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INFLUENCE OF ENGINEERING PROPERTIES OF SOILAND GROUNDWATER MOVEMENT ON GULLY DEVELOPMENT IN RAFINGORA, NORTHERN BIDA BASIN, NIGERIA

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ABSTRACT

The formation and expansion of gullies in Rafingora community, northern sector of the Bida Basin, Nigeria was investigated. This was aimed at determining the controlling factors for gully development in the area, using field gully parameter measurements, hydrogeological mapping and geotechnical investigation of soils from gully sites. U-shaped gullies were mapped with sliding, slumping and block fracturing as the main modes of gully propagation. Relief is gentle; slope angles range from 1.58° to 1.96°, indicating little or no influence of elevation on gully development. Gullies were found to be deeper than 3m, with drainage area of more than 30m. Depth to water in open wells ranges from 5.5m in the north-eastern part to about 16.4m in the south-western part. Gullies in the north-eastern side are mostly shallower than the water table, contrary to the situation in the south-western part. This shows a direct relationship between water table elevation and gully propagation and is further exacerbated by the relatively high average hydraulic of soils. The soils have low plasticity, cohesion, angle of internal friction (AIR) and maximum dry density (MDD). A combination of these poor geotechnical properties makes the soils friable and crumbles easily when in contact with water and offers very little resistance to erosion. Conclusively, gully development in Rafingora is influenced more by bottom erosion due to high hydraulic conductivity and seepage forces, rather than by overland runoff. Reclamation attempts may consider lowering groundwater levels as a major strategy for erosion control in the area.

Keywords: Bida Basin, Gully Erosion, Soil properties, Groundwater, Geo-hazards

INTRODUCTION

The causes of gully erosion with respect to the geologic settings as suggested by the earlier studies are numerous. Some of the identified natural causes include tectonic activities, uplift, climatic factors, geotechnical properties of soil, among others. Anthropogenic causes include farming and uncontrolled grazing practices, deforestation, and mining activities (Ezechi and Okagbue, 1989). The greatest threat to the environmental settings in Nigeria is the gradual but constant dissection of the landscape by soil erosion that often leads to gullies (Igwe, 2003).

In Nigeria, Ofomata (1981) classified the potential erosion susceptible areas based on underlying geology. He indicated that areas of high susceptibility correspond to geological regions of weak unconsolidated sandy formations while least susceptible areas are within the consolidated Tertiary to recent sediments. In south-eastern Nigeria, the classical gully sites are located in the False-bedded sandstone, Coastal Plain sands, Nanka Sands and the Bende-Ameki Formations. The geology therefore plays direct and indirect influence on the gully formation.

Aliyu *et al.* (2022) showed that cohesionless clay of low plasticity and silt of low plasticity have control gully erosion formation along Bakin Kasuwa road, Ungogo, Kano, north-western Nigeria. Nwachukwu and Popoola (2022) revealed that vulnerability of soil to gully erosion is related to its shear strength. Amagu *et al*. (2018), Ojeaga and Afolabi (2022) attributed the cause of gully erosion in the areas they studied to the loose nature of the sands with low amount of fines, making them cohesionless, and easily exposed to agents/factors of gully erosion. Garuba *et al*. (2021) argued that soil properties played a major role in worsening the incidence of gully erosion in parts of Zaria metropolis, north-western Nigeria.

High hydrostatic pressure in the aquifers produce a reduction in the effective strength of the unconsolidated coarse sands in the walls of gullies leading to intense erosion Obiefuna and Nur, 2003. The loose nature of the geologic materials high permeability and shallow water table in the rainy season influenced the growth and development of gullies. Piping is an indicator of dispersive soils and accumulation of free water in the subsoil, as these are some of the prerequisites for piping to occur. Fox *et al.* (2007) argued that gully banks are less affected by overland flow than by other processes such as piping and mass movement as a result of a high water table

Okengwo *et al.* (2015) studied the factors that favour development of gully erosion and landslides in south-eastern Nigeria, suggesting that gully erosion is controlled by physiography, hydrogeology, and engineering properties of the soil materials. Abdulfatai1 *et al.* (2014) indicated that the relatively high sand content and low plasticity of the soil along river Bosso in Minna is susceptible to erosion which is attributed to the dominant granitic rock of the study area.

Rafingora is located in Northern Nigeria where desertification and aridity had been the major environmental problems that has been receiving global attention. Emergence of gully erosion as deep as 12m in the region has been reported by Gabriel and Jibril (2010), Mbaya *et al.* (2012) and Mahmud and Umaru (2018). This research therefore aims at investigating the geological, geotechnical and chemical properties of the rocks and soils in the study area in order to ascertain their control on the gullies. The aim of this research therefore is to evaluate the geological, geotechnical and geochemical factors responsible for gully formation and expansion in Rafingora area in order to decipher appropriate mitigation measures.

MATERIAL AND METHODS

The Study Area

Rafin Gora is situated in Kontagora Local Government Area of Niger state and it lies within latitude of 10° 16′ N to 10°27′N and longitude 5°23′ E and 5°26′ E (Figure 1). The area of a linear settlement covers about 30km^2 with Hausa as the common language spoken by the inhabitants. The area is accessed through the Mokwa-Makera-Kontagora road and characterized by long extensive ridges and plain lands. The entire area has a good drainage networks cutting across the community that discharges into river Kontagora. The elevation ranges from 225 m to 370 m above and most houses built closer to the drainages are exposed to gully effects. The vast and fertile land is mostly used for rice, millet and beans farming.

It experiences a total annual rainfall of about 1100-1332mm with the highest mean monthly rainfall is in August with about 240-300mm (Nigeria Metrological Agency, 2012). The highest monthly temperature is March with temperature of about 37˚C and the lowest temperature is recorded in the month of August with temperature of about 23˚C. The vegetation comprises of shrubs, grasses and tall trees that are easily identified in the dry season compare to the wet season (NIMET, 2012). Geologically**,** the area lies within the basal part of Bida formation (Doko member). Much like its lateral equivalent (Lokoja sandstone), the Bida formation lies unconformably on the crystalline basement and consists of basal conglomerates with a succession of cross-bedded white to grey sandstones intercalated with kaolinitic clays believed to have been derived from nearby deeply weathered basement rocks (Rahaman *et al.,* 2019).

Hydrogeological mapping

This was carried out using tape rule to measure the depth to water in hand dug wells located in the area of study and GPS (Garmin 70) to take the coordinate and elevation of each hand dug well studied. The data obtained was used to calculate the elevation of the water table by subtracting the depth to the water table from the elevation values. This was further used to generate water level map of the area used in delineating its influence on expansion of gully erosion.

Soil Sampling and Geotechnical Investigation

Eight soil samples were taken across the gully profiles and used in determining the geotechnical and geochemical influence on formation and expansion of gullies. Sieve analysis, permeability estimation, organic matter content, pHand temperature were conducted in accordance with the specified standard procedures (BS 1981, ASTM 1979) carried out at the civil Engineering laboratory of the Federal University of Technology, Minna.

RESULTS AND DISCUSSION

Morphological Characteristics and Relief Profiles of the Gullies

The studied gullies (A and B) are both large with gully depth greater than 3m and drainage area greater than 30m. Both the topsoil and subsoil were found to have the same resistance against erosion among the gullies, giving a ‘’U gully shape’’ except in few cases in A where we have a highly resistance subsoil (clay stone) resulting to a “V gully shaped”. The eroding process in both gullies is continuous, with sliding, slumping and block fractures as modes of gully propagation (Figure 1). Table 1 shows that gully A has a maximum elevation of 349.9m and minimum of 237m with slope tilt of 1.58̊ while gully B shows a maximum elevation of 358m and minimum of 237m with slope tilt of 1.96̊.

Figure 1: Slumping and block fractures of gully A. (Long 10° 15’ 48’’; Lat 5° 26’ 48’’)

Table 1. Profiles of gullies A and B in Rafin Gora area.

Gully head point	19415.23366, 37118.26385	19488.81705, 37163.91280
Start Height:	349.909 m	358.342 m
End Height:	237.633 m	237.633 m
3D Distance on Surface:	15459 m	15459 m
Total Climbing:	13.9 m	8.9 m
Total Descending:	126.2 m	128.4 m

Minimum Elevation on Path:	237.23 m	237.44 m
Maximum Elevation on Path:	349.909 m	358.342 m
Azimuth:	114° 12' 31.7"	125° 36' 35.8"
Slope/Tilt:	1.58°	1.96°.

A change in elevation has been identified as one of the factors that influence gully erosion as the increase in steepness increases the run off across the gullies. According to Abegunde *et al.* (2006) the steeper the slope of a field, the higher the velocity and erosive power of the run-off and the greater the amount of soil loss from erosion by water. However, recorded slope angles classify the terrain in this area as gentle, with little or no elevation influence on gully propagation. But it may be responsible for the initiation of gullies in some way.

Hydrogeological Influence on Gully Formation and Expansion

The depths to water in the study area varied with the altitude. At the north-eastern side of gully A, lowest water level was recorded at 5.5 m from the surface. While in the south-western part of the area the deepest water level was recorded at 16.4 m. Across gully A, the bottom of the gullies were all found to be shallower the water table, with average gully depth been approximately 6.27 m.While across gully B, the mean depth of the hand dugs well of 11.55 m (Figure 2) is shallower than the average gully bottom of 13 m, except for one well down slope where water table was deeper than the gully bottom at 8.4m.There is also a direct correlation of water table and slumping where the water table was observed to rise above the gully bottom. The greatest slumping and piping erosion (Figure 1a) was observed on gully banks within these locations. Fox *et al.* (2007) attributed the present of gully slumping and piping erosions to high water table rather than overland flow.

Results from soil analysis across the gullies (Table 2) also indicated that this location has rapid hydraulic conductivity and hence during rainfall, the water table of this area is expected to rise due to high infiltration and percolation. As the soil become oversaturated, hydrostatic pressure set in that overwhelm the cohesiveness of the soil across this area and result into slumping.

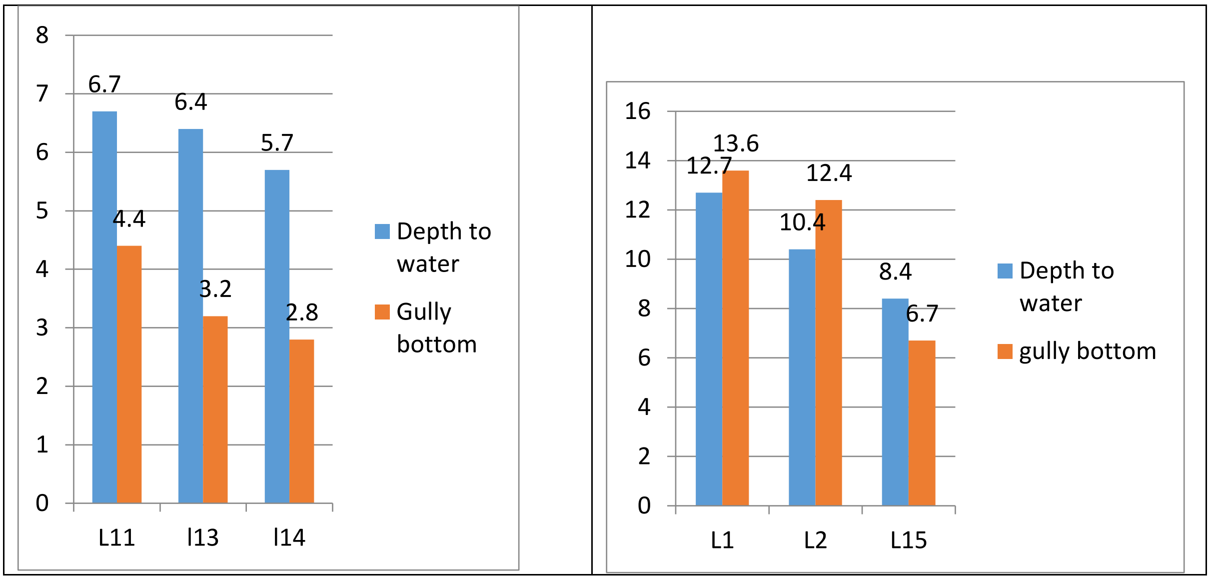

Figure 2: Relationship between depth to water in open wells and gully depth in parts of Rafingora

Gullies (A and B) show various degree of depth greater than 3m (Table 2) and drainage area greater than 30m. Both the topsoil and subsoil were found to have the same resistance against erosion among the gullies except in few cases with eroding process moving up with sliding, slumping and block fractures as modes of gully propagation (Figure 1). Based on the scheme of Thomas (1997), the gullies were classified to be active, large and continuous U-shaped gullies. The implication of this finding is the tendency of gully expansion, upstream with greater impact on roads and houses.

Table 2: Geotechnical properties of Rafin Gora soils

Location	L1	L2	L3	L4	L5	L6	L7	L8	Mean
Depth (m)	14	12	8	4	4	3	4	3	6.5
Width (m)	20	8	5	3	2	2	2	3	5.63
SG	2.64	2.6	2.72	2.77	2.5	2.48	2.66	2.68	2.63
LL (%)	ND	26.85	36.5	54.75	24.45	21.23	39.5	30	33.32
PL (%)	ND	ND	15.17	20.75	13.14	13.79	19.12	13.9	15.97
PI (%)	-	-	21.31	34	10.61	7.46	20.34	16.1	19.52
Cu	2.73	2.5	4	5	9	7	5	1.66	4.61
Cc	1.5	0.25	0.5	0.4	1.44	0.66	2.54	0.92	1.02
O M C (%)	8.4	7.2	8.8	11	9.8	8.4	8.8	9.2	8.3
MDD g/cm^3	1.88	2.09	1.94	2.06	2.0	2.04	1.96	2.02	1.98

AIF(°)	0	0	8	22	18	12	8	10	11
Cohesion	0	0	6.8	18.9	14.8	11.2	9.2	12.5	11.8
K (cm/h)	1.29 x10^{-3}	1.23x 10^{-3}	1.18x10^{-4}	1.29x 10^{-6}	1.24 x10^{-5}	1.26 x10^{-4}	1.25 x10^{-5}	1.28x 10^{-5}	1.27x 10^{-4}

SG: Specific Gravity LL: Liquid Limit; PL Plastic Limit CC Coefficient of Curvature CU Coefficient of Uniformity; OMC: Optimum Moisture Content, MDD: Maximum Dry Density, AIF Angle of internal Friction K: Permeability

Geotechnical Properties of Soil and Gully Development

Results of geotechnical studies show the soils to be poorly graded with average Cu of 4.61 and Cc of 1.02. The soil is low in specific gravity, liquid limit, plastic limit and plasticity index with average value of 2.63, 33.32%, 15.97% and 19.52% respectively (Table 2). According to Oreagbune and David (2010, Ojeaga and Afolabi, 2022; Nwachukwu and Popoola, 2022; Aliyu *et al.* 2022), low plastic limit and plasticity index makes soils to be loose, non-cohesive and slide upon each other in contact with water, or even disintegrate under dry conditions. The mean optimum moisture content of 11% and maximum dry density of between 1.88 g/cm^{3}and 2.09 g/cm^3 classify the soils in Rafingora as sandy clay with little amount of clay as binding material (Ogbonna, 2012).

The AIR recorded ranges between 0 and22˚ with average angle of cohesion of 11.8 (Table 2) show that the soils can only offer little resistance to the effect of surface water and subsurface flow force due to runoff and the seepage flux (Okunlola, 2014). The average coefficient of permeability, K, of 1.27 x 10^{-4}indicates moderately rapid flow (FAO, 2010). It shows that there is moderately rapid base flows, which could result in the collapse of gully sides and consequently advance the growth of gully erosion. A direct correlation of water tab le and slumping where the water tables were observed to rises above the gully bottom indicates the influence of subsurface flow on formation and expansion of gully erosion. This slumping and piping were attributed to subsurface flow rather than overland flow by Fox *et al.* (2007). These locations have rapid hydraulic conductivity and during rainfall, the water table is expected to rise due to high infiltration and percolation that could lead to hydrostatic pressure that can overwhelm the cohesiveness of the soil across.

CONCLUSION

The longitudinal relief profiles of studied gullies show gentle slope tilt of 1.58° and 1.96°respectively indicating little or no influence of elevation that will have aided the velocity and erosive power of the run-off. The geotechnical properties of the soils results revealed that the soil were poorly graded and low in specific gravity and Plastic index that made the soils to be loose and non-coherent. The low AIR and force of cohesion of the soil could offer little or no resistance to the effect of both surface water and subsurface flow. The slumping and piping erosion features are attributed to subsurface flow due moderately rapid hydraulic conductivity of the soils, rather than overland flow. Thus, it is recommended that groundwater flow system of the catchment should be well considered before any reclamation process. This may be accompanied by construction of drainage system to reduce the chance of initiation of rills, which subsequently develop into gullies.

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