GEOLOGICAL AND GEOTECHNICAL ASSESSMENT OF SELECTED GULLY SITES IN LAINDE FULANI AREA NE NIGERIA

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ABSTRACT

The Geological and Geotechnical assessment of selected gully sites in Lainde-Fulani and environs is presented. Field geological study of the area revealed that the area is underlain by Basement Complex rocks. The soils of the area are products of in situ weathering of the underlying basement rocks. Results of sieve analyses show that the soils at the gully sites have sorting values ranging between 0.42 and 2.3, coefficient of uniformity values ranging between 3.0 and10 , and coefficient of curvature values ranging between 0.2 and 1.3. These indicate that the soils are poorly to well sorted and well to poorly graded. The plasticity indices values ranges between 11.0 and 29 with a mean value of about 20 indicating moderate plasticity with slight dry strength and easily friable. Values of maximum dry density ranges between 1.83g/cm^3 and 2.09g/cm^3 at optimum moisture contents of between 7.4% and 11.3% revealing that the soils are generally loose. The hydraulic conductivity and transmissivity values as determined from statistical grain-size method ranges between 3.8×10^{-4} cm/s to 6.4×10^{2}cm/s and 3.8×10^{-2}cm^2/s to 9.6×10^{4}cm^2 respectively. These indicate moderate seepage fluxes and adverse pore pressures and are thus erodible. From the results of the study, recommendations for erosion control such as; afforestation, construction of drainages, grouting and concrete rip-raps were suggested.

Keywords: Geological, Geotechnical, Maximum Dry Density, Optimum Moisture Content, Lainde Fulani Area, Nigeria.

INTRODUCTION

Gully erosion types are the most visible forms of erosion in Nigeria mainly because of the remarkable impression they leave on the surface of the earth. It is a phenomenon that is ravaging the entire landscape of the country and has adversely affected agricultural productivity and thus casting doubt on food security. The greatest threat to the environmental settings is the gradual but constant dissection of the landscape by water. Although the incipient stages of soil erosion through rill and interrill are common and easily managed by the people through recommended soil

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conservation practices, the gully forms have assumed a different dimension such that settlements and scarce arable land are threatened (Floyd, 1965). Therefore, gully erosion problems have become a subject of discussion among soil scientists, geographers, geologists, engineers and social scientists. The danger are discussed in many standard Textbooks and scientific Journals but few people understand its real impact on the agricultural, infrastructural, and socio-economic aspect of both urban and rural development of Adamawa State especially in Lainde-Fulani area.

It was in the light of the above consideration that soil test analysis and geological assessment were conducted with a view of providing the geological and geotechnical parameters that contribute to the genesis and expansion of these gullies. The assessment shall help in suggesting design for appropriate control measures.

Study Area

The study area lies within latitude $8^0$55'N and 9^0 00'N and longitudes 12^0 05'E and $12^0$10'E. The study area is bounded by Fufore to the east, Mayo Belwa and Ganye to the South, Demsa to the North and Taraba State to the West respectively.

It has a total land area of about 183.2Km^2 with a population of about 121,060 (Based on 1991 population census) giving a population density of 66.1 per km^2. The area is traversed by Yola-Jalingo road via Ngurore and Yola-Jada-Ganye road with numerous foot paths linking the villages to the town.

The study area experiences rainy season between April and October and dry season between the months of November to March. Thus, the rainfall is seasonal and it is maximum in the month of August with greatest number of rainy days. The mean annual rainfall in the study area is about 863.8mm (Table 1). Temperature in this area remains high in most part of the year as a result of its proximity to the equator, being as hot as 46°C between the months of March and June (Obiefuna and Simon 2010). It is cold only between the months of December and February with temperatures ranging between 27°C and 32°C during which the air is often hazy due to influence of the dusty harmattan windstorm. The relative humidity is very high during the rainy season and very low during the dry season.

Most of the previous work done in the area were mainly regional in extent (Falconer, 1911 Carter et al 1963, Cratchley and Jones 1965, Dupreeze and Barber, 1965) and have described the geology of the Upper Benue Trough in terms of sedimentary, stratigraphic and hydrogeologic aspects. Subsequently, Kiser, 1968 gave further details on the geology, geological structure, hydrogeology and water quality of the old Northern Nigeria in which the study area is inclusive. Furthermore Wright, 1968, and Offodile, 1992 wrote on the origin of the Benue Trough and Geology of the Cretaceous of the valley respectively. Offoegbu (1988) gave an interpretation of geomagnetic data of parts of Benue Trough whereas Braide (1992) studied the sedimentary and tectonics of the Yola Arm of the Benue Trough with emphasis on facies architecture and their provenance significance. Obiefuna et al (1999) gave detailed account of the geological and geotechnical assessment of selected gully sites in Yola area of North-Eastern Nigeria and made recommendations on how to tackle the environmental hazard. Inaddition Obiefuna and Nur 2003, Valdon et al 2010, Omale et al 2010, Obiefuna and David 2010 and Obiefuna and Simon 2010 respectively investigated the geological and geotechnical properties of soils and gully sites in Bauchi, Gombi, Ankpa, Numan and Jada areas of Northeastern Nigeria.

The main objectives of this research are as follows:

1. To carry out a detailed geological mapping of the Lainde-Fulani 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 Lainde-Fulani 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 in arresting the menace of gully erosion in the area.

Geology of the Study Area

Geologic History

The study area Lainde-Fulani and environs belongs to the hard crystalline Craton Basement. The hard crystalline Craton basements are ancient Precambrian rocks form from series of orogenic circles within the mobile belt of Central Africa. The various dating revealed Liberian – (2500±200my), Eburnean – (1800±200my), and Kibarian – (1200±200my) Orogenic events. (Ogezi 1977). The rocks of these events are commonly gneisses, migmatites and quarzites. However many of the structural traces where obliterated by the late Proterozoic and Pan

African thermotectonics events that spanned from 750my to 500my (Rahaman 1988)

During the Pan African Orogeny, there was structural development resulting in faulting towards NW-SE and SW-SS direction. Pan-African Orogeny was followed by post metamorphic epeirogenic 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).

From the geological mapping it was shown that the lithology of the rock in the study area is basically granites which intruded as coarse grained granite cutting through the middle of the study area (Figure 1). This coarse grained granite is subsequently gives rise to River course alluvium to the north and south of the study area. Recent geological processes that took place in the area may have resulted in the weathering of these granites giving rise to these alluviums.

Major Lithologic Units in the Study Area

Residual Soils

Soils are formed by the disintegration (weathering) of rocks. The disintegration or weathered material may either be found deposited at its place of origin; called residual soil or insitu soil or may be transported by agents of denudation such as water, wind or ice before being deposited as transported or drift soil. The soil which has been formed by weathering of the parent rock and still occupies the position of the rock from which it has been formed is called a residual soil or insitu soil. Such soils are evidently genetically (compositionally) related to the underlying rocks as they are derived from them. After their formation they have remained at the same place without undergoing any significant transport (lateritic soils). These soils are infertile due to their having undergone leaching with their thickness varing from place to place depending on physical or chemical homogeneities of the underlying parent rock. These soils are also called sedentary soils.

The transported soils commonly called the drift soils are those soils which have been formed at some place but are found to occur elsewhere after having undergone considerable transport. These soils have been transported by wind, water, ice or by some other means. Transported soils are unrelated to their underlying rocks compositionally. They occur in stratified manner and have uniform thickness and by virtue of their mode of formation these soils are quite fertile. Examples include, alluvial, glacial or Aeolian and are found along the river channels.

The elluvium are soils comprising deposits formed insitu by chemical and physical decomposition of the underlying basement rocks. They are composed of sands, humus, clayey soils and lateritic soils. Soils in the study area are mostly residual alluvium derived from both physical and chemical weathering of the underlying basement rocks.

Coarse Grained Granites

The coarse grained granites stretch from Wuro Maya in the Central part of the study area to Wuro Buga to the south western part. They are pale brown to grey and show little variation in appearance. The rock consists predominantly of quartz, feldspars, hornblende and biotite. They occur as irregular bodies of inselbergs displaying sharp contact with the surrounding alluvium and are highly fractured giving rise to joints, faults, fissures, and fractures of largely variable dimensions (Figures 1 and 2).

Geological Structures

Any portion of the earth in general can be acted by force which tends to displace and distort the rocky outcrops. And this force arises principally from the weight of the overlying rocks which may be from large- scale motions or movement of materials composing adjacent part of the crust or that of the mantle. Gravity acts on element of the rock. In some cases these force are small or act on for a short period (geologic time) so no significant deformation occurred. Sometimes these forces acts for relatively longer period and spectacular permanent deformations, such as large scale folding may result. Fracture strength of the rocks may be exceeded and faulting is the most conspicuous mode of deformation depending on the nature of the rock, a number of physical and chemical factors like hydro static pressure, temperature pore - fluid pressure, rate-at which the deformational and the composition including the fluid content of the rocks. The types of geological structures identified and mapped in the study area are faults, joints, dykes and veins (Figures 3 to 5) indicating the major trends in the study area.

Faults

Fault is a planner discontinuity between rocks where there has been an observable amount of displacement. Faults are rarely single planner unit; normally they occur as parallel set of plane along which movement has taken place to a greater or lesser extent. Fault are produced as the results of the forces that act within the earth and displaces and distort the rock within the earth. These forces results from the load of the overlying rocks whereas others arises from the large scale movement of materials composing adjacent part of the core or mantle. Some parts of the study area are observed to be highly faulted and while some faults are inherited from offloading by erosion causing some minor fractures, others resulted from stresses acting on the study area.

Joints

Joints were observed and recorded in four locations in the study area and these includes Wuro Sete, Wuro Birji, Lainde-Fulani, Wuro Buba, and Sete Lawan. The Joints are small-scaled parting in a bulk surface of a material which are found around Yolde Mbole and are irregular in shape. They are formed when water has been deposited in the rock, evaporated leaving the rock to dry. When the rock dries, there is a contraction at the middle, which results from the cohesive forces acting on the grains and crack occurs (Obiefuna and Adamu, 2011).

Dykes

A dyke is a discordant igneous rock or solidified magma cutting through the overlying sediments or body of a host rock vertically. Pegmatite dyke has been observed at Wango Sete, Wuro Bentere, and Lainde-Lama. Gotere, The dykes in the outcrop are not affected by weathering of the country rock in which they occur. They can be pronounced in the field because they weather differently from the rock they penetrate. Their preferential erosion is termed to be as a result of cross jointly which most dykes are known. The trends of some major dykes are recorded in Table 2.

Veins

These are fractures filled with remobilized minerals such as quartz, feldspars or both. Veins indicate high albeit transient, pore fluid pressure during deformation and are commonly associated with pressure solution seams called quartzofeldsphatic veins. Veins can be identified in the field based on color difference or textural differences with its host rock Carter et al (1963). The quartzofeldspatic veins observed are found at Mayo Kale and are more felsic than the host rock. These are due to the presence of quartz and feldspar which makes them lighter coloured. They trend mostly in NE-SW and SE direction (Table 2 and Figures 3 to 5). The fault plays major role in weathering of rock in the study area.

MATERIALS AND METHOD

This section deals with methodology of approach that would be adopted in carrying out the research. And it will be carried out in stages. The first stage involved the use of topographic map which was used 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 and field map.The third stage in the data acquisition involved the laboratory analysis of the samples that was collected from the field. The sample (both soil and rock) was collected at 14 places randomly and was subjected to a number of laboratory tests such as grain size distribution, (Sieve) analysis, petrographic analysis, compaction test and atterberg or consistency limit test (liquid and plastic limits). The data of annual rain fall was collected from the Upper Benue Development Authority Yola Nigeria (UBDA).

Laboratory Procedures

Four (4) samples were collected from the field which were closely examined. Their colour, texture and other physical properties was also determined. Others were subjected to petrographic analysis.

Particle size distribution analysis

This was done with the aim of finding the distribution of grain sizes within the soil samples that were collected. The result was used in determining the sorting characteristic of the soil.

The materials used for the analysis includes British standard sieve, a heavy duty balance, a wire brush, 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, 500g of samples was taken in a container of known weight and labeled. To the sample, water was added and then allowed to stand for twenty-four hours. This was aimed at disaggregating all the soil materials. The soaked sample was then washed over 20mm sieve until water was free of fine particles. The washed sample was oven dried for 20hrs 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 material washed off from the original samples was obtained by subtracting the weight of the washed oven dried sample from that of original sample;

The sieves were arranged in a stack with the larger aperture sieve at the top with the smaller aperture sieve 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 on a laboratory reporting sheet and analyzed.

Petrographic Analysis

Thin section preparation

Thin section or slides of rocks was used for the petrographic study of the rock sample. The thin sections were obtained by cutting thin slide 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 on an electric oven or heating plate to harden it. It was then mounted on the rock cutting machine where the specimen was further reduced in thickness by a rotary grinding blade, when the specimen was made very thin-almost transparent, was removed from the machine and finished to the correct thickness (0.03mm) using carborundum 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 rock samples

Microscopic examination was carried out to determine the different minerals contained in the nozel of the study area. The instrument used is the petrographic (polarizing microscope with magnification of x10. The different minerals in the slide were determined.

Atterberg or Consistency limit test

The atterberg or consistency 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 other words, it is that moisture content at which the soil will flow under its own height. Plastic limit is the percentage moisture content at which a soil can be rolled without breaking into threads three (3mm) millimeter 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.

Equipments used

The materials and equipment proposed to be used include; the liquid limit (Cassagrande) apparatus, mortar and pistol an electric oven, BS No. 425 sieve, a grooving tool, glass plate, a balance for weighing water and some numbered specimen containers.

Liquid Limit Test

A portion of the paste was remolded on a glass paten and laced in the liquid limit apparatus and grooved using a standard grooving tool while preventing air trapped. The handle of the Cassangrande 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 and weighed, placed in the oven for 24 hrs 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 no of blows) and the best straight line drawn between the points. The moisture content at twenty five 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 platen into threads. The threads were put into containers like those in the limit test, and weighed. They were then placed in the oven for twenty four 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 (PT) was obtained as the numerical difference between the liquid limit (LL) and plastic limit (PL) as PT = LL - PL.

Compaction Test

Compaction tests are carried out with the aim of determining the moisture density relationships of soils. A number of methods have been developed for this purpose. These include the standard compaction method (also called proctor method), the modified AASHTO 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 in 1933 and has since become the most widely used method of compaction test in the world (BS, 1967, Test II)

Materials Used for the Test.

Materials used for this test include the following: Riffled box, heavy duty balance (up to 2kg with sensitivity of 1 -5kg), large metal tray, rubber hammer, measuring cylinder, scoop and spatula, an oven (10 - 11°C) small numbered specimen containers, the BS CBR mould, steel tamping rod, cee-spanners and water.

Test Procedure

A sample of 6000g air dried soil was thoroughly mixed with 120mm 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 27 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 weighted and a representative sample was taken and used in the determination of moisture content. The specimen was oven-dried for twenty four 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 the different parts of Lainde-Fulani and its environs. The locations of the gully sites are shown in Table 2 and the Photographs of the gully sites are also attached (Plates 1 and 2). However, the depth of the incision of these gullies ranges from 0.6m to 2.l5 m with a mean value 1.25 whereas the width of the gullies vary from 1.36 in to 4.63 m with an average of 2.58 m. The general trending of these gully system are NE, E-W and SE with the NE trend dominating. This indicates that the gully systems are still very much in their early stage of development (Floyd 1965).

Meanwhile, it has been observed that the geotechnics of these areas determine their susceptibility to gully erosion. The geotechnical parameters of ten soil samples from ten gully sites in the study area at depths of 0.6 m and 2.15 m were analyzed using Atterberg limits, Sieve and Compaction methods, California Bearing Ratio (CBR) as well geological assessment. 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 (LL-PL = PI) and were used to measure plasticity of the soil (Figures 6 to 12). This measurement ranges from 15.6% to

37.3% with a mean value of 24.3% (Tables 3, 4 and 5) revealed that the soils are slightly to highly plastic, silty to intermediate fat, friable, low to slight dry strength and can largely be crushed with fingers (Anonymous 1979; Bell, 1983).

Therefore the relatively low cohesion or the friable nature of the soils in parts of the study area account for the gully erosion problem because water flows through the soils with ease and move the soil particles down slope with increase in velocity of motion of the water. The hydraulic properties as determined from statistical grain-size methods indicate mean hydraulic conductivity values ranging between 3.8 x 10^{-4} cm/s and 1 x 10^{3} cm/s cm/s and transmissivity values between 3.8 x 10^{-2} cm^{2}/s and 9.6^{4} cm^{2}/s respectively (Table 6) suggesting high seepage fluxes and pore pressures. High pore pressures and seepage fluxes tend to reduce the shear strength of the soils thus reducing its erodibility. 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 (Figures 13 to 19). Cumulative curves of the various soils from gully sites were plotted. From the curves the graphic mean was calculated using the relation:
Mean = (0 16+050+084)/3

The graphic mean is used to calculate the average diameter of the grain interpreted using Wentworth scale (1922) for sand. The values of the parameters in the relation above were traced from the curves and summarized in Tables 7 and 8. The result of sieve analysis shows a grain size distribution corresponding to coarse grained sands with strongly unimodal curves (Figures 13 to 19).

Compaction Test:

Compaction test shows the Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC) of the soils (Figures 20 to 26).
The results of compaction test show that the optimum moisture content ranges from 8.1% to 12.4% while the maximum dry density ranges from 1.82kg/m^{3} to 2.15kg/m^{3} (Table 4) The maximum dry density values are generally low signifying that the soil is not compact but loose and thus susceptible to erosion.

California Bearing Ratio (CBR Test)

The result of the CBR test ranges from 2.2 % to 8.1 % with a mean value of 95.96 % (Table 3). It indicates that they are generally below the standard value of 10% for subgrade materials (Some gully sites falls within the subgrade level). From the average results of the CBR test, the soils are loose and cannot withstand the ground vibrations when subjected to vehicular traffic. It thus suggests that the soils within the gully sites are susceptible to gully erosion.

Geological Assessment of Gully Sites

The Basement rocks of the area are generally fine to coarse grained in texture, crystalline indurated, compact and well cemented when fresh. They are largely porphyritic and occur as sub circular to large elongate plutonic bodies spanning some tens of kilometres (Haruna et al 2011).

The basement rocks consist essentially of medium to coarse grained granites. The granites are light to dark coloured, massive porphyritic and vary widely in textures with the minerals largely randomly oriented while others show well oriented tabular feldspar or flaky biotite grains showing uniform grain size (Plates 3 to 8). They consist mainly of quartz, mica (muscovite), feldspar (typically perthitic microcline or orthoclase) with plagioclase (calcic albite or oligoclase). The average grain size is between 1mm to 25mm (0.1cm to 2.5cm). They cover about 60% of the total study area. The rocks are intensely weathered and largely affected by tectonism resulting in fracturing giving rise to numerous joints, foliations, shear zones and faults.

However field studies of the gully sites revealed that these Basement Complex rocks have been weathered to residual or transported soils consisting of sands, humus, clayey soils and lateritic soils. They are mostly residual alluvium soils derived from both physical and chemical weathering of the underlying basement rocks. They are formed by the disintegration (weathering) of rocks. The disintegrated or weathered materials may either be found deposited at its place of origin; called residual soil or insitu soil or may be transported by agents of denudation such as water, wind or ice before deposition called transported or drift soil.

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

$$\Theta = (\Phi 84 - \Phi 16)/4 + (\Phi 95 - \Phi 5)/6.6 \quad (1)$$

Where

Θ = Inclusive graphic measure (sorting)

$\Phi 84$ = quartile 84 (84 percent of the particles are finer), and

4 and 6.6 = mathematical constants.

Using equation (1) sorting values ranging from 0.29 to 0.37 were obtained for samples collected at the gully sites (Table 6) which corresponds to poorly sorted to well sorted samples. This indicates that the soils are largely coarse grained well sorted sands and that the fine grained materials such as clays and silts that can provide cohesion are lacking in places.

Ten samples were selected and their slides prepared and observed under a polarizing microscope. From the study of the rock samples under both plane polarized and cross polarized lights the following minerals were observed: quartz, orthoclase, muscovite and iron-oxides. Quartz is generally anhedral in crystal form with weak birefringence and shows grey to white first order interference. It has low relief with parallel to undulose extinction and is colourless under plane polarized light. Orthoclase is colourless under plane polarized light, sub-hedral in form and shows low relief and weak birefringence. It is also non-pleochroic and shows grey to white first order interference colours with parallel extinction and carlsbad twinning. Muscovite is pale yellow to colorless under plane polarized light, anhedral in crystal form and shows moderate relief and moderate birefringence. It is very weakly pleochroic and shows purple to red interference colors and cleaves in one direction. Iron-oxide is opaque under plane polarized light, anhedral in crystal form of high relief and non-pleochrqic. Table 9 is the summary of the mineralogical composition and their percentages. The presence of clay in the gully samples, though in low percentages, may have originated from the weathering of feldspars (Blyth and De Freitas 1992).
Petrographic studies show that other cementing materials are silica in the form of quartz as well as iron oxide (Obiefuna and Adamu 2011).

CONCLUSION

The geotechnical results of the soil samples indicate that the susceptibility of the materials to gully formation is due to its highly weathered nature and has low silt/clay content of sites. The plasticity index is generally slightly low medium, indicating that the soil has low to medium dry strength and hence can easily be crushed by fingers Therefore; it offers little resistance to gully erosion. The geological results confirm the results of geotechnical investigation by revealing that the basement rocks have weathered to residual or transported soils consisting of sands, humus, clayey and lateritic soils. They are formed by the disintegration (weathering) of rocks. The disintegrated or weathered materials may either be found deposited at its place of origin; called residual soil or insitu soil or may be transported by agents of denudation such as water, wind or ice before deposition called transported or drift soil. It further suggest that the soils are largely coarse grained and well sorted indicating that the fine grained materials such as clays and silts that provide cohesion are lacking in places.

RECOMMENDATION

The investigations revealed that gully systems in the area to be in their early stages and therefore easier to control now than when they are left or allowed to evolve into complex forms. The most cost 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 he reported and controlled early enough. The engineering aspects 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 pressures and seepage forces are high.
Agro-forestry methods such as planting of trees like bamboo, grasses etc. to forestall, eliminate or check the development of erosion should be applied. Also trees like Gmelina arborea, Pinus carihacea, Dacroydes edulis. Cassis nidosa and such fruit trees as Traculia Africana, Irvingia gobonensis, 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 is made.

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TABLE 1: METROLOGICAL DATA FOR LAINDE FULANI AND ENVIRONS MONTHLY TOTAL RAINFALL–(mm) from 1982 to 2010 water year (SOURCE: METROLOGICAL DEPARTMENT UPPER BENUE RIVER BASIN DEVELOPMENT AUTHORITY, YOLA ADAMAWA STATE)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL (mm)	NO. OF RAINY DAYS
1982	3.9			38.9	63.8	116.2	260.7	210.8	234.8	32.1			261.2	66
1983				29.4	126.5	155.9	207.1	218.7	126.8	19.7			884.1	53
1984			25.9	87.3	138.1	76.2	242.6	183	168.3	54.5			970.9	53
1985			54	40	159	131.8	200.6	200.7	173.6	10.8			970.5	65
1986				19.1	155.4	107.3	312.2	117.5	78.7	98.6			900.6	65
1987			5	0.3	34.6	105.2	102.5	199.7	127.3	44.1	11.8		678.7	57
1988				21	137.5	168	202	187.2	312.5	55.3			1083.5	74
1989				48.6	174.3	88.3	132.5	437.8	81.5	19.2			982.2	62
1990				42.6	90.1	94.7	225.3	199.6	123.6	32.5	15.4		823.8	58
1991				54.3	217	100.2	164.3	215	86.9	24.9			861.8	69
1992			27.9	49.3	191.1	87.8	105.1	172.5	227.8	5.7	2.1		969.3	64
1993			14.9	59.5	143.1	111.3	218.8	175.5	186.2	73.7			983.4	71
1994				78.9	96.8	193.6	102.8	267.1	106	79.3			924.5	61
1995			3.7	37.6	101.8	180.7	1991.1	239.5	133.8	192.6			1080.8	69
1996			1.7	41.4	183.4	108.1	160	199.9	263.1	52.2			1009.8	74
1997				89.3	68.5	21.2	194.9	133.3	187.2	103.3			977.6	68
1998				51.4	61	97.7	264.9	136.9	355.2	55.7	TR		1022.8	74
1999				8.5	140.8	137.3	138.2	244.6	264.4	192.5			1113.3	73
2000				3.2	148.8	219.4	164.6	201.1	183.2	26.5			947.6	73
2001			TR	43.9	23.7	246.9	208.9	102.1	192.96	28.9			915.8	61
2002				13.4	44.1	119.3	93.6	83.3	949.2	53.5	0.3		656.7	68
2003				10.4	56.5	103.4	143.3	198.8	183.6	88.7			784.7	77
2004				12.4	116.8	118.1	114.6	224.8	150.6	62.7			800	60
2005				30	84.1	103.4	186.3	235.2	130.4	29.7			799.1	62
2006				28.6	63.9	120.3	135.8	172.8	227.8	15.7			764.9	71
2007				62.3	51.1	97.6	250.6	269.2	122.7	494.9			903.4	68`
2008				19.7	115.3	115.1	152.9	194	174.8	37.1			808.9	64
2009				15.1	128.9	200.2	190.4	246.5	238.1	41.0			106.4	72
2010				32.2	76.9	211.1	213.2	199.3	199.0	130.7			1063.6	72

Table 2. Geometry of the Gully Sites

S/N	GULLY SITES	DEPTH(M)	WIDTH(M)	GENERAL TREND
1	Wuro sete	1.52	4.63	54^0
2	Wuro Birji	0.60	1.52	130^0
3	Wuro Mayo	0.80	1.50	125^0
4	Lainde Fulani	1.08	2.40	12^0
5	Lainde Lama	1.20	3.32	48^0
6	Sete Lawan	1.48	1.50	46^0
7	Wuro Buba	1.80	2.42	60^0
8	Wango Sete	0.80	1.36	48^0
9	Wuro Bentere	2.15	4.56	180^0
10	Lainde Takarkuselji	1.06	2.60	140^0
11	Total	12.49	25.81	843^0
12	Mean	1.249	2.581	84.3^0

TABLE 3: SUMMARY OF SOIL TEST IN THE STUDY AREA

Gully Sites	Depth (M)	Width (M)	Plastic Limit	Liquid Limit (%)	Plastic Index (%)	MDD (%)	OMC (%)	CBR (%)
Wuro sete 1	1.52	4.63	30.2	54.4	24.20	1.71	12.5	2.6
Wuro Birji 2	0.60	1.52	18.9	38.0	19.1	1.80	13.4	5.9
Wuro mayo 3	0.80	1.50	29.5	50.0	20.5	1.75	12.3	6.2
Lainde Fulani 4	1.08	2.40	17.4	21.4	4.0	1.84	9.4	8.1
Lainde lama 5	1.20	3.32	20.0	30.0	10.0	1.82	11.3	7.9
Sete Lawan 6	1.80	1.50	17.8	41.2	23.4	1.86	8.4	7.5
Wuro Buba 7	1.8o	2.42	25.9	44.0	18.1	1.77	9.8	7.0
Wango Sete8	0.80	1.36	30.0	59.0	29.0	1.74	16.0	2.2
Wuro Bentere 9	2.15	4.56	37.7	55.4	17.7	1.45	12.5	5.9
Lainde Takarkuselji 10	1.06	2.60	15.6	40.0	24.8	1.85	10.6	6.3
Total	12.49	25.81	243	433.8	190.8	17.59	115.8	59.6
Mean	1.249	2.581	24.3	43.8	19.08	1.759	11.58	5.961

Table 4: Classification of soil according to their liquid limit (After Bell, 1983)

Description	Plasticity	Liquid limitance
Lean or Silty	Low plasticity	Less than 35
Intermediate Fat	Intermediate plasticity	3 5-50
High plasticity	5 0-70	
Very fat Extract	Very high plasticity	70-90
Extract high plasticity	Over 90	

Table 5: Classification of soils based on their plasticity index (After Anon 1979)

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

Table 6: HYDRAULIC CONDUCTIVITY VALUES ESTIMATED FROM STATISTICAL GRAIN SIZE METHODS

	Hydraulic conductivity cm/s			**Transmissivity cm^2/s**			
Sample location	Hazen (1983)	Harleman et al., (1963)	Uma et al., (1989)	Hazen (1983)	Harleman et al., (1963)	Uma et al., (1989)	Thickness (cm)
Wuro sete	1×10^3	6.4×10^2	3.8×10^1	1.5×10^5	9.6×10^4	5.7×10^3	150
Wuro Birji	6.4×10^2	4.1×10^2	2.4×10^1	1.5×10^5	9.4×10^4	5.5×10^3	230
Wuro mayo	4.0×10^2	2.5×10^1	1.5×10^0	5.2×10^3	3.3×10^3	2.0×10^2	130
Lainde Fulani	8.1×10^0	5.2×10^0	3.1×10^{-1}	8.9×10^2	5.7×10^2	3.4×10^1	200
Lainde lama	1.0×10^{-1}	6.4×10^{-2}	3.8×10^{-4}	1.0×10^1	6.4×10^0	3.8×10^{-2}	150
Sete Lawan	3.6×10^2	2.3×10^2	1.3×10^1	7.2×10^4	4.6×10^4	2.6×10^3	200
Wuro Buba	3.6×10^2	2.3×10^2	1.3×10^1	7.6×10^4	4.8×10^4	2.7×10^3	210

Table 7: Graphic mean data interpretation for the study area

S/N	Location	Depth	Calculated Mean	Soil description
1	Wuro sete	1.52	0.293	Coarse sand
2	Wuro Birji	0.60	0.302	Coarse sand
3	Wuro mayo	0.80	0.343	Coarse sand
4	Lainde Fulani	1.08	0.351	Coarse sand
5	Lainde lama	1.20	0.328	Coarse sand
6	Sete Lawan	1.48	0.334	Coarse sand
7	Wuro Buba	1.80	0.362	Coarse sand
8	Wango Sete	0.80	0.373	Coarse sand
9	Wuro Bentere	2.15	0.246	Coarse sand
10	Lainde Takarkuselji	1.06	0.251	Coarse sand

Table 8: Standard table for mean grain size distribution (Wentworth, 1922)

Phi (Ø) 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

Table 9: Summary of Mineralogical Composition of the Study Area

S/N	Location	Sample no	Mineral under plane polars.	Minerals under-cross polars	Minerals (%)
1	Wuro sete	S1	_	Orthoclase Quartz	20 80
2	Wuro Birji	S2	_	Orthoclase Quartz	30 70
3	Wuro mayo	S3	Muscovite	Muscovite Orthoclase Quartz	20 40 40
4	Lainde Fulani	S4	Muscovite	Muscovite Orthoclase Quartz	10 40 50
5	Lainde lama	S5	Muscovite	Muscovite Orthoclase Quartz	10 40 50
6	Sete Lawan	S6	Iron-Oxide	Iron-Oxide Orthoclase Quartz	30 30 40
7	Wuro Buba	S7	Muscovite	Muscovite Orthoclase Quartz	20 40 40
8	Wango Sete	S8	Muscovite	Muscovite Feldspars Quartz	20 30 50
9	Wuro Bentere	S9	Muscovite	Muscovite Orthoclase Quartz	20 40 40
10	Lainde Takarkuselji	S10	Iron-Oxide	Iron-Oxide Orthoclase Quartz	30 30 40

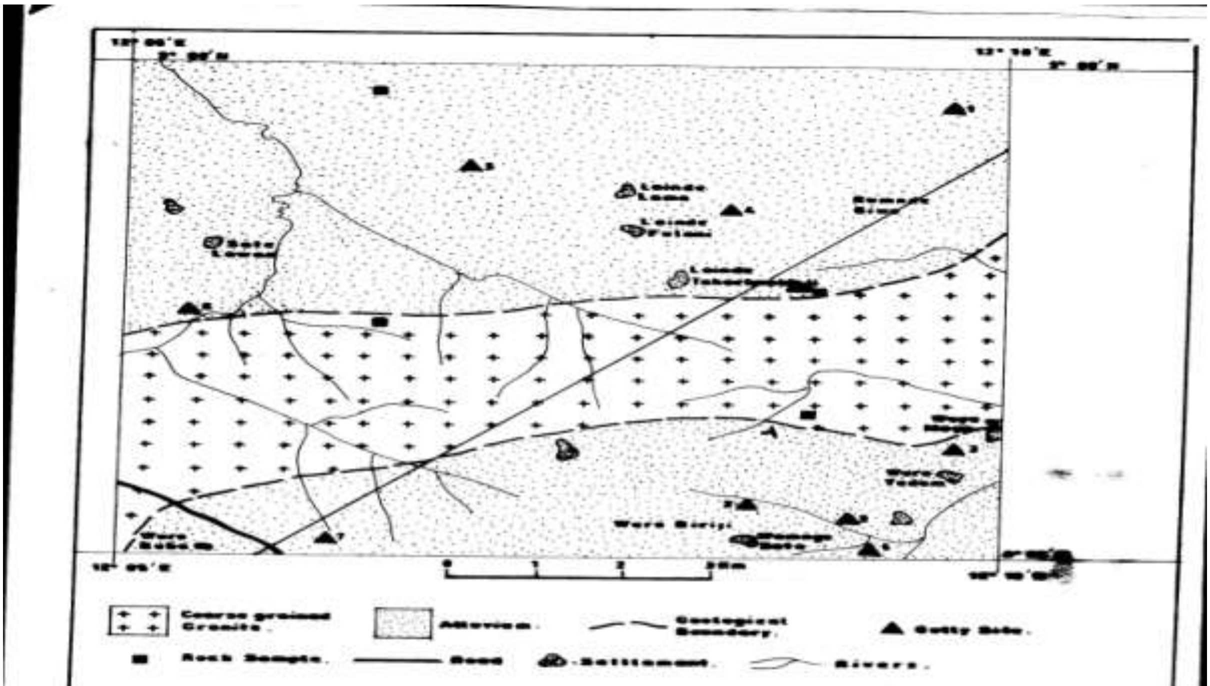

Fig. 1: Geological map of the study area.

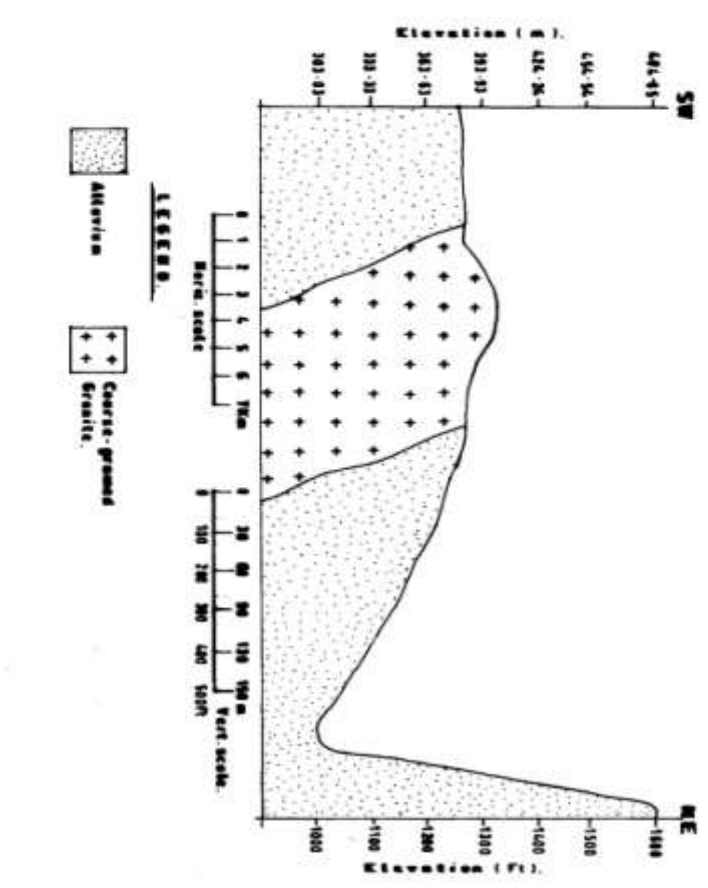

Fig. 2: Geological cross section of the study area.

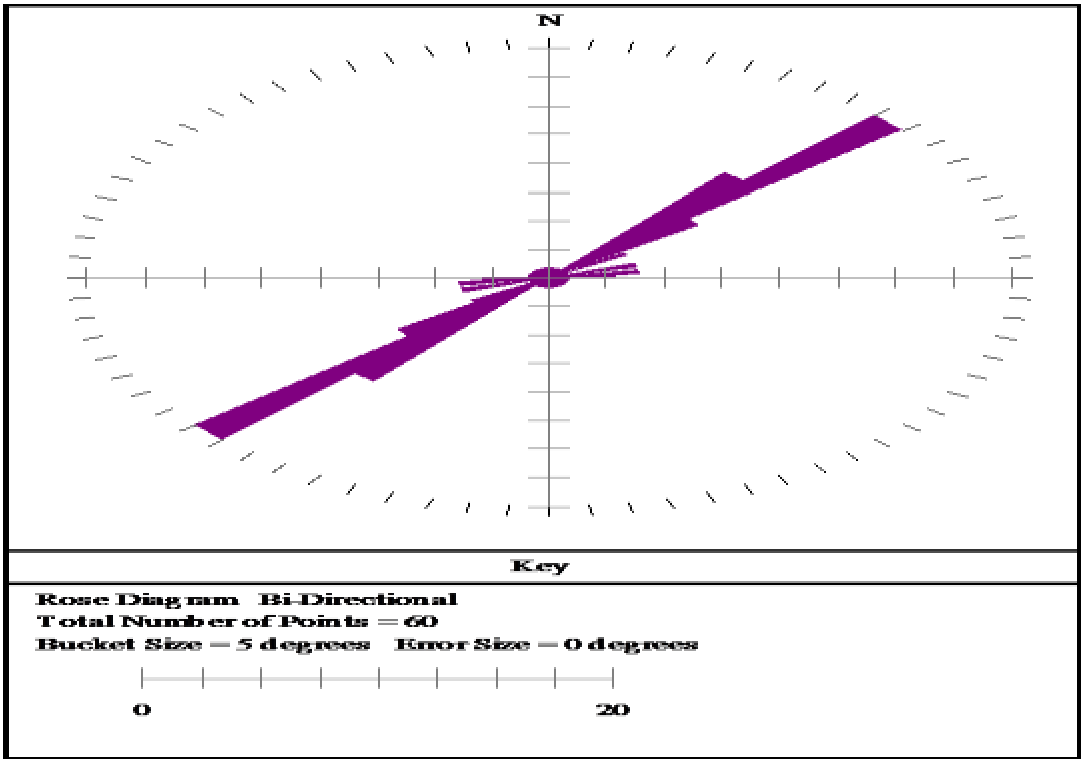

Figure 3: Rose diagram of Lainde Fulani Fault

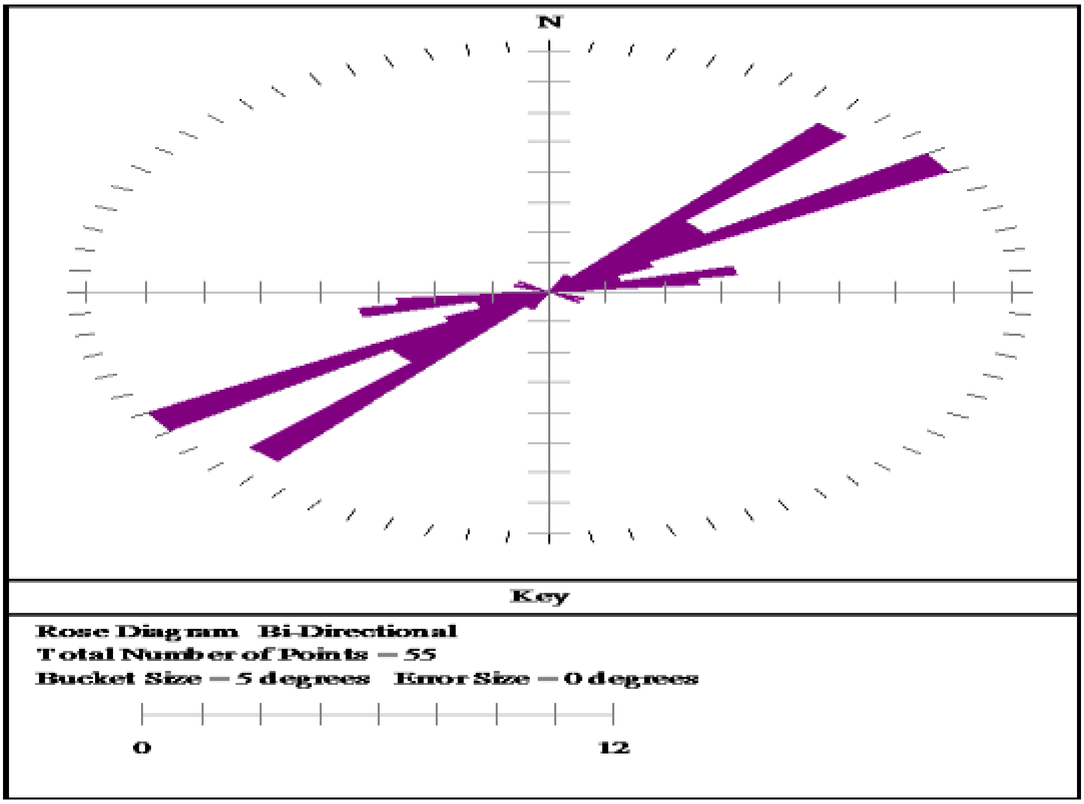

Figure 4: Rose diagram of Lainde Fulani Joint

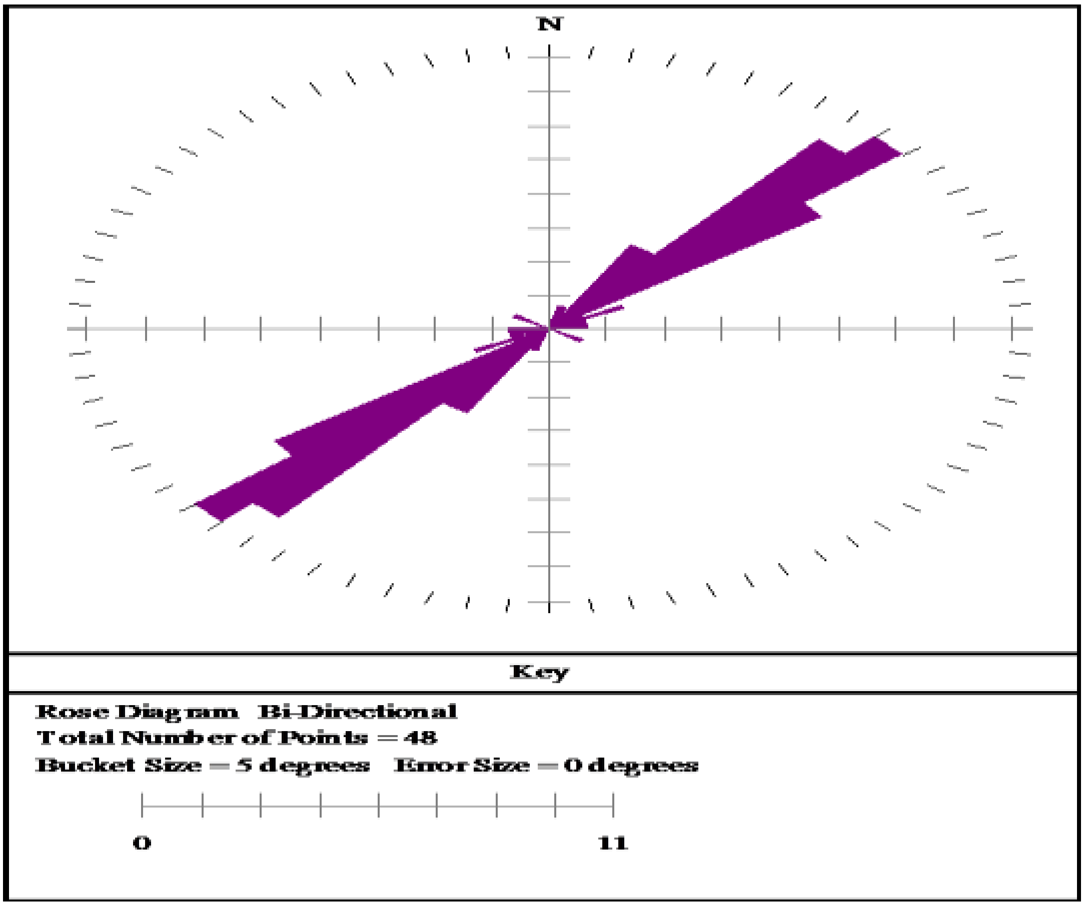

Figure 5: Rose diagram of Lainde Fulani Vein

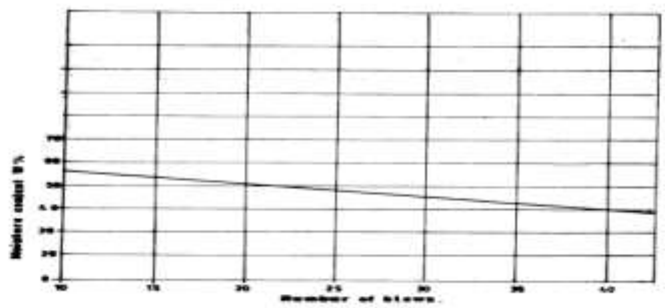

Fig. 6: Plot of plastic and liquid limit data for Wuro Sete gully site (1).

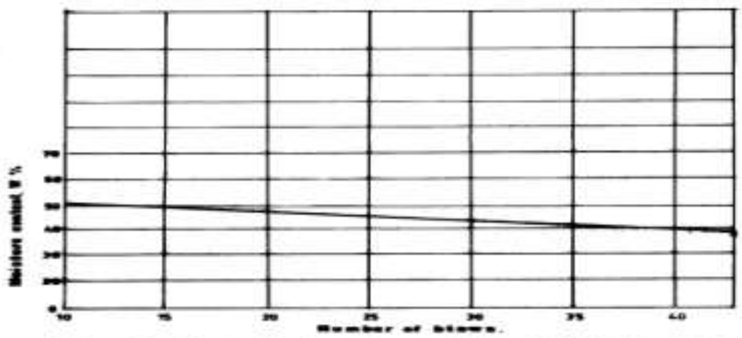

Fig. 7: Plot of plastic and liquid limit data for Wuro Birigi gully site (2).

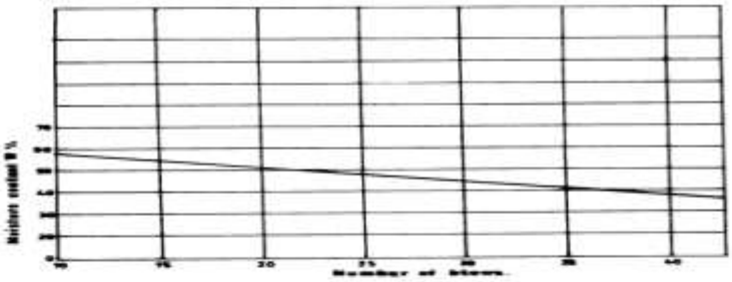

Fig. 8: Plot of plastic and liquid limit data for Waya Maya gully site (3).

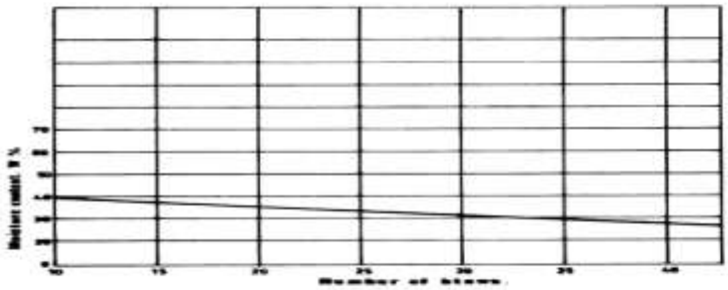

Fig. 9: Plot of plastic and liquid liquid data for [illegible] gully site. (4).

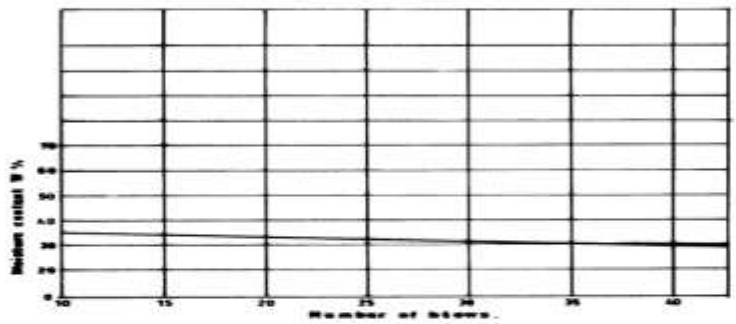

Fig. 10: Plot of plastic and liquid limit data for Lainde Lawa gully site (5).

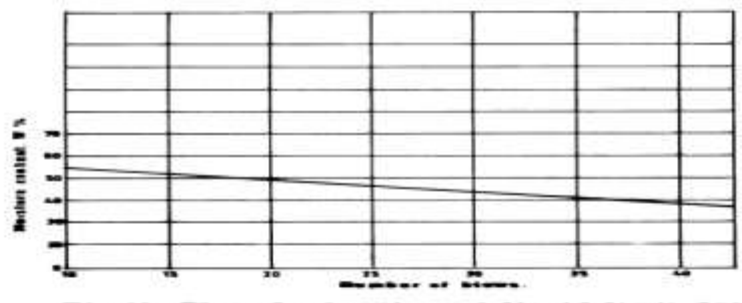

Fig. 11: Plot of plastic and liquid limit data for Sose Lawan gully site (6).

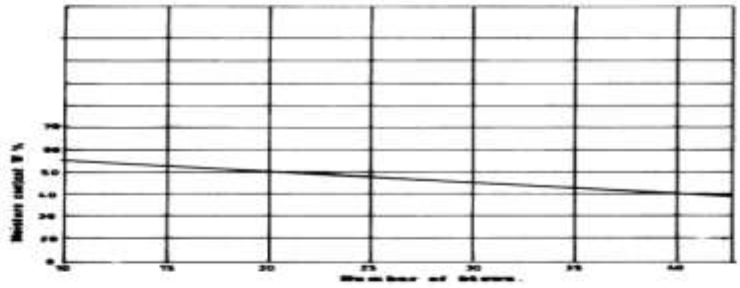

Fig. 12: Plot of plastic and liquid limit data for Wuro Bube gully site (7).

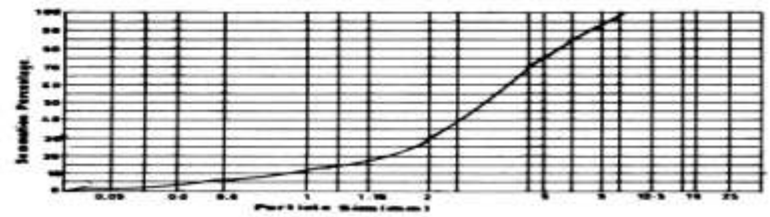

Fig. 13. Particle distribution (PSD) curve for Wuro Sote (1).

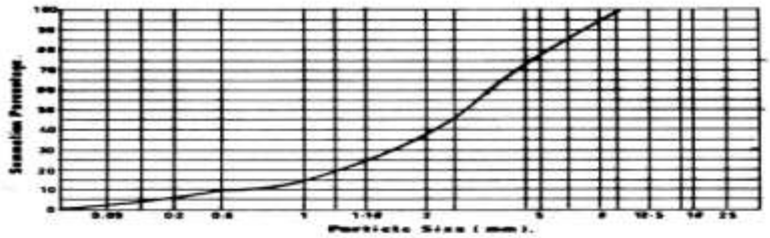

Fig. 14: Particle size distribution (PSD) curve for Wuro Biriji (2).

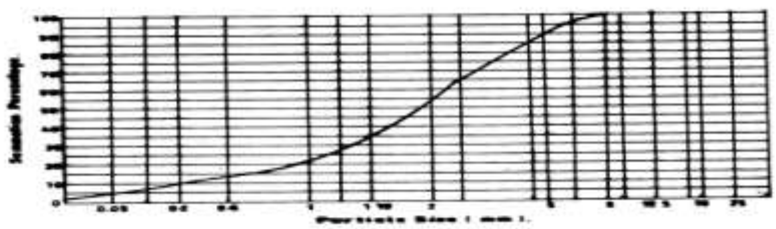

Fig. 15: Particle size distribution (PSD) curve for Wuro Bayo. (3).

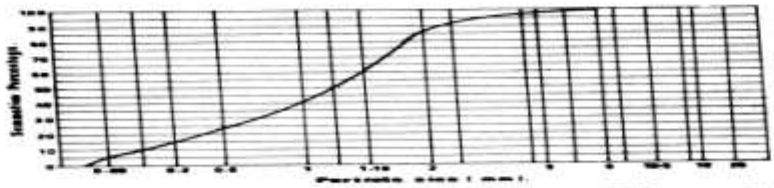

Fig. 16: Particle size distribution (PSD) curve for Lalede Fotami (4).

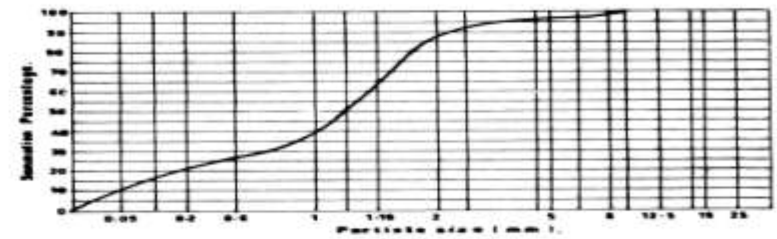

Fig. 17: Particle size distribution (PSD) curve for Laiade Lama (5).

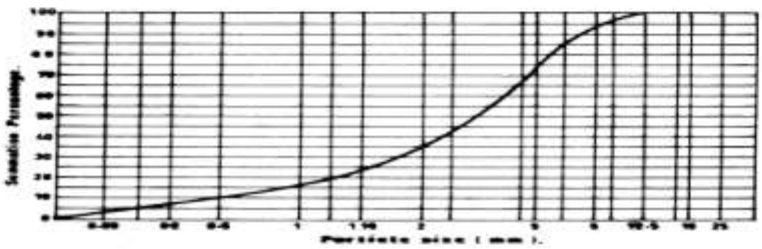

Fig. 18: Particle size distribuition (PSD) curve for Sale Lawan (6).

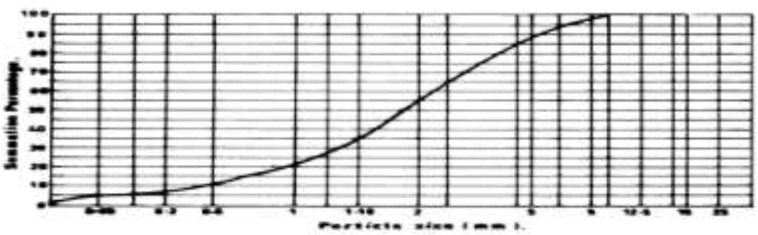

Fig. 19: Particle size distribuition (PSD) curve for Wuro Baba (7).

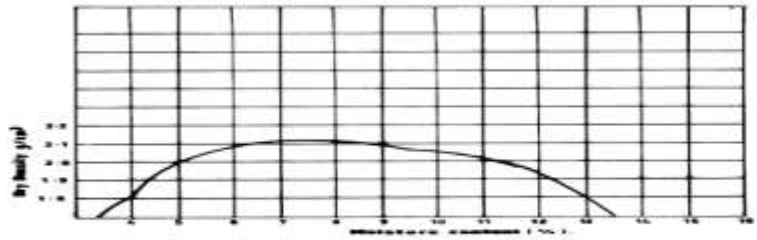

Fig. 20: Plot of compaction test data for Were Sete gully site (1).

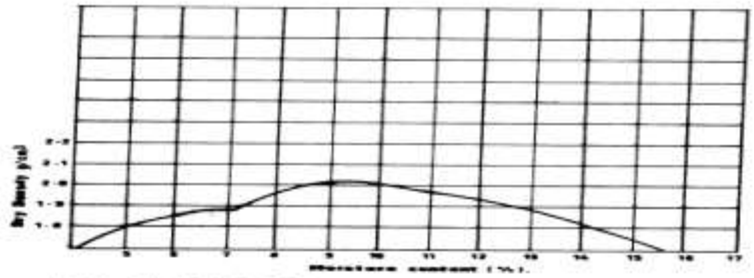

Fig. 21: Plot of compaction test data for Were [illegible] gully site (2).

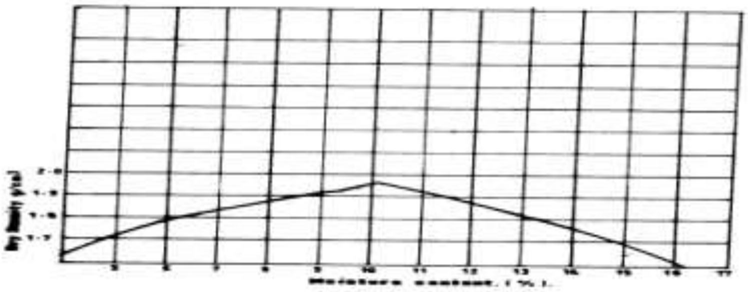

Fig. 22: Plot of compaction test data for Wara Maya gully site (3).

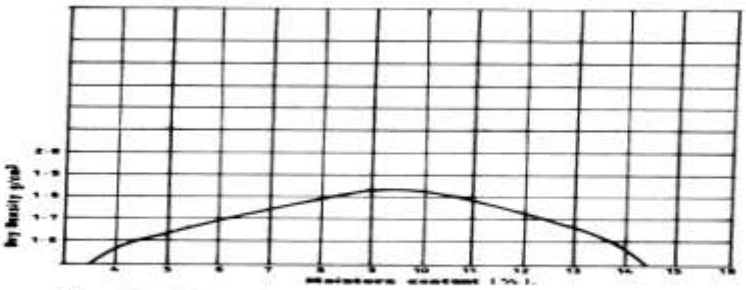

Fig. 23: Plot of compaction test data for Lainde Fulani gully site (4).

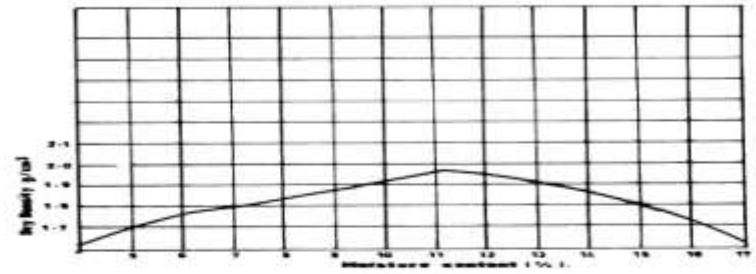

Fig. 24: Plot of compaction test data for Lalade Lama gully site (5).

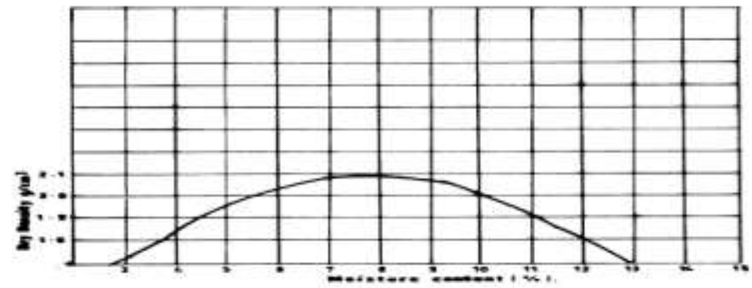

Fig. 25: Plot of compaction test data for Sale Lawan gully site (6).

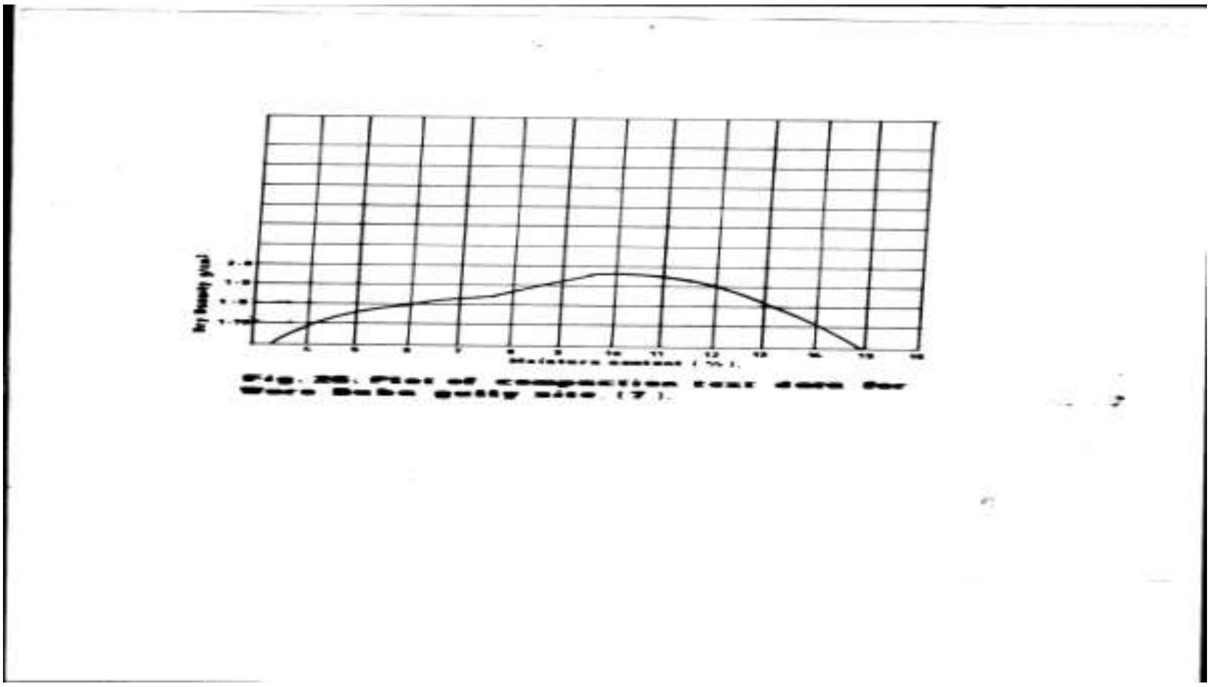

PLATE 1: Gully site in Wuro sete

PLATE 2: Gully site in Wuro Mayo.

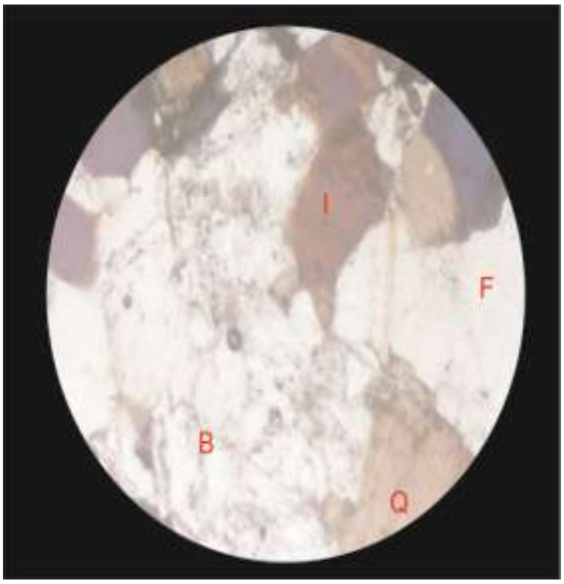

Plate 3: Fe = Iron-Oxide, F=Feldspar, B=Biotite, Q = Quartz. (Feldsparthic Granite)

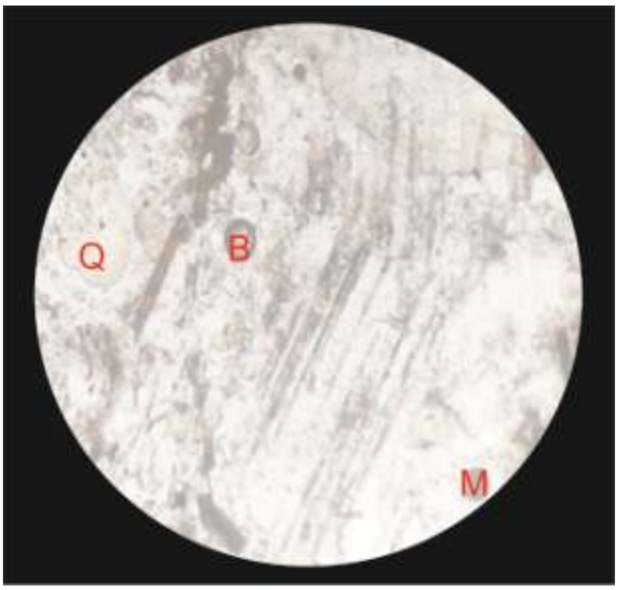

Plate 4: Q = Quartz, B = Biotite, M= Muscovite. (Biotite Granite)

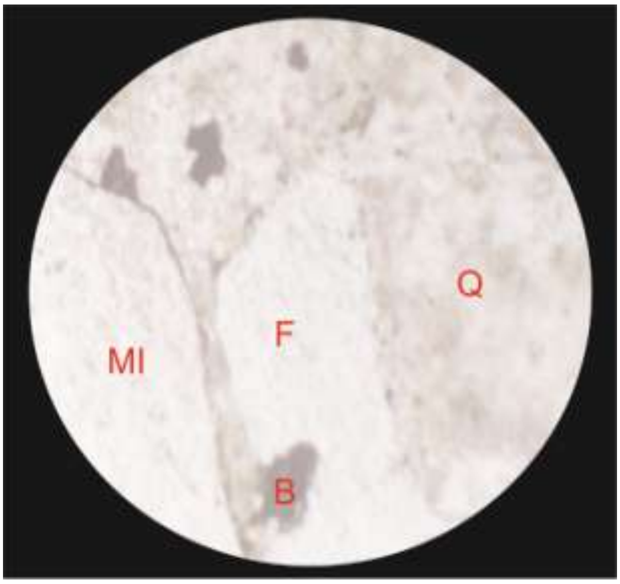

Plate 5:Q= Quartz, F= Feldspar, Biotite. (Granite Gneisse)

Plate 6: M= Muscovite, F=Feldspar, B=Biotite (Biotite Granite)

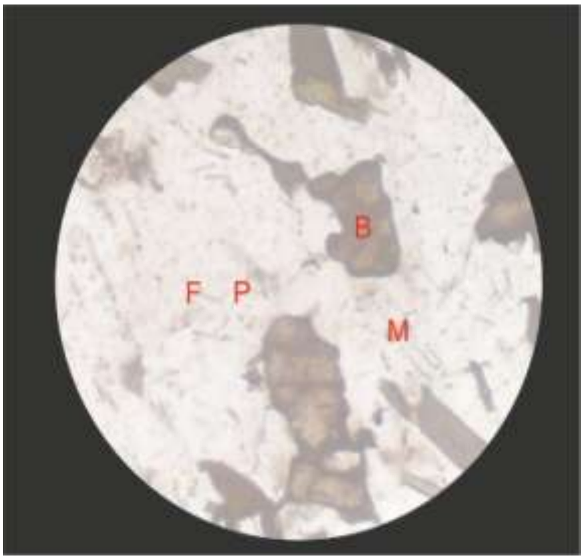

Plate 7: F=Feldspar, P=Plagioclase, Q=Quartz M=Muscovite. (Feldsparthic Granite)

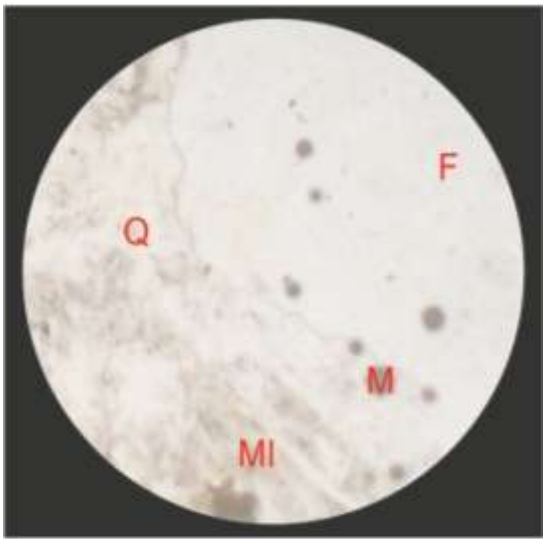

Plate 8: Q= Quartz, F= Feldspar, M=Muscovite, MI=Migmatite (Granite Gneiss)

Reference to this paper should be made as follows Gabriel Ike Obiefuna et al., (2018). Geological and Geotechnical Assessment of Selected Gully Sites in Lainde Fulani Area Ne Nigeria. *J. of Environmental Science and Resources Management* Vol. 10, No. 1, Pp. 1-39