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ORIGINAL RESEARCH ARTICLE

HYDROGEOLOGICAL AND ENGINEERING INVESTIGATIONS OF GULLY SITES IN ZING AND ENVIRONS, NORTHEASTERN NIGERIA

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ABSTRACT

The research area is characterized by problems of gully erosion which have resulted in the destruction of roads and uprooting trees of economic importance. Reduction in the area of arable and other agricultural land, which become divided into smaller parcels and leads to increased farming cost. Hydrogeological and engineering investigations were conducted in Zing and environs, Taraba State of Nigeria to characterize the rock materials that aid gully erosion in the area. The methods involve three (3) stages, reconnaissance survey, detailed field mapping and laboratory analysis. The area is underlain by porphyritic granite and Biotite granite. The geologic structures include fractures, dykes, and veins which trend NNW to SSE, NW-SE and NNE to SSW. The results of geotechnical parameters indicate that the plastic limit ranges between 0 to 24.2%, liquid limit ranges from 20.1% to 43.9%, plasticity index ranges between 11.2 to 19.7%. The coefficient of uniformity ranges between 4.2 and 11.5 while the coefficient of curvature ranged between 0.53 and 1.99. The optimum moisture content was from 8.3 to 9.8%, while maximum dry density is from 1.75 to 1.91mg/m^3. The angle of internal friction was between 28° to 40°, while the cohesion is between 0 to 54KN/m^2. The statistical grain size methods gave hydraulic conductivity values ranging from 2.35 x 10^{-3}m/s to 8.64 x 10^{-5}m/s. The hydraulic head distribution map indicates that the gully sites are located in the discharge areas. The discharge areas are characterized by high hydrostatic pressure which decreases effective stress and in turn reduces the shear strength of materials, enhance, internal erosion in form of piping and cave ins in the discharge areas. From the results of the study, recommendations such as sand mining/excavation along the rivers should be avoided, ridging perpendicular to river bank are reduced, dumping of refuse on the river channels and floodplains should be discouraged and houses should not be constructed along the river banks.

1.0 Introduction

Gullies are widely spread in Nigeria and it has adverse effect on agricultural productivity (Okunlola et al., 2014; Obiefuna et al., 2018). Some effects of erosion include Major changes to the patterns of overland flow causing sedimentation in watercourses and leading to increased rates of erosion where more subsoil material is exposed. Sedimentation and increased flooding affecting fences, farms and public roadways. Bank erosion problems. In the area of erosion, 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. Based on the predominant erosion mechanism, Onuoha and Uma (1987) classified the active gully spots into three; the first group is composed of gully due to accelerated erosion which is called the classical gully erosion and the second group involved mass wasting, landslides, slumping and soil creep. Floyd (1965) and Egboka and Nwankwo (1979) attributed the original and growth of complex gullies of the south eastern Nigeria to the effect of agricultural and human activities.

Ishaku et al. (2002) noted that the loose nature of geologic materials, high permeability and shallow water table in the rainy season influenced the growth and development of gullies in Lassa area of Adamawa state. The rise in water table tends to reduce the effective stress of the materials and increase the hydrostatic pressure. It also reduces the shear strength of the materials, enhanced internal erosion in form of piping and cave-ins in the discharge areas. Obiefuna and Simon (2010) carried out geological and geotechnical assessment of gully sites in Jada area, northeastern Nigeria. 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 low silt/clay content of sites. The plasticity index is generally slightly low to 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. Compaction test results indicated that the maximum dry density values are generally low signifying that the soil is not compact but loose and thus susceptible to erosion. Mbagwu and Bazzofi (1998) worked on soil characteristics related to the resistance of breakdown of dry soil aggregation by water drops. Soil samples collected from North Central Italy were analyzed in the laboratory. The result showed that soil properties determined the resistance of the soil aggregates to water drop impact, using the clay content which was the highest. Muoghalu and Ikegbunam (1997) studied "Gully erosion in Abagana, Anambra State", using the experimental analysis and Horton's calculation of slope length. The eroding force per unit area was calculated for various slopes at 17 locations. From the result derived, it was discovered that slopes between 2.3° and 7° were found in the lowland areas and it was in those areas that most of the gullies abounded at a general elevation of 122mm to 18m. Ezechi (2000), in his work on the influence of runoff and lithology in the rate of Gullies in the Eastern Nigeria, using the geological model, he reported that in certain areas of the South Eastern region where lithologies are weak and the eroding energy of runoff maximum, the susceptibility of such areas to gully erosion was high. He urged that before any construction activity, the lithology of the area should be adequately examined. The research is aimed at determining the hydrogeological and engineering parameters of rock materials that aid in gully erosion in Zing and environs.

2.0 The Study Area

The study area lies between latitudes 8°36′ 00″ to 9° 00′ 00″ N and longitudes 11° 43′ 00″ to 11° 47′ 00″ E (Figure 1) and covers an area of about 54km^2. The area is bounded to the East by Mayo-Belwa and to the North by Jada local government Area of Adamawa state and to the west and South by Yorro local government area of Taraba state. The climate of the area is typically a tropical climate marked by two distinct seasons; dry and rainy seasons. The mean annual rainfall in the area ranges from 819-1761 mm (Ray and Yusuf, 2011). The rainfall starts from April and ends in October. The onset of the rains is April, with low amount but increases gradually reaching a maximum in August, and drops gradually with cessation in October. According to Areola (1983), the study area is characterized by hydromorphic and ferruginous tropical soils which are highly influenced by local variation in altitude and human interference. The soil type is a mixture of loams and sands, and on the hilly terrain it is deep loamy found in between rocks (Ray and Yusuf, 2011). Along the banks of streams and rivers are clay loam soils which support the growth of a variety of crops in the area. The area is located within the Savannah grassland belt, particularly in the Guinea Savannah sub-region which is characterized by scattered, deciduous tall trees with broad leaves and tall grasses (Ogidiolu, 2000). On relief configuration, the study area is categorized into two zones, highland/mountain range and lowlands. The highlands occupy the southern region stretching from west to south in chains of mountain (Shebshi mountains), with elevation ranging from 1,800-2,400 meters above mean sea level (Areola, 1983). He further stated that the lowland occupies about 60% of the region hosting most of the settlements in the region.

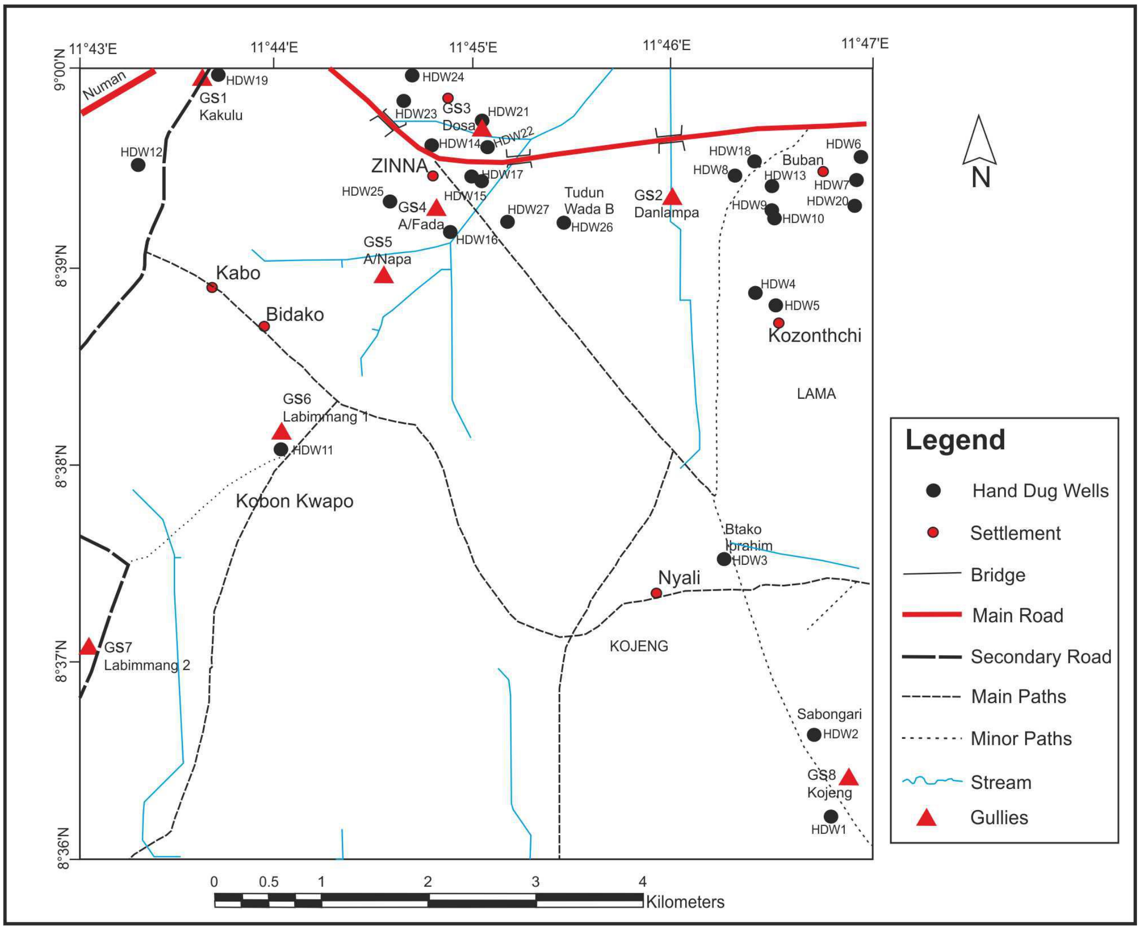


Figure 1: Map of the study area showing locations of gully sites and other infrastructures.

3.0 Materials and Methods

3.1 Sample Collection

A total of eight soil samples were collected from eight different gully sites. The geometric dimensions (widths and depths) of the eight gully sites were measured using a graduated leveling staff and meter tape. The Systematic geological mapping was carried out in the area, using Global Positioning System, compass Clinometer, geological hammers and chisels, Hand lens, contoured topographic map sheets, etc. The static water levels in wells were measured using a level indicator in some selected 27 hand-dug wells (Figure 1). The elevation and coordinates of the area were determined using the Global Positioning System (GPS). The static water level was subtracted from the elevation to obtain the hydraulic head values. These hydraulic head values were used to construct hydraulic head distribution map use of GIS.

3.2 Laboratory Analysis

3.2.1 Sieve/Gradation Analysis

About 200g of prepared samples were washed and dried. The samples were sieved and the amount retained on each sieve were collected and weighed to determine the percentage of material passing each sieve size. The cumulative percentage retained and cumulative percentage passing were calculated. The coefficient of uniformity (Cu) and coefficient of curvature (Cc) were calculated using equations 1 and 2 to determine the grading of soil. For a material to be well graded it must fulfill one or all of the following: that Cc is between 1.0 and 3.0; and or Cu must be greater than 4.0 for gravels and greater than 6.0 for sands. Otherwise it is poorly graded. D10 = grain size value at 10% passing, D30 = grain size value at 30% passing, D60 = grain size value at 60% passing has been used to calculate Cc and Cu (Vukovic and Soro,1992).

$$C_u = \frac{D_{60}}{D_{10}} \tag{1}$$

$$C_c = \frac{(D_{30})^2}{(D_{10})(D_{60})} \tag{2}$$

where: C_u is coefficient of uniformity; C_c is coefficient of curvature; D_{10} is grain size value at 10% passing; D_{30} is grain size value at 30% passing; D_{60} is grain size value at 60% passing

3.2.2 Atterberg's Limit Test
A portion of the soil sample was dried and disaggregated in a mortar using a rubber pestle. The material was sieved using the No. 425 sieve. Only the material passing the sieve was used for the test. The sieved sample was then soaked in distilled water to form a paste and then left over night, while reserving a portion of the dry sieve materials. Measurement of atterberg limit test was carried out in the department of Civil Engineering, Federal Polytechnic, Bauchi.

3.2.3 Liquid Limit Test
A portion of the paste was remoulded on a glass platen and placed in the liquid limit apparatus. It was grooved using a standard grooving tool. The handle of the Cassagrande apparatus was then rotated which caused the blows to be jarred against the base plate and the groove got closed. The number of blows required to close the groove was recorded. A sample of material was then taken and its moisture content was determined gravimetrically. The above procedure was repeated four more times each time adding a little amount of the dry sample material to the paste in order to effect a change in the moisture content. The specimens collected were then placed into an oven for twenty-four hours; the moisture content was determined by measuring the weight. The result obtained was plotted on a graph and the best straight line was drawn between the points. The moisture content at twenty-five blows defines the liquid limits.

3.2.4 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 content was rolled with the palm on a glass plate into threads. The threads were placed into containers like those in the liquid limit test and weighed, and then placed in an oven for twenty-four hours after which they were reweighed and the weight difference gives the plastic limit. The results of the two test when analyzed to give the plasticity index (P1) which is the numerical difference between the liquid limit (LL) and plastic limit (PI = LL – PL).

3.2.5 Compaction Test
A sample of known weight of air dried soil was subdivided into three parts of approximately equal surface, and each was roughened in order to obtain a better bond between them. After compaction, the mould and its content were then weighed and the representative samples were taken and used in the determination of moisture content. The specimen was oven dried for twenty-four hours and the moisture content was obtained by determining the weight difference. This procedure was carried out three times on each sample. The result of the analyses was then used to determine the optimum moisture content and the corresponding maximum dry density.

3.2.6 Shear Strength/Triaxial Test
Triaxial test was used to determine the shear strength properties of soil samples. A test sampler of 50 mm in diameter with a height and length of between 2 and 3 m using the optimum moisture content obtained from compaction test was prepared. The sample was encased by a thin membrane and placed inside a plastic cylindrical chamber of 59 mm diameter and height of 3 m filled with water. Eight soil samples were used for the test and each sample was subjected to a normal stress or confining pressure by compression of the fluid in the chamber. Rock work software was used to plot the graph or normal stress to determine the angle of internal friction and cohesion.

3.3 Statistical Grain Size Analysis Methods
The hydraulic conductivities of the soil samples were determined using empirical equations as summarized by Vukovic and Soro (1992).
as follows: several empirical methods from studies and presented a general formula:

$$K = \frac{g}{v} C.\, f(n).d_e^2 \qquad (3)$$

where: K= hydraulic conductivity; g = acceleration due to gravity; v = kinematic viscosity; C = sorting coefficient; f(n) = porosity function, and de=effective grain diameter. The values of C, f (n) and de are dependent on the different methods used in the grain-size analysis. Porosity can be derived from the empirical relationship between porosity and the coefficient of grain uniformity (U) according to Vukovic and Soro (1992) as follows:

$$n = 0.255(2 + 0.83U) \tag{4}$$

where: U is the coefficient of grain uniformity and is given by:

$$U = \frac{d_{60}}{d_{10}} \tag{5}$$

where: d_{60} and d_{10} are the grain size diameter in (mm) for which 60 and 10% of the sample respectively are finer (Odong, 2007). The empirical formulas which were formed on the same basis as represented in Equation (1) vary with C, f (n) and de. The different empirical formulas employed in this study are presented below:

3.3.1 Hazen method

Hazen formula was originally developed for determination of hydraulic conductivity of uniformly graded sand but is also useful for fine sand to gravel range, provided the sediment has a uniformity coefficient less than 5 and effective grain size between 0.1 and 3 mm(Carrier, 2003).

$$K = \frac{g}{v} \times 6 \times 10^{-4} [1 + 10(n - 0.26)] d_{10}^2 \tag{6}$$

3.3.2 Kozeny-Carman method

The equation is one of the most widely accepted and used derivations of permeability as a function of the characteristics of the soil medium (Odong, 2007). The equation however is not appropriate for soil with effective size above 3 mm or clayey soils (Carrier, 2003).

$$K = \frac{g}{v} \text{ x } 8.3 \text{ x } 10^{-3} \frac{n^3}{(1-n)^2} d_{10}^2 \tag{7}$$

3.3.3 Breyer method

The formula is often considered most useful for materials with heterogeneous distributions and poorly sorted grains with uniformity coefficient between 1 and 20, and effective grain size between 0.06 and 0.6 mm (Cheng and Chen, 2007).

$$K = \frac{g}{v} \times 6 \times 10^{-4} \log \frac{560}{U} d_{10}^2 \tag{8}$$

3.3.4 Slitcher method

The formula is most applicable for grain size between 0.01 and 5 mm (Carrier, 2003).

$$K = \frac{g}{v} \times 1 \times 10^{-4} n^{3.287} d_{10}^2 \tag{9}$$

3.3.5 Terzaghi method

Terzaghi formula is most applicable for large-grain sand (Cheng and Chen 2007).

$$K = \frac{g}{v} . C_r \left[\frac{n - 0.13}{\sqrt[3]{1-n}}\right]^2 d_{10}^2 \tag{10}$$

Where the C_t= sorting coefficient of average value 8.4×10^{-3} is used in this study.

3.3.6 USBR method

The formula is most suitable for medium-grain sand with uniformity coefficient less than 5 (Cheng and Chen, 2007).

$$K = \frac{g}{v} \times 4.8 \times 10^{-4} \times d_{20}^{0.3} \times d_{10}^{2} \quad (11)$$

3.4 Measurement of static water level and elevation

Measurement of static water level in wells was carried out using water level indicator while measurement of elevation was carried out using the GPS. The static water level was subtracted from the elevation to obtain the hydraulic head values. These hydraulic values were used to construct hydraulic head distribution map employing the use of GIS.

4.0 Results and Discussion

4.1 Geology of the study area

The porphyritic granite underlies more than half of the study area. They range from light to grey color and are coarse grained in texture (Figure 2). The porphyries ranged from 1.6 to 4mm in size (Figure 2). The Biotite granite underlies the extreme northern corner of the study area around Buban and kozonthchi (Figure 3). From the geological mapping, it shows that the lithologic units in the study area are basically porphyritic granite which is the oldest rock. The older rock was intruded by Biotite granite which is the younger rock.

Figure 2: Outcrop of Porphyritic granite at Kojeng

The geological structures observed in the study area are fractures, dykes, veins, micro faults and fault zones. Fractures observed in the study area were trending NNW- SSE (Figure 4). Fine grained granite dyke was observed in the area which was weathered and dominantly trending NW- SE direction. A dyke is a discordant igneous rock or solidified magma cutting through the overlying sediments or body of a host rock vertically (Figure 5) The veins observed in the study area are all quartz vein with a mean exposed length of 15.7 m with a mean thickness of 6cm (Figure 6). Veins are fractures filled with remobilized minerals such as, quartz feldspars or both. The soils in the area are the by-product of insitu weathering of the underlying rock. The geologic structures which represent deformational features enhance rock weathering by allowing flow of water to enhance chemical weathering.

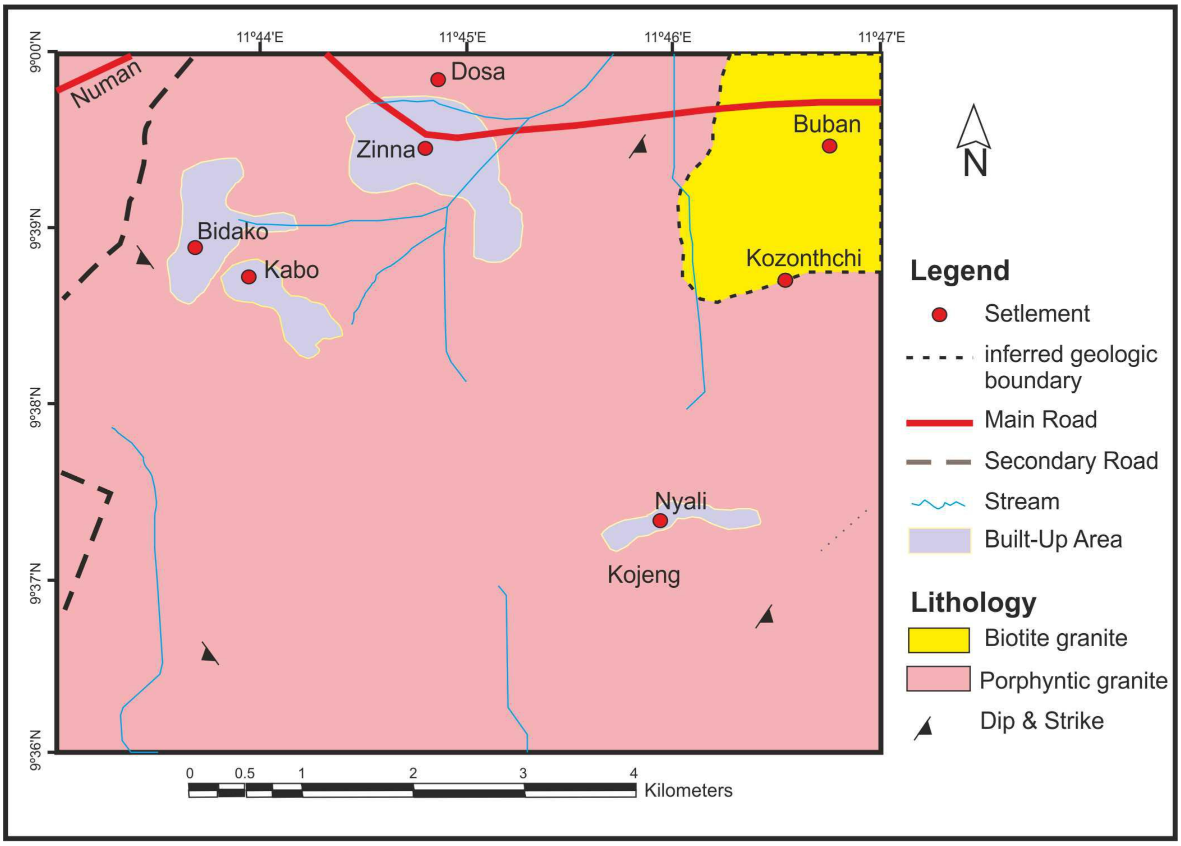


Figure 3: Geological map of the study area

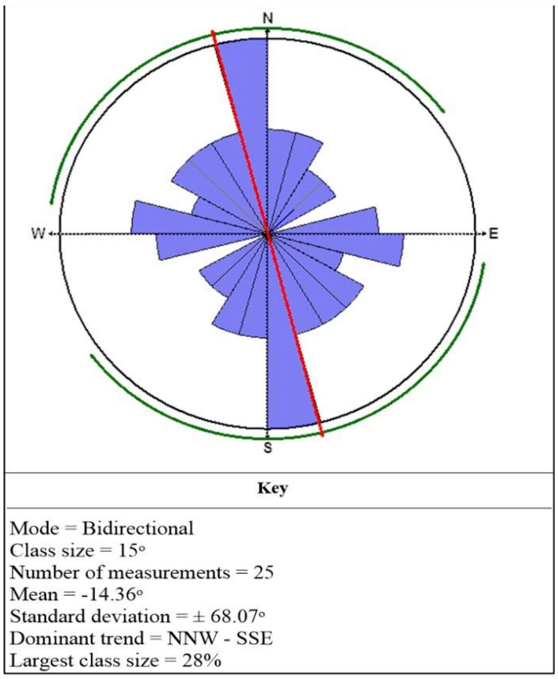


Figure 4: Rose diagram of fractures

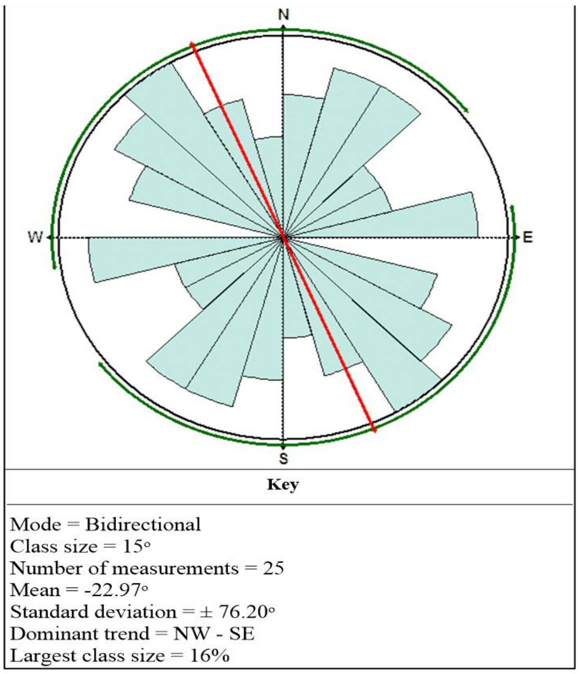
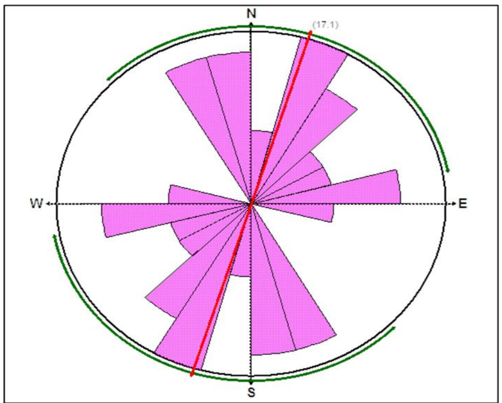


Figure 5: Rose diagram of dykes



Key

Mode = Bidirectional
Class size = 15°
Number of measurements = 23
Mean = 17.14°
Standard deviation = ± 63.24°
Dominant trend = NNE - SSW
Largest class size = 22%

Figure 6: Rose diagram of veins

4.2 Engineering Assessment of the Gully Site

Table 1 shows that the results of the plastic limit ranges between 0- 24.2%. According to Clayton and Juckes (1978), plastic limit <35% implies low plasticity, 35% to 50%= implies intermediate plasticity, and >50% signifies high plasticity. Based on the above standard, the soil in the study area possesses low plasticity. The liquid limits ranged from 20.1 to 43.9%, this indicates low to intermediate plasticity. Low liquid limit is attributed to low amount of fine fractions and indicate that the soil may change consistency with minimum change in water content. Therefore, low liquid and plastic limit could result into loose, non-coherent soil which would slide upon getting in contact with water, or it will disintegrate under dry conditions. The plasticity index ranged s between 11.2%-19.7%. Based on the above standard values, the plasticity index of soils in the study area is moderately plastic (Table 2), this finding is similar to the result by Obiefuna and Adamu (2012). Figure 7 show plots of optimum moisture content against soil properties of the study area.

Table 1: Summary of laboratory results for soil from gully sites in the study area

Gully Location	Kakulu GS1	Danlapa GS2	Dosa GS3	Anguwan Fada GS4	Anguwan NEPA GS5	Labimmang 1 GS6	Labimmang 2 GS7	Kojeng GS8
Depth (m)	1.65	2.74	3.05	1.01	1.83	1.86	1.71	1.73
Width (m)	0.3	1.58	1.06	0.39	0.37	1.39	1.04	1.22
Natural Moisture Content (%)	26.78	32.01	19.96	20.99	22.66	18.87	43.18	41.53
Plastic Limit (%)	0	18.8	0	0	0	0	24.2	17.8
Liquid Limit (%)	27	30	20.4	20.6	23.1	20.1	43.9	36
Plasticity Index (%)	-	11.2	-	-	-	-	19.7	18.2
Relative Consistency Cr	-	-0.18	-	-	-	-	0.04	-0.3
coefficient of uniformity (Cu)	11.5	8	6.67	9.05	10.87	6.67	4.2	11.5
coefficient of curvature (Cc)	1.13	0.78	0.95	1.81	0.85	0.53	1.3	1.99
Soil Classification	Gravelly sand soil	Gravelly sand soil	Gravelly sand soil	Gravelly sand soil	Gravelly sand soil	Gravelly sand soil	Gravelly sand soil	Gravelly sand soil
Optimum Moisture Content (%)	9.4	9.2	9.8	9.3	9.5	8.3	9.6	8.3
MDD Mg/m^3	1.82	1.75	1.8	1.91	1.79	1.83	1.83	1.84
Angle of Friction °	37	35	28	30	40	33	29	37
Cohesion, C KN/m^2	33	0	28	48	0	37	54	33

Table 2: The standard for plasticity index (Burmister, 1997)

Plasticity Index value	Remarks
0	Non plastic
1 to 5	Slightly plastic
5 to 10	Low
10 to 20	moderately plastic
20 to 40	Highly plastic
>40	Very highly plastic

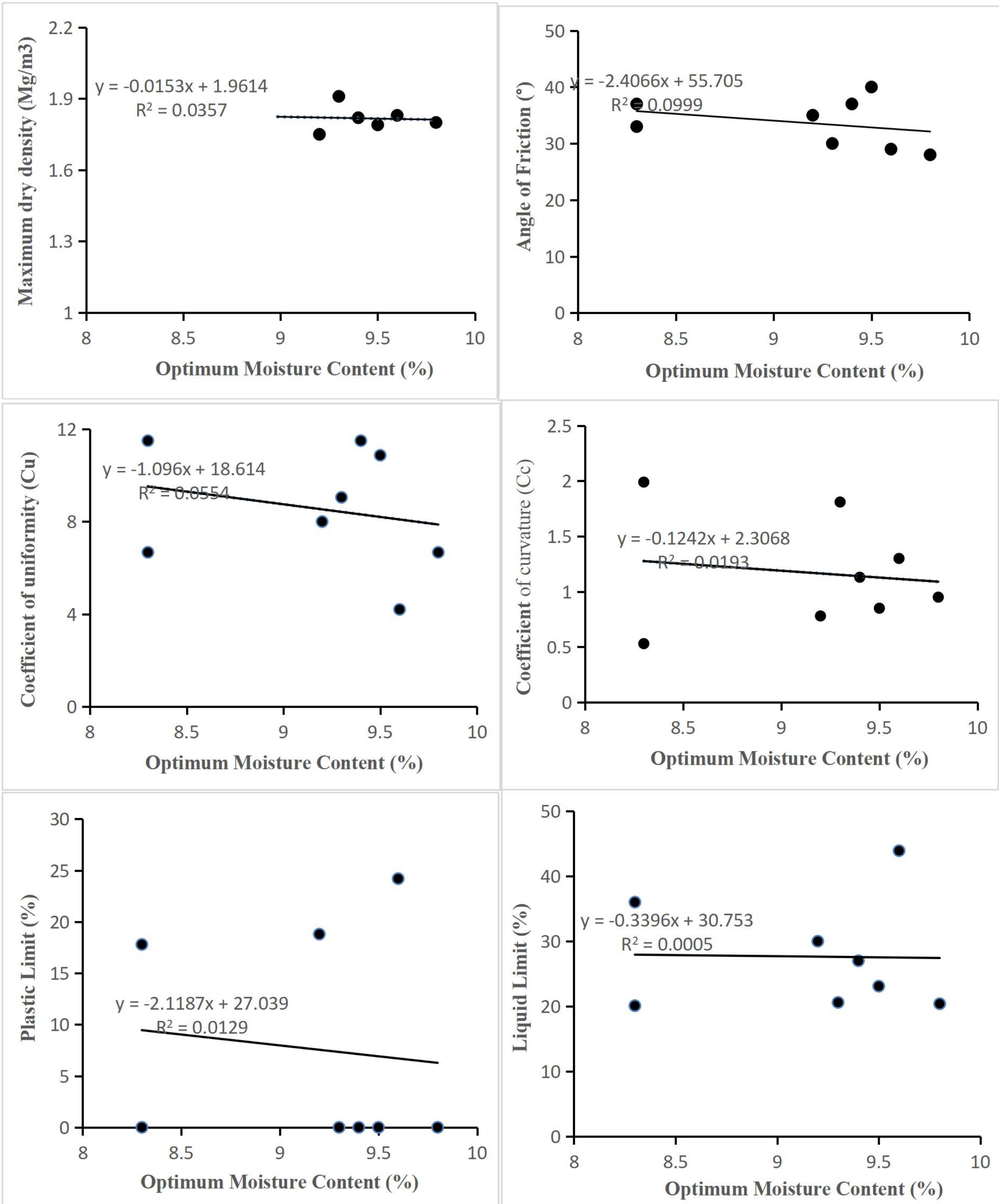


Figure 7: Plots of optimum moisture content against soil properties of the study area

The sieve analysis results show that the coefficient of uniformity, Cu ranges from 4.2 to 11.5 while the coefficient of curvature Cc ranged between 0.53 to 1.99 (Table 3). These materials are highly susceptible to gully erosion. This agrees with Obiefuna et al. (1999) and Obiefuna et al. (2018) who concluded that high sand and low silt/clay content in the soil contribute to gully development. The compaction result shows that the optimum moisture content (OMC) ranged from 8.3 to 9.8% while maximum dry density (MDD) was from 1.75 to 1.91mg/m^3. These values are within the range classified as sandy clay by O'Flaherty (1988). Similar values were obtained by Ishaku et al. (2002) also classified as low and that such soils are considered loose with little amount of clay as binding material. A Low value of MDD indicates that the soil is not compacted but loose and has high void ratio and prone to short dispersion times (Hudec et al., 2006). The triaxial shear test result shows that the angle of internal friction is between 28 to 40° while the cohesion is between 0 to 54 kPa. These values are low when compared with the values of cohesion of 65 kPa and 26° angle of friction classified as average by Okunlola et al. (2014). This range makes it favorable for gully erosion to flourish.

The results of hydraulic conductivity determined from the use of the different empirical formulas are presented in Table 2. The average hydraulic conductivity values obtained using the six different statistical grain size methods ranges from 2.34 x10-3 m/s to 2.35 x10-4m/s which corresponds to the hydraulic conductivities of clean sand to gravel (Freeze and Cherry, 1979). Among the statistical grain size methods, Breyer gave the highest values followed by Slitcher, Kozeny-Carman, Terzaghi and Hazen, and USBR have the least values. Similar result was obtained by Ankidawa et at. (2020), in Otukpo and environs, Benue State, Nigeria. Their result of hydraulic conductivity ranging from 2.01 x 10-4 m/s to 7.06 x 10-4 m/s indicating clean sand formation.

Table 3: Soil particle size distribution and hydraulic conductivity values computed from the statistical grain size method

Location of Gully Site	Lithology	D10 (mm)	D20 (mm)	D30 (mm)	D50 (mm)	D60 (mm)	U	n	Cc	Hazen m/s	Kozeny-Carman m/s	Breyer m/s	Slitcher m/s	Terzaghi m/s	USBR m/s	Average m/s
Kakulu GS1	Gravelly sand-soil	0.02	0.039	0.072	0.19	0.23	11.5	2.69	1.1	5.96E-5	2.22E-4	3.86E-6	1.02E-3	1.52E-4	3.41E-7	2.43E-4
Danlanpa GS2	Gravelly sand-soil	0.03	0.049	0.075	0.18	0.24	8	1.95	0.8	9.48E-5	6.02E-4	9.51E-6	7.93E-4	2.54E-4	5.77E-7	2.92E-4
Dosa GS3	Gravelly sand-soil	0.039	0.062	0.098	0.2	0.26	6.67	1.67	1	1.35E-4	1.29E-3	1.68E-5	8.05E-4	3.88E-4	9.90E-7	4.39E-4
Anguwan Fada GS4	Gravelly sand-soil	0.042	0.087	0.17	0.29	0.38	9.05	2.17	1.8	2.09E-4	1.07E-3	1.81E-5	2.21E-3	5.45E-4	2.16E-7	6.75E-4
Anguwan Nepa GS5	Gravelly sand-soil	0.023	0.04	0.07	0.19	0.25	10.9	2.56	0.9	7.47E-5	2.97E-4	5.18E-6	1.14E-3	1.91E-4	3.61E-7	2.85E-4
Labimmang 1 GS6	Gravelly sand-soil	0.033	0.05	0.065	0.17	0.22	6.67	1.67	0.6	9.68E-5	1.15E-3	1.20E-2	5.77E-4	2.78E-4	6.00E-7	2.35E-3
Labimmang 2 GS7	Gravelly sand-soil	0.031	0.049	0.072	0.17	0.13	4.2	1.14	1.3	5.54E-5	5.92E-6	1.17E-5	1.45E-4	3.00E-4	5.77E-7	8.64E-5
Kojeng GS8	Gravelly sand-soil	0.02	0.038	0.072	0.17	0.23	11.5	2.69	1.1	5.96E-5	1.65E-4	3.86E-6	1.02E-3	1.52E-4	3.2E-7	2.34E-4
Average										9.81E-5	6.00E-4	1.51E-3	9.64E-4	2.83E-4	4.98E-7	5.76E-4

4.3 Hydraulic Head Distribution

Groundwater flow takes place from the south eastern and flows towards north southern part of the study area (Figure 8) and it flows from the north western towards the northern and also flows from the south eastern toward the northern, it also flows towards the eastern and north western part of the study area to the northern. The recharge areas occur in the western parts of the study area around Labimmang1, in the south east around Nyali and in the north east around kozonthchi and also around Kakulu. The discharge areas occur around Dosa, Zinna, Danlanpa and Kojeng of the study area. The hydraulic head distribution map indicates that the gully sites were located in the discharge areas. The discharge areas are characterized by high hydrostatic pressure. High hydrostatic pressure decreases effective stress and in turn reduces the shear strength of materials, and enhances internal erosion in form of piping and cave ins in the discharge areas.

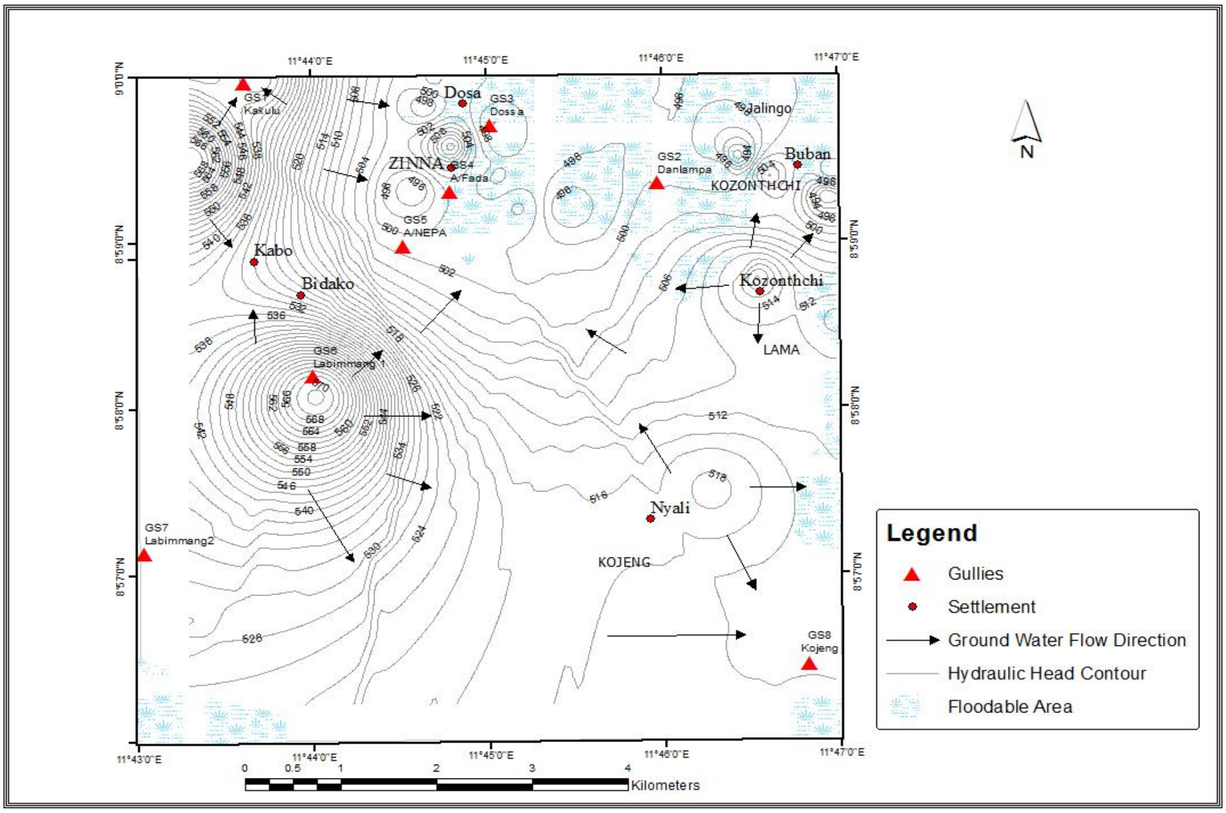


Figure 8: Hydraulic head distribution map showing ground water flow direction.

4.4 Other Factors Contributing to Gully Erosion in the study area

Factors that were found contributing to gully erosion in the study include; Dumping of refuse along stream channels (Figure 9a) which results in the flooding and increase in runoff down the stream channel. This was more prominent in Dosa area. Sand mining/excavation (Figure 9b) is a common practice along stream channels in the study area. They use it to make local blocks/ bricks for building purposes. This practice helps in the increment of stream channel and thus influencing gully development. Soil tillage and building of domestic/farm structures were also observed as other contributory factors that encourage the development of gully erosion in the study area.

Figure 9: (a) Refuse dump in Dosa area, (b) Sand excavation for making local bricks in Kakulu area, (c) Farm ridges placed perpendicular to s stream channel.

5.0 Conclusion

The geological investigation reveals that the area is underlain by porphyritic and Biotite granite. The engineering parameters indicate loose, non-coherent soil which slide upon getting in contact with water or disintegrate under dry conditions. These materials are highly susceptible to gully erosion due to high permeability. The low maximum dry density indicates loose and high void ratio which is prone disintegration of the soil materials. The hydraulic conductivity values of the soil materials indicate permeability of silty sand to gravel which is an indication of high permeability. The gully sites are located in the discharge areas which were characterized by high hydrostatic pressure, low effective stress and in turn this reduces the shear strength of the materials and enhances internal erosion in form of piping and cave ins in the discharge areas. Mitigation measures towards minimizing the menace of gully erosion in the study area should include regulated sand mining activities (especially sand mining/excavation) taking place along the rivers. improved farming practices that would check the development of gully erosion, regulated dumping of refuse on the river channels and flood plains, and appropriate positioning of domestic and farm structures away from erosion-prone zones.

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