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Geological, Geotechnical and Geophysical Investigation of Gully Erosion in Ilorin, Kwara State Nigeria

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Abstract

Geological, Geotechnical and Geophysical investigations were carried out on some selected gully sites in Ilorin with the aim of unravelling the underlying factors that causes the formation or aid the gully development. Reconnaissance assessment of the area revealed that the area is underlain by Basement Complex rocks. The soils of the area are products of insitu weathering of the underlying basement rocks. A total number of 39 soil samples were obtained systematically at three distinctive lithologies for geotechnical analysis. The test includes Sieve Analysis, Atterberg Limit test and Shear strength. The results of the laboratory test revealed that the soil at the gully site are predominantly Sands which range from 20-85%, with mean of 40.6%. Uniformity coefficient (cu) range from 3.5 – 18.9 and coefficient of curvature (cc) range from 0.5 – 3.4. This indicates that the soil from the gully sites are within the medium to coarse grain with very low percentages of fines (silts; range from 2-11% with average of 6.9% and clay 3-46% with average of 19.1%). The liquid limit (LL) ranges from 19.0-50% with mean of 32.8% and the Plasticity index (PI) range from 9.3-27.3% with mean of 15.7%. With regard to the aforementioned characteristics, the soils at the gully sites are loose sands with low amount of fine fraction, hence, cohesionless and are easily exposed to agents and factors of gully erosion. The results from the geophysical analysis shows that the geoelectric layers have high resistivity values which shows the presence of low plasticity and friable gravelly sand which constitutes part of the overburden across the study area. This research addresses to a great extent, the effect of local geology, geotechnical properties of the underlying soils, geophysical properties of the lithology associated with human activities on the formation of gully sites.

Keyword: Gully, Geophysical properties, Goetechnical properties, Underlying Basement, Overburden

1. Introduction

Environmental degradation is a global issue, significantly impacting economies and ecosystems. In Nigeria, the environment faces challenges like pollution, deforestation, erosion, flooding, and global warming, largely due to human activity and land mismanagement. Given Nigeria's tropical location and diverse landscapes, the country is especially susceptible to climate-induced hazards, such as flooding, erosion, drought, and desertification.

A key consequence of these issues is gully erosion a severe soil degradation form characterized by steep channels with unstable walls. Gully erosion often starts with intense, sporadic water flows post-heavy rains. Poesen *et al*. (2003) explain that gullies form in zones of weakness in the soil, such as faults, and create deep channels that hinder land accessibility and agricultural use. Gully erosion not only reduces soil fertility but also negatively impacts water quality by increasing sediment in reservoirs. The channels are challenging to

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rehabilitate, complicating sustainable land management. According to Tamene and Vlek (2008), the impacts are often worse in developing countries, where limited resources hinder effective responses. In southeastern Nigeria, gully erosion damages transportation, degrades farmland, contaminates water supplies, isolates settlements, and displaces communities (Grove, 1959; Nwajide and Hoque, 1979; Egboka and Okpoko, 1984; Onu, 2011).

1.1 Study area

The study area is located in Ilorin between latitudes 8°24’47.48”N - 8°26’50.11”N and longitudes 4°33’25.88”E - 4°37’8.99”E. Ilorin is underlain by Precambrian basement complex rock with loamy soils of medium to low fertility. High seasonal rainfall and temperatures lead to the formation of lateritic soil types due to mineral leaching (Ajibade and Ojelola, 2004). The area’s elevation varies from 273m to 394m, with the highest point being Sobi Hill.

1.2 Climate of the study area

The climate of Ilorin is characterized by both wet and dry seasons. The rainy season begins towards the end of April and last till October while the dry season begins in November. Ilorin experiences both wet and dry seasons. The rainy season starts in late April and lasts until October, while the dry season extends from November to April. During the dry season, temperatures range between 33ºC and 35ºC from November to January and rise to 34ºC to 37ºC from February to April, often making days extremely hot. Annual rainfall varies between 990.3mm and 1318mm, showing a double peak pattern and high temporal and spatial variability. Relative humidity ranges from 75% to 88% during the rainy season (May to October) and from 35% to 80% in the dry season (Ajibade and Ojelola, 2004).

1.3 Drainage setting of the study area

The primary drainage system in Ilorin is the Asa River, flowing south to north and dividing the city into two parts: the eastern side, which includes the Government Reserved Area (GRA), and the western side, comprising the city’s indigenous areas. Ilorin’s drainage pattern is dendritic, with rivers Agba, Alalubosa, Okun, Osere, Aluko, Yalu, Odota, and Loma draining into Asa River (Ajibade and Ojelola, 2004).

2. Methodology

The study included gathering literature, geological maps, and field equipment like geological hammers, sample sacks, GPS, and an ABEM Terrameter SAS4000 for geophysical analysis. Fieldwork focused on locating gully sites and systematically collecting soil samples for geotechnical analysis.

2.1 Geophysical investigation

1D Vertical Electrical Sounding (VES) and 2D resistivity imaging were used to analyze subsurface erosion-related characteristics. Data was acquired using ABEM’s Terrameter SAS4000 and processed with WINRESIST software, providing insights into subsurface lithology, stratigraphy, and groundwater levels.

Plate 1: Geophysical Investigation at Amoyo gully erosion site in Ilorin

2.2 Soil sampling

The soil samples were collected systematically at each gully sites. The gully wall was divided into three lithologies (Upper layer, middle layer and the lower layer) based on their physical appearances and soil samples were taken on each layer making 3 soil samples at each location, summing up to a total number of 39 soil samples at 13 gully sites spread across Ilorin town. The soil samples were obtained incipient gullies at depths of 1.8m and 4.5m. The soil samples were wrapped in a sack and labelled accordingly.

Plate 2: Sample Collection on the 2nd Lithology

2.3 Geotechnical Analysis

The geotechnical tests carried out includes:

i. Grain size classification (Mechanical and Hydrometer)
ii. Shear Strength
iii. Atterberg Consistency Limits (Liquid Limit, Plastic Limit and Plastic Index)

All Analysis followed BSI 1377(1990) procedure

Plate 3: Sample Collection on the 2nd lithology

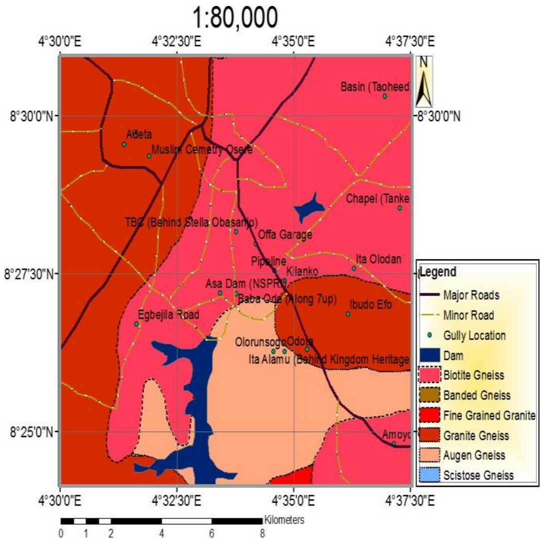

Plate 4: Composite map of Geology, bedrock and gully locations

3. Result and Discussion

The study area is underlain by basement complex rocks, including older granite, migmatite, granite gneiss, and granite (Adelana *et al.*, 2007). These rocks have weathered in-situ, forming sandy lenses and pockets, particularly visible along the Asa River channel and in places like Ganmo. These sand pockets serve as aquifers for underground water, contributing to river flow during the dry season. The Asa River itself comprises alluvial clays and gravels that facilitate underground water recharge.

The basement rocks are generally fine to coarse-grained, crystalline, indurated, and well-cemented. Field observations show that these rocks have weathered to form soils consisting of sand, humus, clay, and laterite. These are largely residual soils, originating from the physical and chemical weathering of the underlying rocks, although some are transported by water, wind, or ice.

3.1 Laboratory analysis results

Soil samples from gully sites are predominantly sandy, with sand content ranging from 20-85% (mean: 40.6%). The soils are classified as medium to coarse-grained, with uniformity coefficients (cu) from 3.5 to 18.9 and curvature coefficients (cc) from 0.5 to 3.4. Fines include silt (2-11%, average: 6.9%) and clay (3-46%, average: 19.1%). Liquid limits (LL) range from 19.0-50% (mean: 32.8%), and plasticity indices (PI) range from 9.3-

27.3% (mean: 15.7%). These characteristics reveal that the soils are primarily loose sands with low fine fractions, making them cohesionless and susceptible to gully erosion.

Table 1: Summary of the Characteristics, Geophysical and the Geotechnical parameters of the Gully sites

		Nature				Geophysical				Geotechnical			
Gully Site	Shape	Depth (m)	Width (m)	Longitude (East)	Latitude	Depth to Basement (m)	Geo Electric layer	Resistivity (Ωm)	Curve Type	Sand (%)	Fines (%)	Plasticity Index	Flow Index
Amoyo	U	3.8	0.4	4°37'8.99"	8°24'47.48"	10.9	4	125.6	H	74	26	12.4	20.1
Ita Alamu	U	1.8	0.3	4°35'17.53"	8°26'17.8”	13.3	5	118.6	AH	78	22	9.5	16.4
Kilanko-A	U	2.5	0.7	4°34'48.63"	8°27'22.8"	8.7	4	125.4	KA	70	30	16.2	20.3
Pipeline	U	3.5	0.3	4°34'35.22"	8°27'32.09"	8.7	3	227.2	QH	92	8	17.4	21.7
Ita Olodan	U	3.2	0.2	4°36'17.83"	8°27'34.2"	11.3	4	227.2	QH	92	8		
Megida Est	U	3.6	0.4	4°36'57.76"	8°30'18.35"	7.5	4	1563.1	H	92	8	9.95	14.7
Kilanko	U	4.5	0.3	4°34'47.6"	8°27'28.52"	12	4	312.8	H	70	30	14.7	14.7
Adisco	U	2.8	0.5	4°34'12.77"	8°27'54.84"	7.4	4	282.4	A	90	10	16.2	16.7
Coca Cola	U	2.5	0.2	4°33'46.86"	8°27'15.78"	16.6	4	150.8	H	89	11	20.2	20.5
NSPRI	U	3.2	0.3	4°33'24.39"	8°26'11.21"	7.2	4	453.7	H	70	30	16.1	19.4
Osere M-C	U	3.3	0.4	4°32'24.61"	8°28'54.77"	7.2	4	453.7	H	77	23	17.7	28.9
Odota	U	3.1	0.6	4°30'48.87"	8°27'14.89"	5.9	4	1357.6	H	93	7	27.9	0.7
Baba Ode	U	2.6	0.5	4°34'6.93"	8°27'7.24"	3.7	4	534.4	H	88	12	20.4	0.95

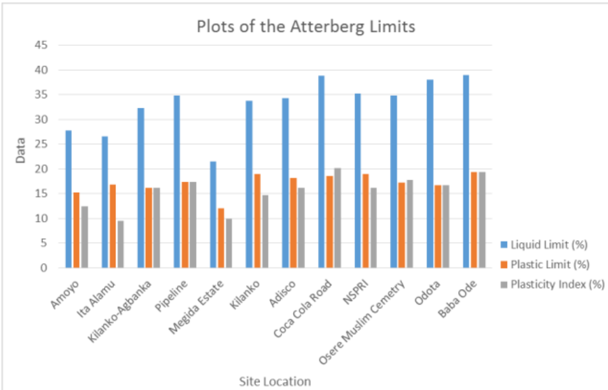

Figure 1: Bar Chart plot of the Atterberg Limits

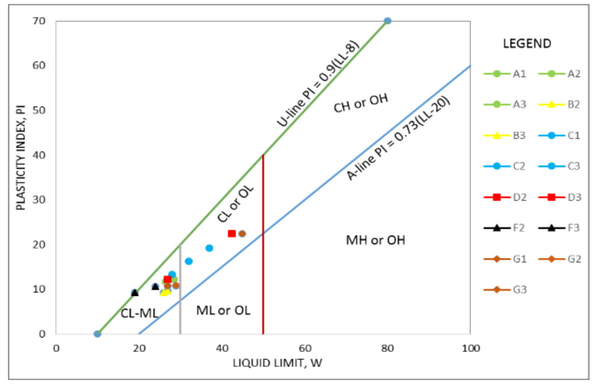

Figure 4: Plasticity chart of soil samples

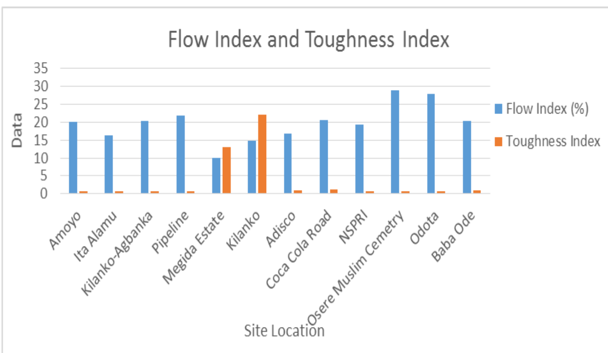

Figure 2: Bar Chart plot of Flow Index and the Toughness Index of the Gully sites.

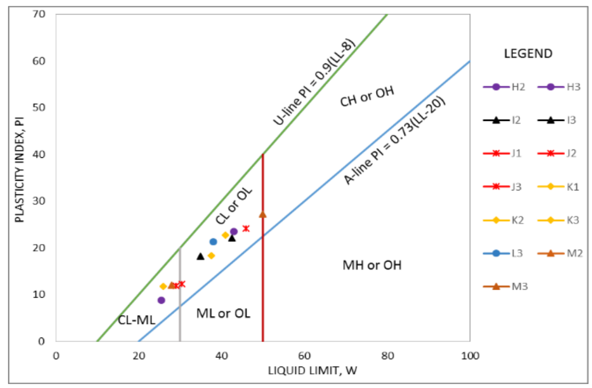

Figure 5: Plasticity chart of soil samples

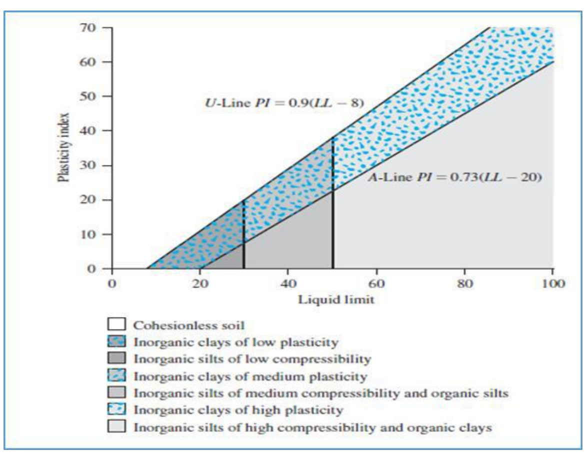

Figure 3: Plasticity chart, USCS (Das, 2010)

Geophysical investigation

The Vertical Electrical sounding investigation revealed presence of low plasticity and friable gravely sand which constitute part of the overburden across the study areas. The results from the geophysical analysis also shows that the geoelectric layers have high resistivity values which shows the presence of low plasticity and friable gravelly sand which constitutes part of the overburden across the study area.

Lithology	Number of Layer	Top sandy soil			Laterite			Weathered Basement rock			Fractured/slightly weathered basement rock			Fresh basement rock			Curve type
		Resistivity (Ω m)	Thickness (M)	Bottom depth (m)	Resistivity (Ω m)	Thickness (M)	Bottom depth (m)	Resistivity (Ω m)	Thickness (M)	Bottom depth (m)	Resistivity (Ω m)	Thickness (M)	Bottom depth (m)	Resistivity (Ω m)	Thickness (M)	Bottom depth (m)	
VES1	4	72.3	0.5	0.5	358.6	1.5	2.0	36.5	8.9	10.9				125.6			
VES2	5	105.8	1.0	1.0	179.9	2.9	13.8	171.7	6.4	10.2	171.7	13.3	23.5	118.6			
VES3	4	140.6	0.5	0.5	368.7	1.2	11.7	77.6	7.0	8.7				247.5			
VES4	3	64.5	0.5	0.5	21.8	1.1	1.6							125.4			
VES5	4	227.2	0.7	0.7	180.1	3.4	4.0	6.9	7.3	11.3				79.9			
VES6	4	189.4	0.7	0.7	514.5	1.3	1.7	188.9	5.5	7.5				1563.1			
VES7	4	937.3	0.8	0.8	137.9	0.9	1.7	63.0	10.3	12.0				312.8			
VES8	4	38.8	1.0	1.0	41.1	1.9	2.9	33.9	4.6	7.4				282.4			
VES9	5	150.8	1.0	1.0	131.9	3.3	4.2	68.9	2.6	6.9	14.5	9.7	16.6	70.9			
VES10	4	168.6	0.9	0.9	87.0	1.1	2.0	22.9	5.2	7.2				639.4			
VES11	4	78.5	0.8	0.8	36.0	1.9	2.7	9.0	4.5	7.2				453.7			
VES12	4	73.8	1.4	1.4	29.0	1.8	3.2	44.3	2.7	5.9				1357.6			
VES13	4	136.3	0.5	0.5	7.5	1.2	1.8	6.3	2.0	3.7	534.4						

4. Summary and Conclusion

The geotechnical properties of residual soils derived from the granitic basement rocks in the study area make it highly susceptible to gully erosion. The sandy, cohesionless soil structure, along with human activities, increases the area's vulnerability to erosion. Key findings and recommendations are as follows:

i. Geological Observations: The basement complex rocks have weathered into residual or transported soils, including sands, humus, clay, and lateritic soils, which are prone to erosion.
ii. Soil Structure: The soil profile primarily consists of cohesionless sand with low fines, resulting in poor binding between particles and reduced resistance to erosion.
iii. Plasticity and Consistency: Low liquid limit (LL) and plasticity index (PI) indicate that the soil can shift states with minimal changes in water content, leading to high instability.
iv. Geophysical Analysis: Vertical Electrical Sounding revealed low plasticity and friable gravelly sands, highlighting areas prone to gully formation at varying depths.

Recommendations

i. Waste Management: Prohibit dumping of refuse in floodplain areas, especially around Kilanko and Pipeline gullies.
ii. Construction Restrictions: Discourage construction near flood-prone areas.
iii. Soil Stabilization Techniques: Use methods like grouting, concrete structures, check-dams, and dewatering to reduce pore water pressure and seepage at Baba Ode.
iv. Groundwater Control: Adopt subsurface horizontal drains, drainage galleries, well-point systems, or deep groundwater abstraction to stabilize soil by lowering groundwater

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