Journal of Inventive Engineering and Technology (JIET)
ISSN: 2705-3865
Volume-2, Issue-2, pp.12-21
www.jiengtech.com
Research Paper Open Access

GEOLOGICAL AND GEOTECHNICAL CONTROL OF GULLY EROSION ALONG BAKIN KASUWA ROAD, UNGOGO, KANO, NORTH-WESTERN NIGERIA

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ABSTRACT : *Gully erosion is an environmental hazard that is devastating the engineering infrastructures. This study was carried out to investigate the geological and geotechnical control of gully erosion in the study area. Geological field mapping was carried out to assess the causes and extent of erosion. Soil samples were collected from four (4) gully sites at depth between 0 - 5m, 0.5 - 1m and 1 - 1.5m for geotechnical analyses. Four (4) index properties of soil were determined: Specific gravity, sieve analysis, Atterberg Limits and compaction test both in accordance with British standard code: BS-1377-2, 1990. Specific gravity values were used to determine the probable risk of erosion. The grading index recorded from the sieve analysis showed that coefficient of uniformity ranged between 17.2 - 1.13 and coefficient of curvature ranged between 6.01 - 0.85. The coefficient of permeability falls between coarse sand and silt. The plasticity index of the soil samples were found to be 4%, 5%, 9%, 2%, 7%, 6% 2%, 20%, 9%, 11%, 3%, and 3%. All the soil samples from gully sites have their plot clustered within clay of low plasticity and silt of low plasticity indicating cohessionless properties thus the potential for the control of gully erosion formation in the area. The optimum moisture content and the maximum dry density of the soil indicated that soils are majorly loose sand and this could pave way for erosion susceptibility. Mitigation measures such as Landfilling, construction of check dam, geo-textile, fencing and stabilization are recommended for the control of gully erosion in the area.*

KEYWORDS*: Gully erosion, plasticity, soil and control.*

Date of Submission: 17-07-2022 Date of acceptance: 29-07-2022

I. INTRODUCTION

Erosion is the gradual/quick geomorphologic process whereby surface layer of weathered rocks or sediment are removed, transported and deposited elsewhere by action of running water thus leaving an exposure of lower soil layer (Egboka, 2000). Soil erosion has been reported from the earliest of times as rigorous environmental hazard (Poesen et al., 1998; Tebebu et al., 2010).

It occurs from place to place based on the variation of the mineral constituent of the soil. It is one of the environmental hazards that pose serious danger to the roads, bridges, building, soil productivity, and other engineering structures (Bruce, 2006); the end result of the risk leads to damage of farm lands, loss of natural habitat, loss of plant and animal diversity, deterioration of soil water quality, destruction of socio-infrastructural facilities, and displacement of people (Okoro et al. 2011).

The factors that contribute to control of gully erosion includes: geomorphology, geology, soil texture and structure, climate/vegetation cover and biological diversity (Ofomata, 1988). It can be caused by precipitation, porosity, permeability, hydrogeology, and geotechnical properties of the soil materials and also due to anthropogenic activities such as construction, deforestation, mining and overgrazing and lack of proper land policies and management (John et al., 2015).

The study area lies between Latitudes (12˚7'30"N, 12˚4'45"N) and Longitudes (8˚28'30"E, 8˚30'55"E). The study area forms part of the plains of the Hausa land with elevation not greater than 500m above mean sea level. The general relief of the study area is between 450m and 480m.

There is no systematic study of the geological and geotechnical control on erosion available in the study area, therefore, Knowledge of the geological and geotechnical conditions of the area under study is essential to provide basic information of the geologic condition and will guide the policy makers in rehabilitation and maintenance of the road.

This work is aimed at investigating the geological and geotechnical control of gully erosion along the road of the study area. With the following objectives: to study the geology of the area; to determine the grading index of the soil; to evaluate the plasticity of the soil of the study area and to establish the optimum moisture content and maximum dry density of the soil.

II. LITERATURE REVIEW

The geology plays direct and indirect influence on the gully formation. The indirect effect is on the soil formation and the nature of soil which contribute significantly to erosion processes. High erosion risk is associated with units of loose and unconsolidated geological formations while least susceptible areas are within the consolidated lithology (Ofomata, 1981). The type of gully erosion with respect to their modes and conditions of formation is based on the nature of the underlying geology bearing on the initiation and propagation of gullies (Ezechi, and Okagbue, 1989). However, surface geology, soil types, topography anthropogenic factors are among the factors that lead to the formation and dimensional increase of the gullies (Thomas et al., 2004; Lakew and Belayneh, 2012; Pathak et al. 2005). The nature of underlying geology, hydrogeology, and engineering properties, slope stability of the land and human activities contributes to the origin and distribution, and development of gullies (Okagbue and Ezechi, 1988; Bocco et al., 1990; Okengwo et al., 2015).

The erodibility process of soil is influenced by soil properties: structure, texture especially with respect to cohesiveness, organic matter, particle size distribution, structural stability, infiltration capacity, clay content and nature of the underlying substratum (Morgan, 1986; Amangabara, 2012). Soil erodibility is based on the physical characteristics of each soil. Sand, sandy loam and loam textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils (Wall et al., 2003).

However, geotechnical properties of gully sites differ from place to place depending on the geologic conditions, soil formation and resulting sediment deposition. Geotechnical properties such as grain size distribution, Atterberg limit, moisture content and specific gravity were used to characterize gully sites (Omoru et al., 2015).
Zaman et al. (2016) conducted investigation on the geotechnical hazard analysis of river embankment of Bangladesh and argued that the geotechnical properties of the eroded river bank are important in controlling the river bank stability and many past works had indicated that these properties are spatially variable. Abdulfatai et al. (2018) conducted a research on the geological and geotechnical investigation of gully erosion along River Bosso and concluded that the geotechnical characteristics of the residual soils are from predominantly granitic rocks which make it to be vulnerable to gully erosion as it is supported by anthropogenic activities.
The specific gravity was considered to be one of the causative agents in the formation of gully erosion. Soil with low specific gravity values favours erosion development (Charles et al., 2015). The specific gravity data were used in determining the probable risk of river bank erosion (Hasan et al., 2018).

Atterberg Limit is considered as causative agent in the control of gully formation (Ezechi and Okagbue, 1989; Ehiz and Uwadia, 2013; Valdon et al., 2010). From the work of Charles et al. (2015) it is deduced that soil from gullied areas or erosion prone region are non-plastic and non-cohesive, due to little amount of clay being the binding material (Chikwelu and Ogbuagu, 2014).

Additionally, Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of soil have great relationship between particle sizes, grain shapes, mineral composition (importantly clay content) and specific gravity in respect to the control of gully erosion (Das, 2010).

III METHODOLOGY

The field mapping was carried identify and study the field relations of the rock exposures and locate erosion prone areas with the area under investigation. The soil samples were carefully collected from four (4) gully sites; three (3) samples were collected at different depth for laboratory analyses. Four (4) index properties of soil were determined by laboratory techniques: Specific gravity, sieve analysis, Atterberg Limits and compaction

A. SPECIFIC GRAVITY

This is the ratio of the unit weight of soil to the unit weight of water. It is required for the classification of the soil and determination of void ratio and density.

The conical flask was clean and dried by rinsing blowing warm air through it. The conical flask was weighed empty. The first soil specimen was transferred to the conical flask and then weighed. Sufficient air-free distilled water was added into the conical flask/dry soil and allowed it to settle for about 1hr and then weighed. The conical flask was then emptied, wiped, properly dried and then filled with water and weighed. The procedures above were followed for the second specimen so as to determine the average of the particle density (BS-1377-2, 1990).

B. SIEVE ANALYSIS

About 500g weight of soil sample was soaked in water for 24hours and then washed thoroughly, the sample was then oven dried at temperature of 105-110^{o}C for 24 hrs. The stack sieves were arranged serially from the larger opening to the finest. A bottom pan was placed under sieve 0.063(µm). The sample was then poured into the stak of sieves and then covered. The sieve shaker was then run for about 10-15mins. Thereafter, the shaker stops and the sieve removed. The amount of soil retained on each sieve and the bottom pan were weighed and recorded. The procedures above were repeated for other soil samples. The percentage of soils retained, cumulative percentage of soil retained and percentage finer were calculated (Umoro *et al.*, 2015).

The percentage finer (passing) against sieves opening were plotted on semi-logarithmic graph. The D_{10}, D_{30}, D_{50} and D_{60} were read from the graph and coefficient of uniformity Cu and coefficient of curvatures Cc, were calculated Abdulfati *et al*. (2018). The coefficients of permeability with respect to D_{10} and between D_{10} and D_{50}were calculated (Hazen, 1983; Odong, 2007).

C. CONE PENETROMETER TEST

This index practically established moisture content at which a soil passed from the liquid state to the plastic state. It provided a means of classifying a soil, especially when the plastic limit is known.

To determine the Liquid Limit (LL), about 300g of soil paste prepared for the sieved soil was placed on the glass plate. The paste was mixed for at least 10min using the two palette knives. Some portion of the paste was placed into the cup with the pallet knife and smooth level surface was ensured. The cup was then placed under the tip of the cone and the cone was set in the correct position so that the cup marked the surface of the soil. The stem of the dial gauge was lowered to contact the cone shaft and the dial gauge was then recorded to the nearest 0.1mm. The cup was then released for about 5s. The differences between the beginning and the end of the drop as the cone penetration were recorded. The cone was cleaned and was lifted carefully to avoid scratching.

About 10g of paste was taken and placed on bowl from the area penetrated by the cone for the determination of moisture content. The water was been added at least three more times using the same specimen and the procedures above were repeated and each time soil was removed from the cup for the addition of water the cup was washed and dried.

The samples were then taken to oven for about 24hrs and the moisture content of the soil were calculated. The relationship between the moisture content and the cone penetration with the percentage content as abscissa and the cone penetration as ordinates, both linear scales and the best straight line fitting of the plotted points were drawn using excel. The penetration (mm) at 20 moisture content (%) is the liquid limit of the specimen.

The plastic limit is the established moisture content at which the soil is too dry to be plastic. It is used together with the liquid limit to determine the plasticity index which when plotted against the liquid limit on the plasticity chart providing a way of classifying cohesive soils.

It is performed on a proportion of the sample taken from that used for the liquid limit determination. About 20g of soil was taken from the paste prepared during liquid limit and rolled like a ball. The ball of wet sample was placed between the palms and rolled further to form a thread. The thread was rolled between the fingers, from the fingertip to the second joint with the glass rolling plate. Enough pressure was applied to reduce the thread's diameter to 3mm by the forward and backward movement of the hand.

The soil was picked up, molded between the fingers until the thread shears longitudinally and transversely. When the pieces of soil crumbled, in order to reform a thread and continue rolling; the first crumbling point is the plastic limit. The portion of the crumbled soil thread was gathered together and then transferred to three different moisture content containers and covered with the lid and then taken to oven for the determination of moisture content of the soil.

Plasticity Index (PI) was obtained from the difference between liquid limit and the plastic limit. Liquidity Index (LI) was employed to determine the ratio of the difference between natural moisture (w) and plastic limit (PL) to the plasticity index (PI) of a clay soil in its natural state. The Over-consolidated clays may have LI <0 although unconsolidated clays may have LI >1.

D. COMPACTION TEST

This was adopted to examine the soil properties due to changes in moisture content. It determines the maximum dry density to which soil may be compacted by a given force and also showed when the material is wetter or drier than its optimal moisture content, (Nyles *et al*., 1999).

About 5kg of air-dried soil on which compaction test is to be done was weighed. The water was then added and mixed thoroughly. Proctor mould and its base plate were weighed and then attached the top of the mold. The mixed soil was poured into the mold in three layers and each layer was compacted at 25 blows by the proctor hammer. The top attachment of the mould was removed from the mould and then trimmed the excess soil above the mould with straightedge.

The mold, base plate and compacted mixed soil were weighed altogether. The base plate was then removed from the mold. Small portion of sample was taken from top and bottom of the mold into the known mass moisture cans, weighed, and oven dried for about 24hrs for moisture content determination. The compacted soil was then removed from the mould, water was added to raise the moist content by about 2%, and then thoroughly mixed with the left over moist soil sin the pan.

The procedures above were repeated for about 5 times until the weight of the mould and compacted soil reduced from the previous procedures and percentage moist (w), wet density (ρw) and dry density (ρd) were determined.

IV RESULTS AND DISCUSSION

A. GEOLOGY OF THE STUDY AREA

The geology map of the study area indicated that the area is basically underlain by granitic rocks of the basement complex of North Western Nigeria. However, geological activities were noted to have taken place in the area which includes jointing and fracturing of some rock exposures which may contribute to development of erosion of the area. The rock exposures were coarse grained and compositionally consists of basically feldspars and quartz and biotites with some accessory minerals.

B. LABORATORY ANALYSES

The specific gravity was used to determine soils that soil that are either cohesion or cohessionless, or even loose. This factor affects the erodibility of the soils hence, specific gravity results could be used to determine the probable risk of erosion loose that may affect the erodibility of the soil. From Table (1), it is seen that sample 2M has the highest specific gravity of 2.59 and sample 4T is the least with a value of 2.32.

Particle sizes soils with < 35% that passes through the No.200 sieve are classified to be A-2-7 while soils with >35% pass through the No. 200 sieve are classified to be A-4 which is typically granular in compositions (AASTHO, 1993). These materials are therefore unfit for use as base, subbase and subgarde in road construction. The fine fractions (claye soil) are classified as fair to poor road material although the coarser fractions (granular) are classified as good engineering materials (road construction).

The grain size distribution shows that the soils are predominantly sandy with low contents of clay materials which would serves as binding cementing materials. These fine particle contents in the soil established the presence of silts and clay sediments. Sediments with high sand or silt contents with less clay particle usually erode easily even under a flat terrain. Therefore, any runoff on the surface would intensify the intensity of the gully erosion in the area.

The grading index recorded showed that Cu ranged from 17.2 - 1.13 and Cc ranges from 6.01 - 0.85. A soil is said to be well graded when the soil has wide range of sizes with good representation of all sizes from the least to the highest sieve and are more resistance to erosion due to increase in density and strength but the poorly graded soil does not have good representation of the all size particles for the least to the highest sieve size (Das, 2010); are vulnerable to erosion due to decrease in density, decrease in friction angles and increase in void ratio (Obiefuna et al., 1999).

Permeability is a complex property that is affected by physical properties of the soil and the liquid medium passing through it (DeGroot and Ostendorf, 2012). From the work of Carter and Bentley (1991) it is confirmed that the coefficient of permeability (K) of soils from the study area falls between gravel and sand (Fig.1). The coarse grained content of soil with low contents of fines could result to high flow rate of pore water and subsequent seepage pressure which implies that high amount of water will infiltrate to underground which could promote further expansion of the gullies (Onwuemesi and Egboka, 1991).

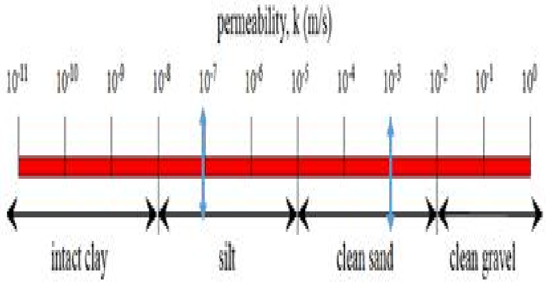

Fig. 1: Coefficient of permeability of soil (After Carter and Bentley, 1991)

Table 1: Geotechnical test results of the soil from the study area

S/N	Sample No.	SG	Sieve analysis				Atterberg limits				Compaction		
			Cu	Cc	K at D_{10}	K at D_{10}-D_{50}	LL (%)	PL (%)	PI (%)	LI	W (%)	OMC (%)	MDD(Mg /cm^3)
1	1T	2.48	12.67	4.25	2.3×10^{-4}	1.47×10^{-5}	23	19	4	1.01	23.04	7.89	2.17
2	1M	2.58	17.92	0.1	1.1×10^{-2}	7.9×10^{-4}	22	17	5	2.8	31.00	7.84	2.07
3	1B	2.54	2.57	0.96	1.0×10^{-2}	1.5×10^{-6}	19	10	9	1.2	20.98	10.67	2.13
4	2T	2.47	1.44	1.03	8.1×10^{-3}	8.5×10^{-7}	21	19	2	2.0	21.32	7.84	1.86
5	2M	2.59	10.1	0.14	1×10^{-4}	6.1×10^{-6}	21	14	7	1.14	22.17	10.38	2.07
6	2B	2.49	1.32	1.52	1.1×10^{-3}	5.4×10^{-7}	20	14	6	1.19	22.26	10.08	2.13
7	3T	2.40	1.38	1.14	6.4×10^{-3}	6.4×10^{-7}	24	23	1	1.0	24.00	11.17	1.92
8	3M	2.37	6.06	5.3	3.2×10^{-4}	1.1×10^{-3}	20	0	20	1.0	20.03	7.74	2.13
9	3B	2.48	7.06	5.3	2.9×10^{-4}	8.1×10^{-4}	26	17	9	1.32	24.86	6.72	2.12
10	4T	2.32	8.0	6.01	2.3×10^{-4}	8.5×10^{-6}	15	10	5	1.02	21.35	8.31	2.0
11	4M	2.53	1.3	0.93	1×10^{-2}	3.8×10^{-7}	23	21	2	0.03	20.34	11.38	2.03
12	4B	2.56	1.13	0.85	1×10^{-2}	7.9×10^{-4}	26	22	4	1.25	26.96	10.07	2.01

SG- Specific Gravity; Cu- Coefficient of Uniformity; Cc- Coefficient of Curvature; K- Coefficient of permeability; LL- Liquid limit; PL- Plastic Limit; PI- Plasticity Index; LI- Liquidity Index; W- Moisture Content; OMC- Optimum Moisture Content; MDD- Maximum Dry Density

It is apparent that grain size distribution has impact on permeability. Coarse grained soils have large pores and larger interconnection between the pores while, smaller pores have very narrow interconnection. Additionally, fine particles fill the pore spaces between the larger grains thus decreasing the sizes of void and the associated interconnection. For instance sample 4B (1×10-2 & 7.9×10-4) with the highest permeability as compared to sample 2T (8.5×10-3& 8.1×10-3), this indicated that the particle size distribution has significant effect on permeability which in turn induces gully erosion in the area (Carter and Bentley, 1991).

Igwe et al. (2013) reported that when the coefficient of permeability (k) ranges between 10– 7 to 10–5 m/s such material is are categorized as moderately to highly permeable materials and this implies when these soils come in contact with water, the soils will retain water and will lead to the rapid weakening due to poor drainage and exposure to the surface (Adeyemi, 2013).

Liquid limits and plastic limits were employed to determine the plasticity index which describes the cohesive properties of the soil (Onwemesi, 1990). The values of liquid limit ranged between 19 - 26% and mean 22.25%, Plastic limit ranged between 23 -0% with a mean of 15.5%. While plasticity index ranged between 3 - 20% with a mean of 6.75%. This showed that the soils cohessionles Clayton and Jukes (1978). These cohessionles soils could be accountable for the gully erosion problems in the area because the water flows through the soil with ease and soil particles are moved very easily down slope as the velocity of water increases.

The plasticity index is used in determining the strength properties of the soils for road construction (Adeyemi, 2013). From the values obtained (Table 1) all the studied soils have the potential of causing major deformation due to their non-plastic (non cohesive) properties (Federal Ministry of Works and Housing, 1997).

The OMC ranges between 6.72 to 11.38% and MDD ranges between 86 to 2.17Mg/cm3 this aid to classified the soil to be sandy O'Flaherty (1988) The studied soils are majorly loose sand with low maximum dry densities describing un-compacted properties of the soil and this could pave way for erosion susceptibility (Gabriel and Jibrin, 2012; Umoro et al., 2015).

C. GULLY CONTROL

The danger of gully erosion around Ungogo area has called for urgent measures to reduce the risk on the road and bridge collapse, and building structures. The best practice to control this hazard is to employ engineering techniques by stabilization of river banks and river flow, landfilling, construction of check dam (Rock/sand bag, loose rock and wire-bound loose, Brushwood and/or Gabion) and geo-textile.

It is worthy to note that the best soil for foundation of pavement structures must always be compacted above the MDD and the OMC values to yield the maximum strength prevent inflow of water and distribute in line with the recommendation by Federal Ministry of Works and Housing (1997)

V. CONCLUSION

The evaluation of the geological and geotechnical index properties (specific gravity, sieve analyses, compaction and Atterberg limits) that result to gully erosion in Ungogo has been carried out as a holistic approach for investigating the behavior of the earth materials and measurement of soil properties of the gully soils. The geological map of the study area was produced in order to have insight on surface and subsurface geology. The geometry of the gullies and the extent of degradation had been ascertained.

The study area is geologically underlain by coarse grained granites that are poorly exposed and intensely weathered. The presence of more poorly graded and gap graded soils within the soil layers may increase the voids thereby decrease the strength and densities of the soil. The soils are of low plasticity thus cohessionles which is an evidence of the causative factor for the growth of the gullies. The soils are majorly loose sand with low maximum dry densities showing un-compacted properties of the soils and could be responsible for gully formation in the area.

ACKNOWLEGDEMENTS

This paper is part of the results of the project of the year 2020 funded by the Nigerian Building and Road Research Institute (NBRRI) under the leadership of our able DG/CEO Professor Samson Duna.

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