Site

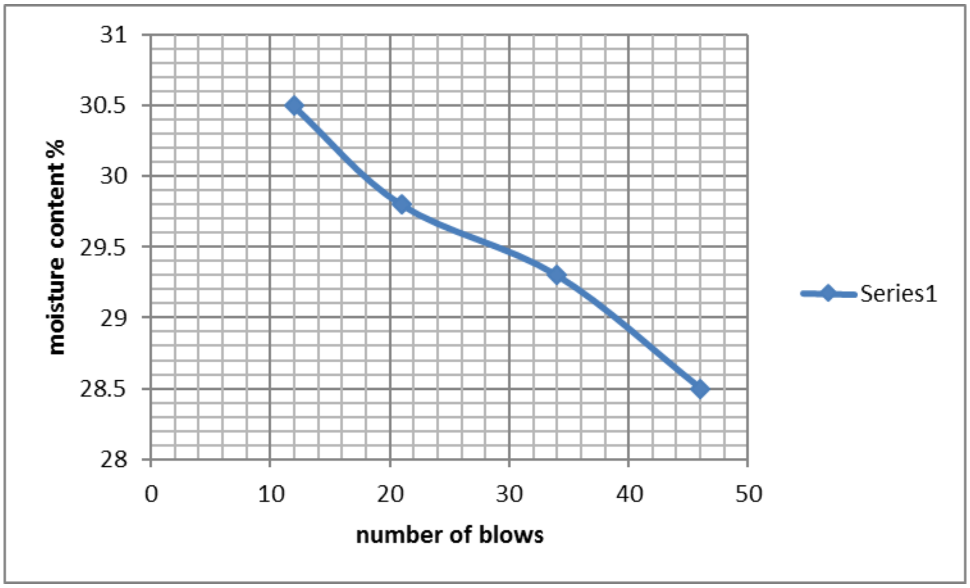

Figure 6 Plot of Plastic and Liquid limit Data for Bolki Gully Site

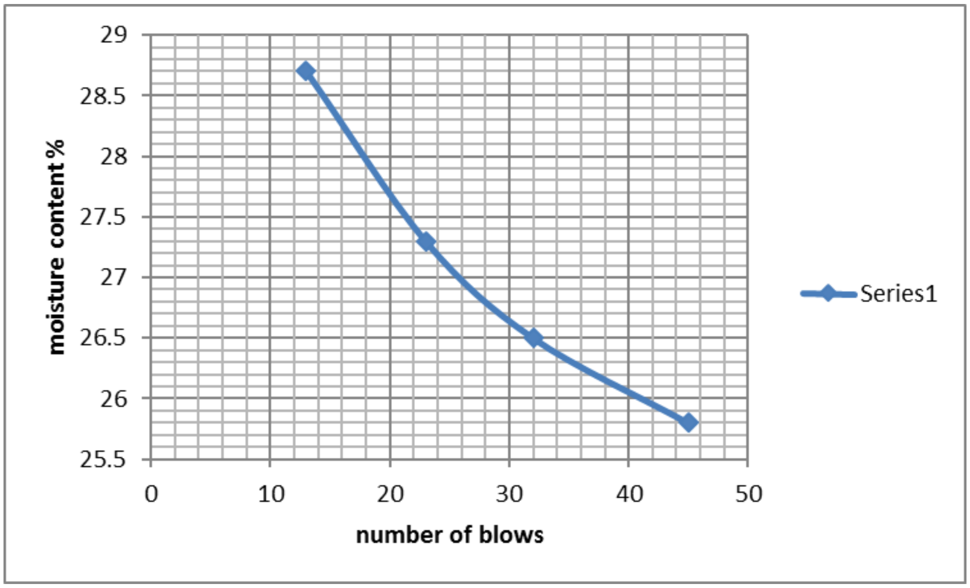

Figure 7 Plot of Plastic and Liquid limit Data for Garin Lamba Gully Site

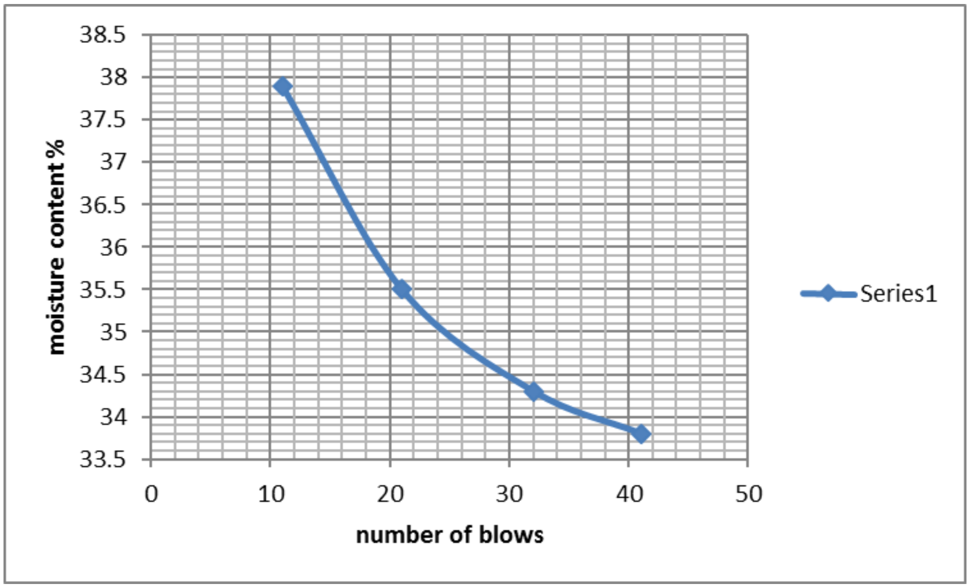

Figure 8 Plot of Plastic and Liquid limit Data for Sangere Loko Gully Site

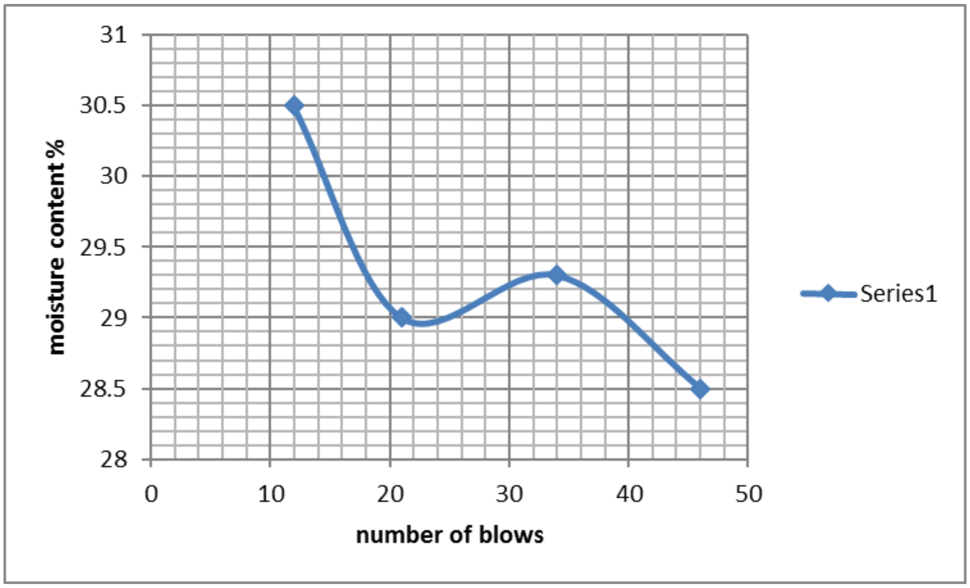

Figure 9 Plot of Plastic and Liquid limit Data for Purudomon Gully Site

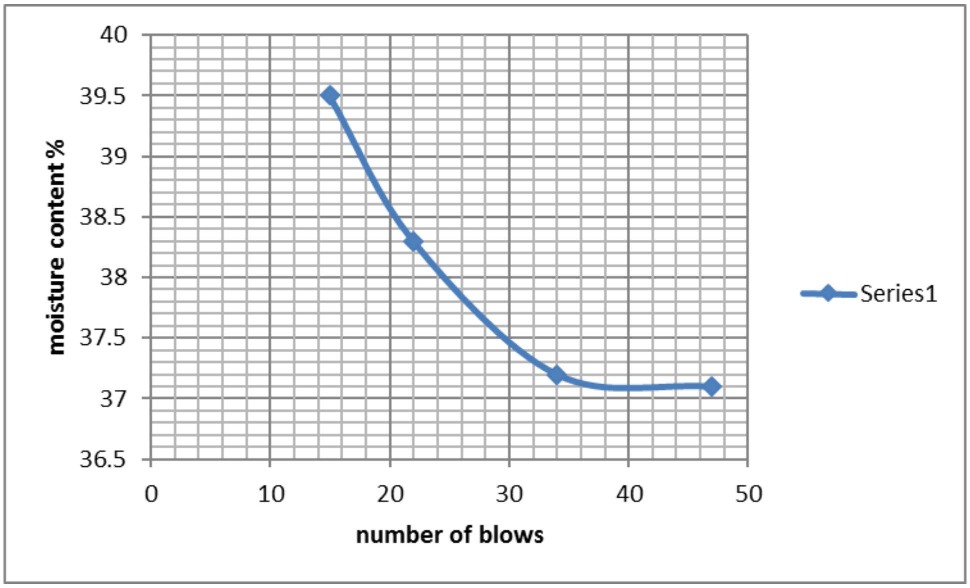

Figure 10 Plot of Plastic and Liquid limit Data for Dubande Gully Site

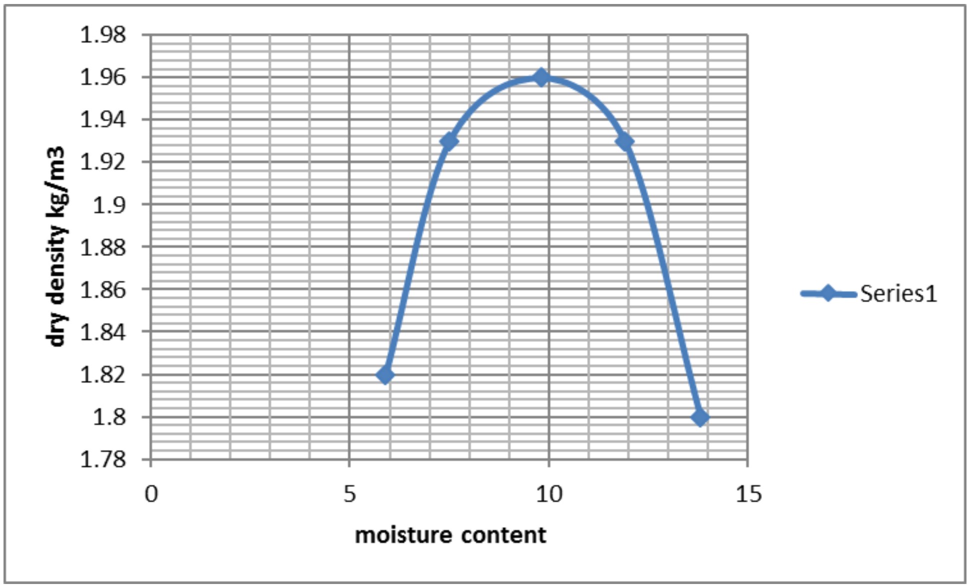

Figure 11 Plot of Compaction Test Data for Malero Gully Site

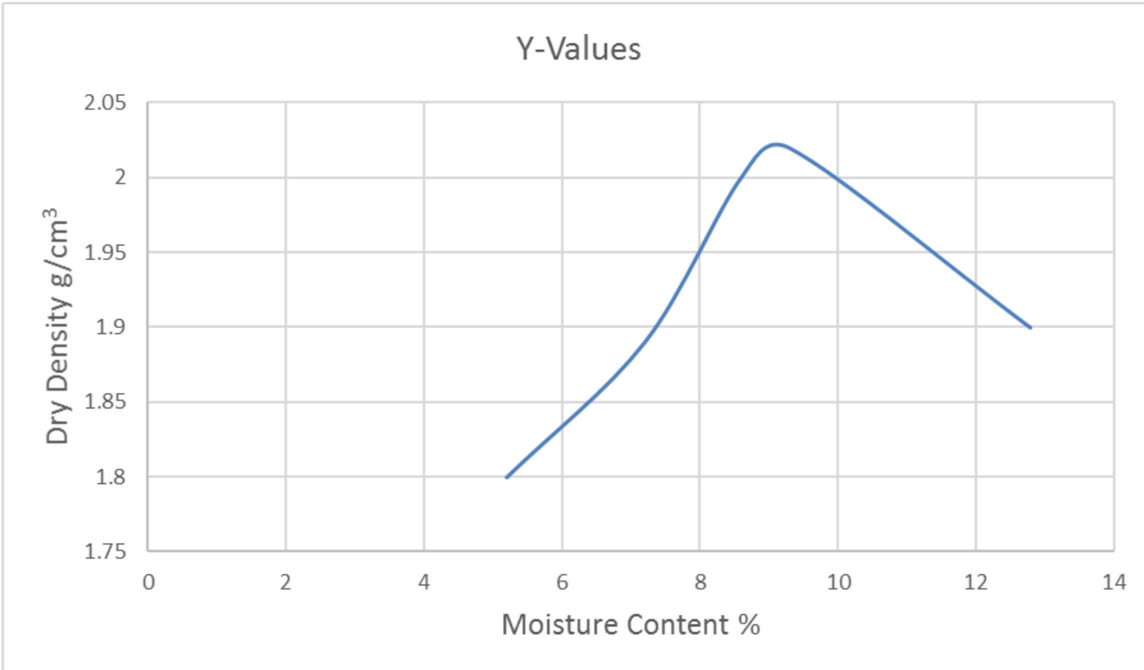

Figure 12 Plot of Compaction Test Data for Dadinkowa Gully Site

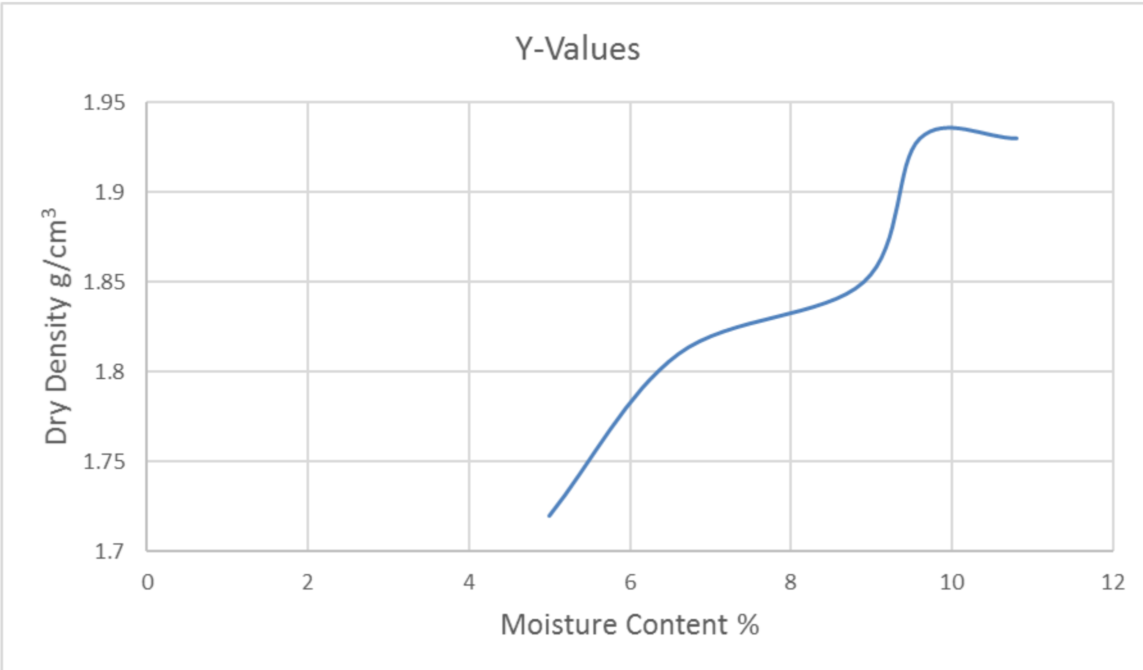

Figure 13 Plot of Compaction Test Data for Kaulare Gully Site

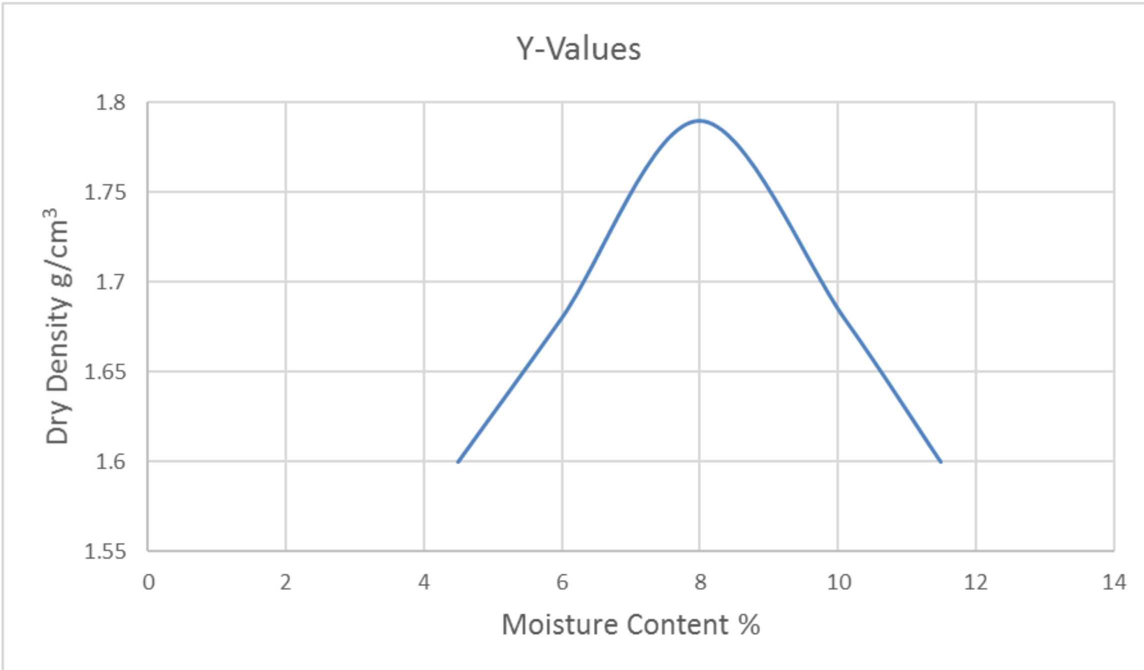

Figure 14 Plot of Compaction Test Data for Bolki Gully Site

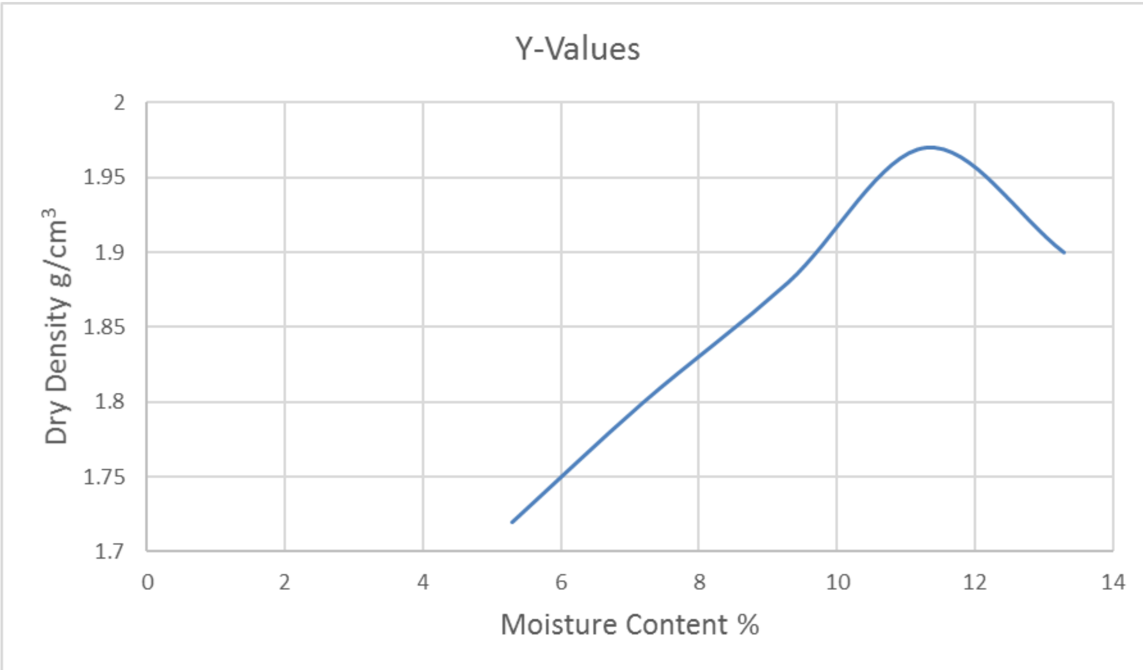

Figure 15 Plot of Compaction Test Data for Garin Lamba Gully Site

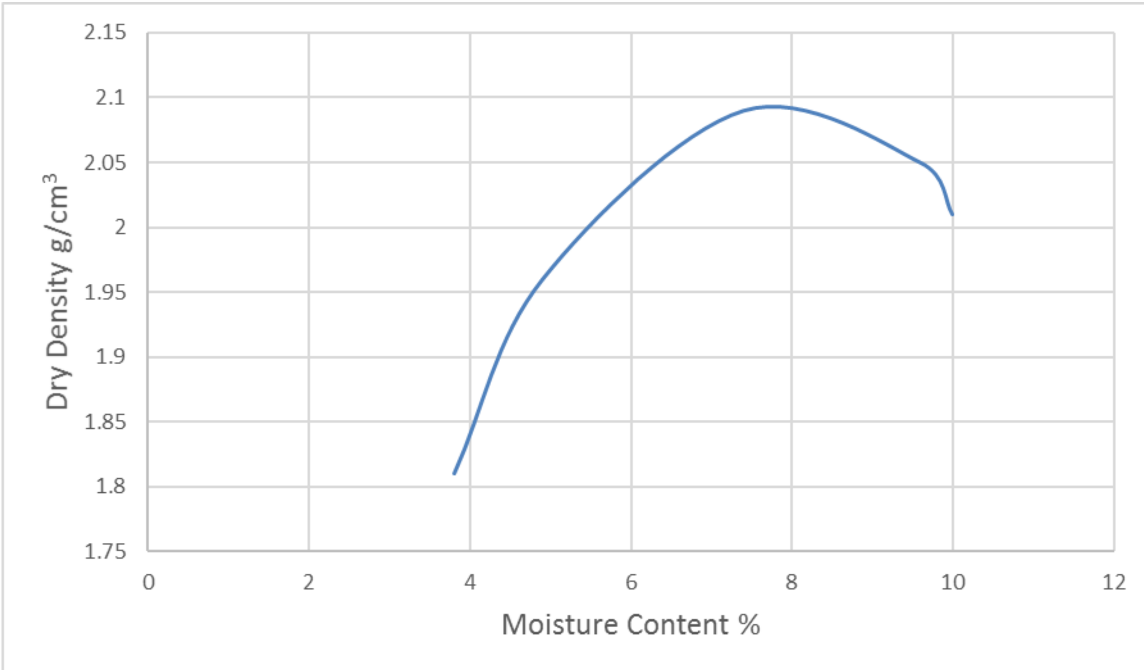

Figure 16 Plot of Compaction Test Data for Sangere Loko Gully Site

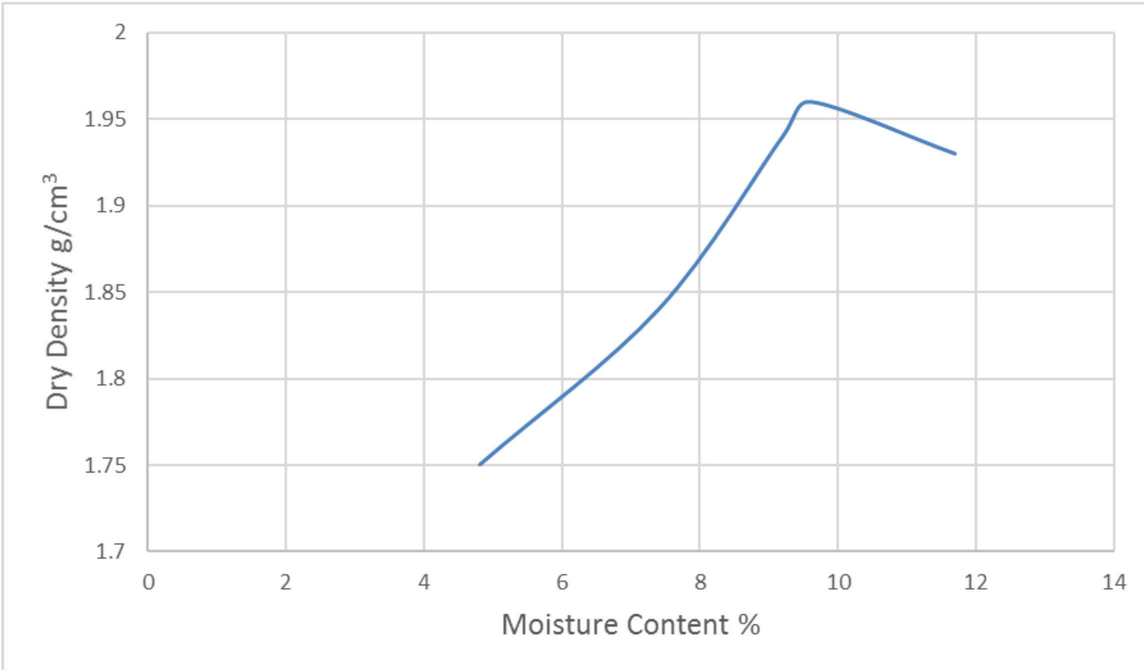

Figure 17 Plot of Compaction Test Data for Purudomon Gully Site

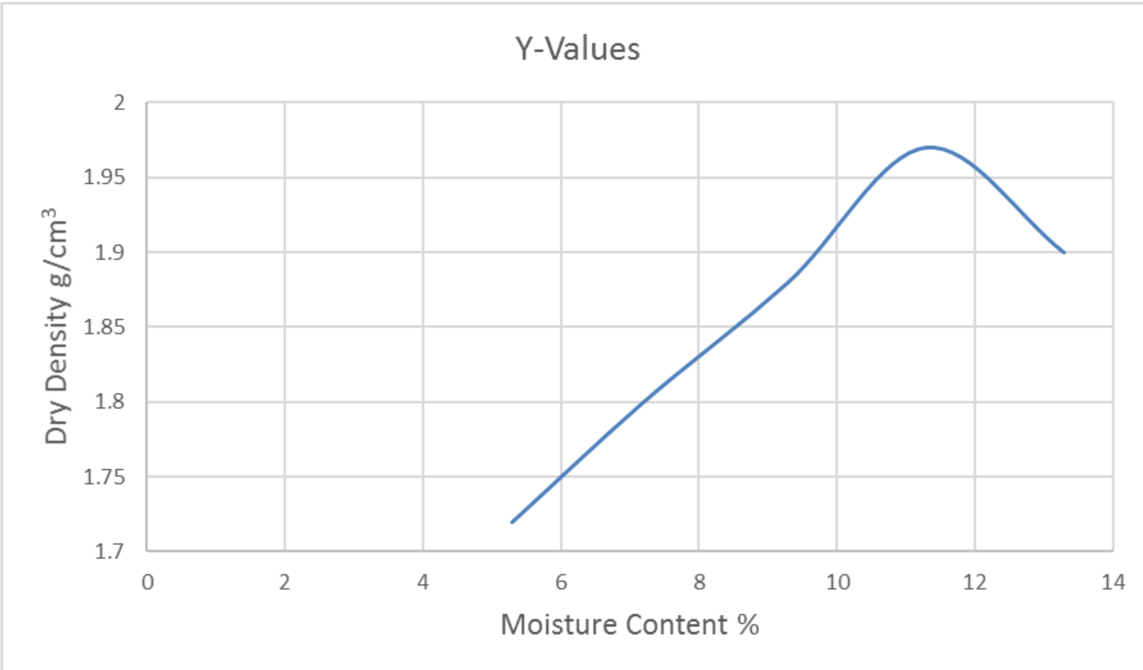

Figure 18 Plot of Compaction Test Data for Dubande Gully Site

Table 2: Summary of Soil Tests in the Study Area

Gully Sites	Depth (m)	Width (m)	Plastic Limit (%)	Liquid Limit (%)	Plastic Index (%)	MDD Kg/m^3	OMC (%)
Malero	3.2	65	13.15	25.2	12.05	1.96	9.8
DadinKowa	4.0	60	18.0	34.0	16.0	1.89	9.6
Kaulara	1.3	17.5	21.9	43.2	21.3	1.80	10.2
Bolki	2.0	9.9	16.0	28.0	12.0	1.78	9.6
GarinLamba	1.5	9.5	15.1	27.1	12.0	2.21	6.1
SangereLoko	2.0	42	16.0	35.0	19.0	2.09	8.0
Purudomon	6.0	46	16.0	29.4	13.4	2.07	8.6
Dubande	2.0	30	21.3	38.2	16.9	1.82	9.1
Total	22	279.7	137.45	260.1	122.65	15.62	71.0
Mean	2.75	34.96	17.18	32.51	15.33	1.95	8.86

Table 3: Classification of Soil According to their Liquid Limit (After Bell, 1983)

Description	Plasticity (Plastic Limit)	Liquid Limitance
Lean or silty	Low plasticity	Less than 35
Intermediate Fat	Intermediate plasticity	35 – 50
High Plasticity	High Plasticity	50 – 70
Very Fat extract	Very high plasticity	70 – 90
Extract high plasticity	Extra high plasticity	Over 90

Table 4: Classification of Soils Based on Their Plasticity Index (After Anon I979)

Class	Plasticity Index	Description
1	Less than 1	Non plastic
2	1 – 7	Slightly plastic
3	7 – 17	Moderately plastic
4	17 – 35	Highly plastic
5	Over 35	Extremely plastic

Sieve Analysis

Sieve or particle size analysis involves the division of rock samples by sieving into sized fractions. The result can be used to distinguish between sediments of different environment and to classify soils. Cumulative curves of the various soils from gully sites were plotted (Appendix 1A – H). From the curves the graphic mean was calculated using the relation: Mean = (0.16+0.50+0.84)/3.

The graphic mean is used to calculate the average diameter of the grain interpreted using Wentworth scale for sand (Wentworth, 1922). The values of the parameters in the relation above were traced from the curves. The results of sieve analysis revealed a grain size distribution ranging from medium to coarse grained sandstone with strongly unimodal curves (5 and 6).

Table 5: Graphic Mean Data Interpretation for the study area

S/N	Location	Depth (m)	Calculated Mean	Soil Description
1	Malero	2.0	1.121	Medium Coarse Sand
2	Dadinkowa	2.0	1.131	Medium Coarse Sand
3	Kaulara	2.3	1.231	Medium Coarse Sand
4	Bolki	2.8	1.434	Medium Coarse Sand
5	Garinlamba	2.1	0.204	Medium Coarse Sand
6	Sangereloko	1.6	0.211	Medium Coarse Sand
7	Purudomon	10.3	0.342	Medium Coarse Sand
8	Dubande	3.4	0.297	Medium Coarse Sand
	Total	26.5	5.97	
	Mean	3.31	0.75	

Table 6: Standard table for mean grain size distribution (Wentworth, 1922)

Phi (ϕ) range	Description terms
-1.00 – 0.00	Very coarse sand
0.00 – 1.00	Coarse sand
1.00 – 2.00	Medium sand
2.00 – 3.00	Fine sand

Geological assessment of gully sites

The basement complex rocks underlying the study area consist essentially of granites and granite gneiss which is intruded by the fine grained basaltic rocks. They are largely fine to coarse grained, granular and phaneritic in texture, crystalline indurated, compact with interlocking crystals up to 1 cm thick somewhat equigranular matrix of feldspar and quartz with scattered darker biotite and hornblende peppering the lighter coloured minerals and well cemented when fresh.

The granites are light to dark in colour and consist essentially of quartz, biotite, feldspar and hornblende. The average grain-size is between 0.15 cm to 2 cm and cover less than 4 % of the study area. The granite gneiss are essentially light to grey in colour, fine to coarse grained interlocking texture, foliated, banded with lenses of light coloured granula\r minerals such as quartz and feldspar and dark coloured minerals such as biotite and hornblende. The dark minerals are arranged in a streaky banding with grain-size varying between 0.12 cm to 1.80 cm and cover about 6 % of the study area. The basalt is dark gray-coloured, dense, mafic, fine-grained, and vesicular and is composed essentially of olivine, calcic plagioclase, feldspar and pyroxene minerals with phenocrysts of olivine and pyroxene in a groundmass of calcic plagioclase and quartz with accessory iron-oxide. The grain-size varies from less than 1 mm to more than 1 cm in size and constitute about 8 % of the study area.

Field studies of the gully sites revealed that these basement complex rocks have been largely weathered to residual or transported soils consisting of clays, sands, humus and lateritic and saprolithic soils. The disintegrated or weathered materials may either be found deposited at its place of origin to form insitu soil (Elluvium) or may be transported by agents of denudation such as water and/or wind before deposition to form drift soil (Alluvium). Furthermore, break down of rocks to depth of many meters induced by physical and chemical weathering of stable minerals such as quartz forms sand deposites whereas the weathering of unstable minerals such as feldspar, olivine, pyroxene and hornblende induced by chemical alteration of rocks minerals by groundwater forms clay soils found underlying the gully sites as well as slopes and stream valleys.

According to Folk and Ward (1957), the sorting characteristics of a rock sample can be evaluated using the following equation:

$$\Theta = (\text{Ø}84 - \text{Ø}16)/4 + (\text{Ø}95 - \text{Ø}5)/6.6 \quad (1)$$

Where

Ө = Inclusive graphic measure (sorting)

Ø84 = quartile 84 (84 percent of the particles are finer), and

4 and 6.6 = mathematical constants

Thus employing equation (1) the sorting values ranging from 0.20 to 1.43 were obtained for samples collected at the gully sites (Table 6) which correspond to poorly to well sorted samples. This indicates that the soils are largely medium to coarse grained, largely well sorted and that the fine grained materials such as clays and silts that can provide cohesion are lacking in many of the gully sites. Furthermore the hydraulic properties as determined from statistical grain size methods indicate hydraulic conductivity values ranging between 3.04 x 10-5 cm/s and 1.42 x 10-2 cm/s and transmissivity values ranging between 1.31 x 10-6 cm2/s and 2.25 x 10-4 cm2/s respectively (Table 7 and Figures 19 to 26). These thus indicate relatively high permeability, high seepage fluxes and pore pressures which will reduce the shear strength of the soils and hence enhance its erodibility.

Table 7 Hydraulic Parameters values estimated from statistical grain-size methods

		Hydraulic conductivity cm/s			Transmissivity cm^2/s			Thickness (cm)
S/N	Sample Location	Hazen (1893)	Harleman et al., (1963)	Uma et al., (1989(	Hazen (1893)	Harleman et al., (1963)	Uma et al., (1989)	
1	Malero G1	$1.05x10^{-7}$	$1.03x10^{-2}$	$3.20x10^{-4}$	$1.02x10^{-5}$	$3.30x10^{-4}$	$1.02x10^{-5}$	3.20
2	Dadinkowa G2	$5.89x10^{-6}$	$5.77x10^{-3}$	$1.80x10^{-4}$	$2.36x10^{-7}$	$2.31x10^{-4}$	$2.20x10^{-5}$	4.00
3	Kaulara G3	$2.36x10^{-4}$	$2.31x10^{-3}$	$7.22x10^{-5}$	$3.07x10^{-10}$	$3.00x10^{-5}$	$9.39x10^{-7}$	1.30
4	Bolki G4	$2.35x10^{-7}$	$2.31x10^{-2}$	$7.20x10^{-4}$	$4.70x10^{-9}$	$4.62x10^{-4}$	$1.44x10^{-5}$	2.00
5	Garinlamba G5	$2.35x10^{-7}$	$2.31x10^{-2}$	$7.20x10^{-4}$	$3.53x10^{-9}$	$3.47x10^{-4}$	$1.08x10^{-5}$	1.50
6	Sangere G6	$1.05x10^{-7}$	$1.0x10^{-2}$	$3.20x10^{-4}$	$2.10x10^{-9}$	$6.40x10^{-6}$	$4.20x10^{-6}$	2.00
7	Purudomon G7	$2.35x10^{-7}$	$2.31x10^{-2}$	$7.20x10^{-4}$	$1.41x10^{-8}$	$1.39x10^{-5}$	$4.32x10^{-5}$	6.00
8	Dubande G8	$6.25x10^{-7}$	$1.60x10^{-2}$	$5.0x10^{-4}$	$1.25x10^{-8}$	$3.20x10^{-4}$	$1.00x10^{-4}$	2.00
	Mean	$3.04x10^{-5}$	$1.42x10^{-2}$	$4.44x10^{-4}$	$1.31x10^{-6}$	$2.25x10^{-4}$	$1.57x10^{-5}$	2.75

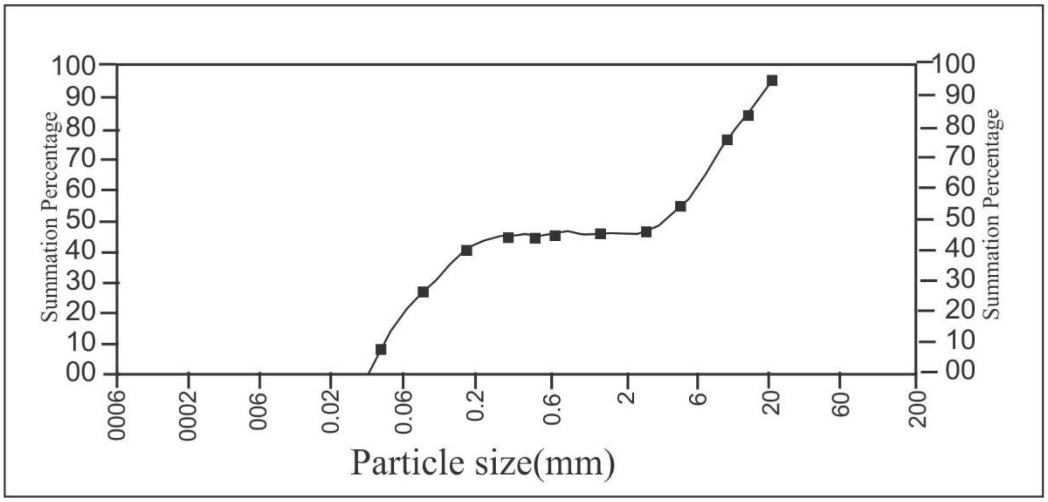

Figure 19 Particle Size Distribution Curve for Malero Gully Site

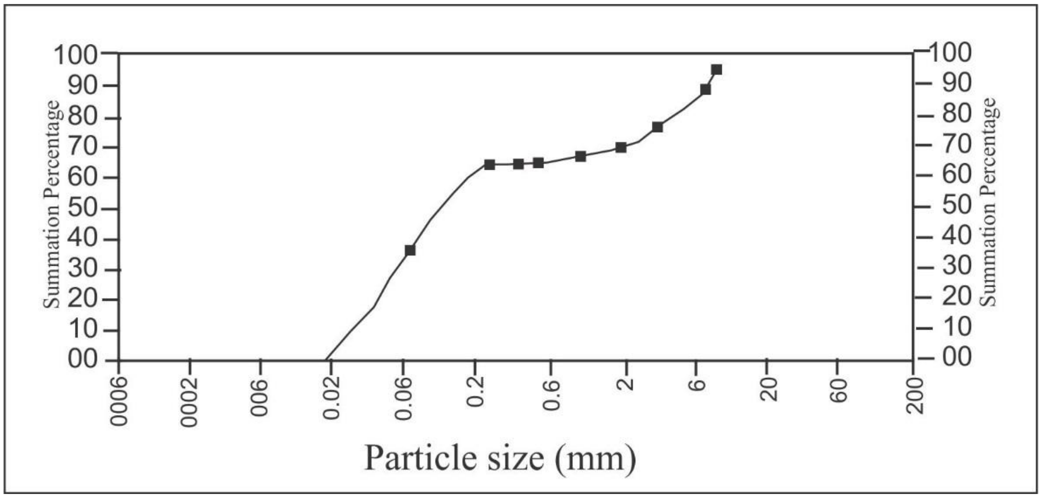

Figure 20 Particle Size Distribution Curve for Dadin-Kowa Gully Site

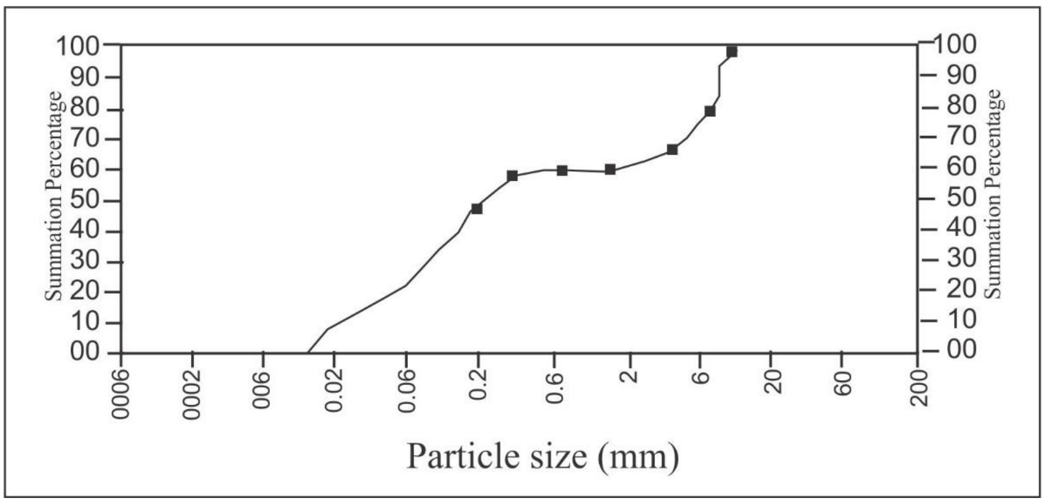

Figure 21 Particle Size Distribution Curve for Kaulara Gully Site

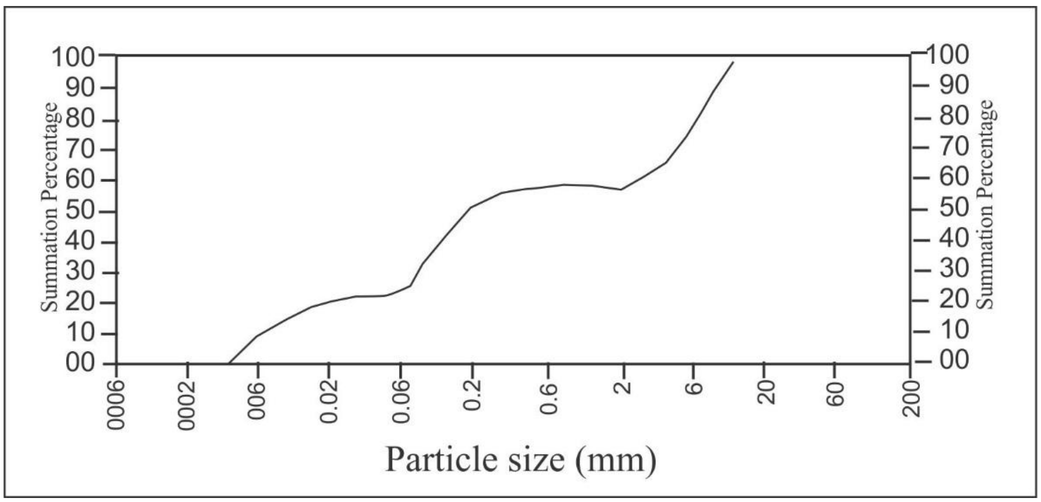

Figure 22 Particle Size Distribution Curve for Bolki Gully Site

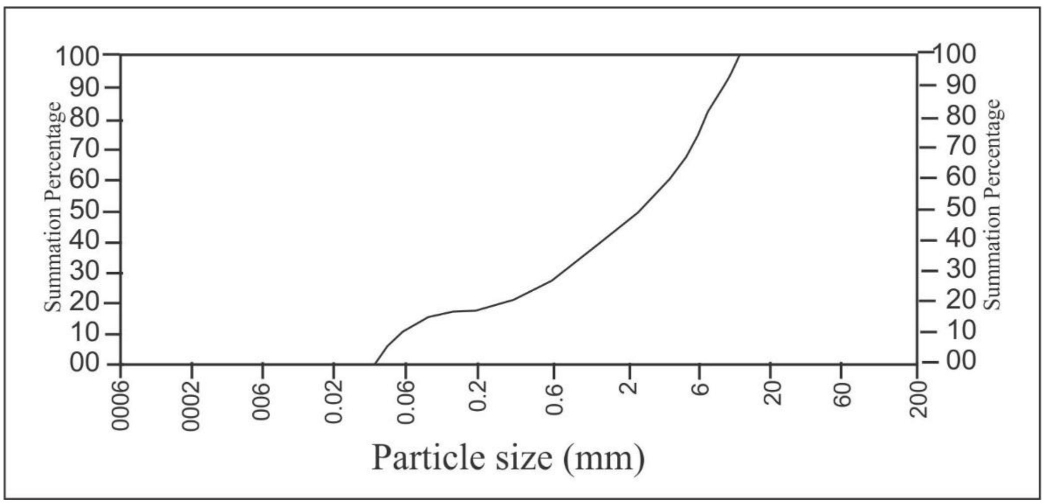

Figure 23 Particle Size Distribution Curve for Garin Lamba Gully Site

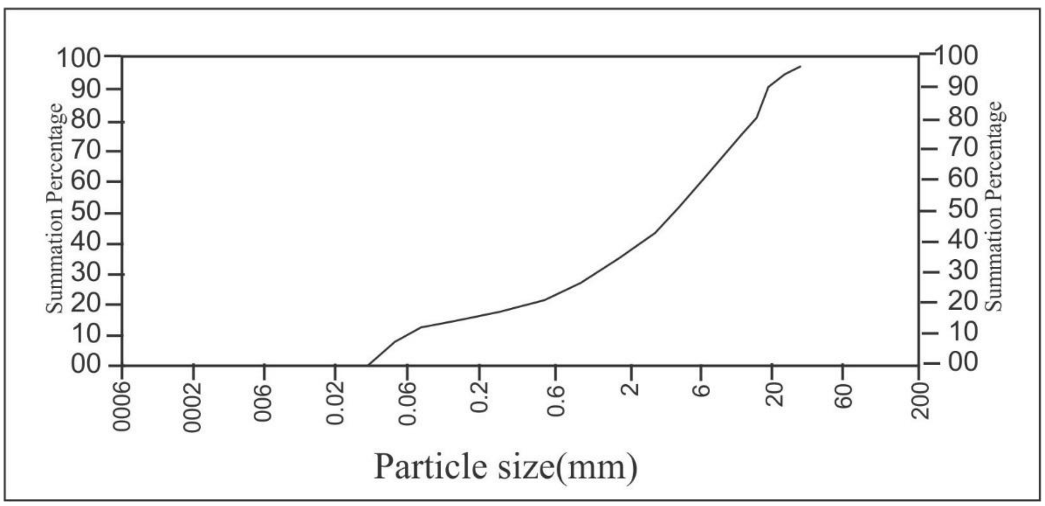

Figure 24 Particle Size Distribution Curve for Sangere Loko Gully Site

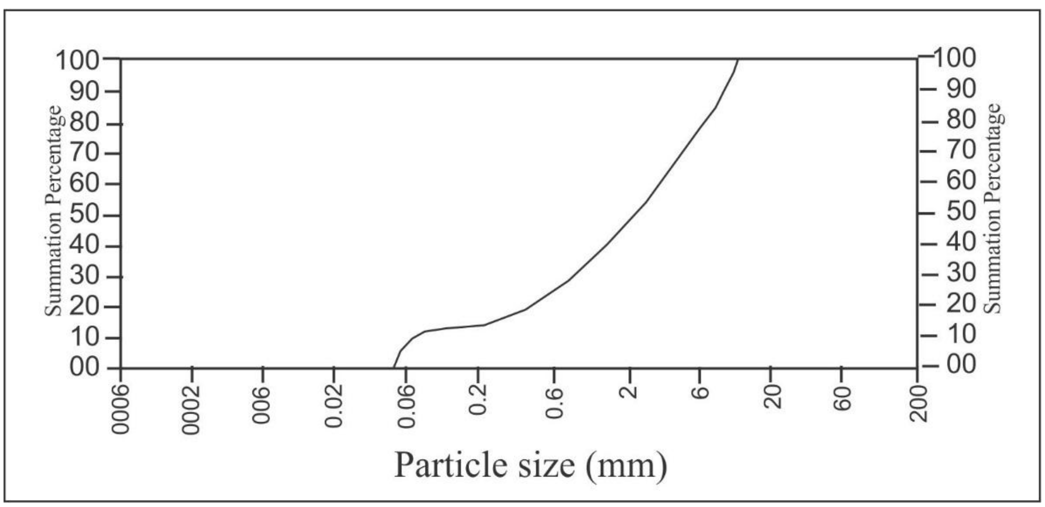

Figure 25 Particle Size Distribution Curve for Purudomon Gully Site

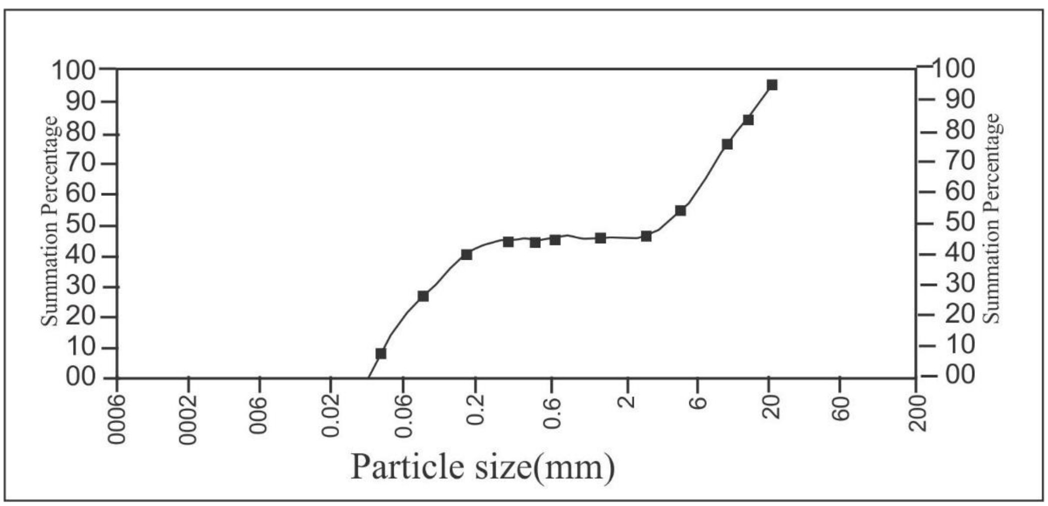

Figure 26 Particle Size Distribution Curve for Dubande Gully Site

Conclusion

The area under study lies within the Northeastern basement complex of Nigeria. It is located within the Nigerian Topographical Map of Zummo N.E, Sheet 176 between latitudes 9°45' 00" to 9°49' 00” N and longitudes 12°30' 00" to 12° 36' 00" E with an areal extent of $84.6km^2$. Eight soil samples from eight gully sites within the study area with an average depth of incision of about 2.75 and an average width of 34.96 were analyzed and results presented and interpreted.

Most geological problems associated with gully erosion development and spread in Nigeria originate from, or are enhanced by the activities of man, the socio-economic losses associated with such activities often exceed the expected grains. In assessing for the susceptibility to gully erosion in Sangere Loko in Song Local Government Area of Northeastern Nigeria, some geological and geotechnical test have been carried out, which were used to infer the surface processes that contributed to the formation and continued expansion of gullies in Song area.

The plastic limits of the soils vary from 13.15% to 21.90 % whereas the plasticity index varies from 12 % to 21.30 % revealing soils of low to moderate plasticity as well as friable, easily crushed by fingers, poorly cohesive soils that are susceptible to gully erosion. It thus offers little resistance to gully erosion. The compaction test display maximum dry density values of 1.78 kg/m^3 to 2.21 kg/m^3 with an optimum moisture content values of 6.10 % to 10.20 % revealing generally loose soils that are susceptible to gully erosion.

Moreover, forces of denudation such as running water and wind have subsequently acted on the rocks resulting in the production of alluvial deposits or residual soils that make it easy for running water to dislodge the soil particles creating gullies in the process. The results of sieve analysis revealed a grain size distribution ranging from medium to coarse grained soil with strongly unimodal curves as well as high hydraulic properties that that reduces the shear strength of the soils and thus make susceptible to gully erosion.

Recommendation

The investigation revealed that gully systems in the area are in their early stage and therefore easier to control now than when they are left or allowed to evolve into complex forms. The most important reducing gully erosion control measure is early control. Thus, in addition to reducing causative activities through legislation at various levels of government, developing cases need to be reported and controlled early enough.

The engineering aspect of soil erosion control should be geared towards changing the slope characteristics of the area so that the amount and velocity of run-off are decreased. Other soil stabilization techniques such as grouting, dewatering and construction of concrete ripraps should be applied where pore pressure and seepage forces are high.

Agro-forestry methods such as planting of trees like bamboo and grasses to forestall, eliminate or check the development of erosion in the study area. Also, trees like Gmelinaarborea, Pinuscarihacea, Pinuscarihacea, Dacroydesedulis, Cassis nidosa, Traculia Africana and Irvingiagobonensis, which have high rate of survival are recommended for erosion control in the study area. These will intercept raindrops and decrease the speed with which they hit the unconsolidated earth. Other agricultural practices that tend to stripe off the protective vegetation cover of the soil, like bush burning, over cultivation and over grazing should be discouraged.

Finally, the investigations provide the geological and geotechnical characteristics of the soils of the study area. This is used to infer the surface and subsurface processes that contribute to the formation and continued expansion of gullies in the study area. From the above, all engineering aspects of soil erosion control measures as well as the appropriate soil stabilization in the area should be done.

REFERENCES

Adamawa State Diary (2005) Meteorological Informations for Adamawa Area of Northeastern Nigeria

Amagu, A.C; Eze, S.N; Jin-Ichi, K and Nweke, M.O (2018) Geological and geotechnical evaluation of gully erosion at Nguru Edda, Afigbo Sub-basin SE Nigeria Journal of Environment and Earth Science vol 8 No 12 pp 148-158

Bassey, N.E; Dada, S.S and Omitogun, A.A (2006) Preliminary Structural Study of Satellite Imagery over Basement rocks of Northeastern Nigeria and Northern Cameroun Jour of Mining and Geology vol 42 No 1 pp 73-77

Bassey N.E (2007) Brittle Deformation Features of Michika Area, Hawal Basement Complex, NE Nigeria Global Journal of Geological Sciences vol 5 No 1 and 2 pp 51-54

Bell F.G (1983) Fundamentals of Engineering Geology Butterworth Publishers London

Carter, J.D; Barber, W; Tait, E.A and Jone, G.P; (1963).The Geology of part of Adamawa, Bauchi, and Borno provinces north – eastern Nigeria, Geological survey of Nigeria bull. 30, pp 35 – 53

British Standards BS (1377 (1967) Compaction Tests of Soils Royal Charter London.

Dupreeze, J.W Barber W. (1965). The distribution of chemical quality of Groundwater in northern Nigeria, Geol. Surv. Of Nigeria bull.36,pp 19-33.

Ekwueme B.N (1993) An Easy approach to Igneous Petrology University of Calabar Press, Calabar 385pp

Falconer, J.D, (1911).The Geology and Geography of northern Nigeria. McMillian London, pp 286.

Federal Survey of Nigeria, (1968).Topographical map sheet of Zummo, sheet 176.

Floyd, B; (1965). Soil erosion and deterioration in eastern Nigeria, Nigeria Geography Journal vol. 8 pp 33 – 44

Folk R.L and Ward K.C (1957) Brazos River Bar; A Study of the Significance of Grain-size parameters. Jour. Of Sedimentary Petrology 27. Pp 3-26

Grove, A.T (1951) Land-use and Soil Conservation in parts of Southeastern Nigeria Research Paper delivered to the Department of Survey and Geo-informatics Nnamdi Azikiwe University Awka Nigeria

Geological Survey of Nigeria (2011). Geological map of Nigeria Scale 1:100,000. All right reserved.

Kiser, R.T (1968) Chemical Quality of Water in Northern Nigeria Geol. Surv. Of Nigeria Bull Open File Report

Obiefuna, G. I., A. Nur, A. U. Baba, and N. E. Bassey (1999) Geological and Geotechnical Assessment of selected gully sites in Yolaarea; Northeastern NigeriaTnt. Journal of Environmental Hydrology San Antonio Vol. 7, paper 6.

Obiefuna G, I., and David, S.E (2010) Geological and Geotechnical Assessment of Selected Gully Sites in Jada Area NE Nigeria Journal of Environmental Sciences and Resource Management Vol. 2 No 1

Obiefuna, G. I., Ojodale C.O and Danjuma B (2018) Geological and Geotechnical Assessment of selected Gully Sites in Lainde Fulani Area NE Nigeria Jour. Of Environmental Science and Resource Management vol 10 No 1 pp1-13

Ofomata G.E.K (1965) Factors of Soil Erosion in the Enugu Area of Nigeria Nigerian Geographic Journal vol 8 No 1 pp 45-59

Ogbukagu, I.M (1976) Soil Erosion in the Northern Parts of Awka-Orlu Upland Nigerian Journal and Geology vol 13 pp 6-19

Ogezi, A E.O (1977) Geochemistry and geochronology of basement rocks of northwestern Nigeria Unpublished PhD Thesis University of Leeds UK

Okunlola, I.A; Abdulfatal, I.A Kolawole, L L and Amadi, A.N (2014) Geological and geotechnical investigation of gully erosion along River Bosso, Minna, North Central Nigeria Journal of Geoscience and Geomatics vol 2 No 2 pp 50-56

Onwuemesi A.G (1990) Hydrogeophysical and geotechnical investigation of the Ajalli Sandstone in Nsukka and Environs with reference to groundwater resources and gully erosion problems Water Resources-Journal of Nigerian Association of hydrogeologists vol 2 No 1

Oyawoye M.O (1970) The Basement Complex of Nigeria In Dessuvagie T.F, Whiteman A.J (ed) African Geology University of Ibadan

Rahaman, M.A (1988) Geology of Nigeria and Crustal Evolution (2^{nd}) Edn Macmillian Publishers Ibadan Nigeria

Uma K.O and Onuoha K.M (1987) Groundwater Fluxes and gully Development in Southeastern

Nigeria earth evolution Sci. Vol. 20, pp25-130.

Upper Benue River Basin Development Authority UBRBDA (1994) Meteorological Year Book

Wentworth C.K (1922) Scale of Grack and Class: Terms for classic sediments Journal of Geology vol. 33 pp 377-392