

Investigation of Soil Index Properties in Ajalli and Its Environs in Anambra State, Nigeria

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Abstract

In order to ascertain the engineering properties and erosion susceptibility of the soils in Ajali and its surroundings in Southeastern Nigeria, this study offers the geotechnical evaluation of those soils utilizing Particle Size Distribution (PSD) and Atterberg Limit analyzes. Six soil samples were taken from significant borrow pits in Ajali, Enugwu-Abo, Ufuma, Ndiowu, Isi-Ulo, and Ndikelionwu, where building supplies are frequently obtained for foundation and road construction. The particle size distribution, specific gravity, liquid limit, plastic limit, and plasticity index of the soils were determined through laboratory analyzes carried out in compliance with established geotechnical methods. According to the results of the particle size distribution, medium- to coarse-grained sands make up about 85% of the soils' weight, with fine-grained sand and coarse silt making up about 14% and 1%, respectively. The soils range from very poorly sorted to moderately sorted, indicating variations in depositional and textural characteristics. The average specific gravity value obtained is 2.67, which is typical of lateritic and sandy soils derived from sedimentary formations. Atterberg limit results showed average values of 63.45% liquid limit, 19.13% plastic limit, and 44.33% plasticity index, indicating moderate to high plasticity with appreciable intergranular cohesive strength. The predominance of sandy fractions suggests high permeability and weak resistance to erosion, particularly in areas dominated by non-plastic or weakly plastic soils. However, the moderate clay content observed in some locations contributes to improved cohesion and reduced susceptibility to particle detachment. The study concludes that the soils possess varying engineering behaviors, with moderate suitability for construction purposes but significant vulnerability to erosion and land degradation in poorly consolidated zones. The findings provide useful baseline information for geotechnical design, erosion control, road construction, and sustainable land-use planning within Ajali and its environs.

Keywords: Geotechnical evaluation, Particle size distribution, Atterberg limits, Soil erodibility, Ajali Sandstone, Southeastern Nigeria.

Introduction

Given that the characteristics of a soil affect the stability and longevity of structures like highways, foundations, and embankments, it is a crucial component in engineering construction. Determining soil gradation, plasticity, permeability, compressibility, and erosion susceptibility requires geotechnical assessment employing Particle Size Distribution (PSD) and Atterberg Limit tests (Adeyanju et al. 2020; Eberemu and Nwofor 2021). While Atterberg limits assess consistency and moisture-related behavior, which are crucial for soil classification and engineering compatibility, PSD analysis offers information on the amounts of gravel, sand, silt, and clay within soils (Ochepo et al. 2019; Oyediran and Durojaiye 2019).

The Ajali Sandstone Formation, which is primarily composed of poorly cemented sandy elements that are extremely susceptible to erosion and land degradation, underlies Ajali and its surroundings in southeast Nigeria. Due to heavy rainfall, poor drainage, and insufficient geotechnical soil assessment, the region regularly faces gully erosion, infrastructure failures, and environmental instability (Egboka et al. 2020). According to earlier research, soils with a significant clay content and moderate plasticity show better stability, while soils dominated by medium- to coarse-grained sands with low fines content typically have weak cohesion and high erodibility (Akinwumi et al. 2022; Nwankwoala and Oborie 2023).

Despite increasing infrastructural development within the region, detailed geotechnical investigations remain limited. Therefore, evaluating the soils using PSD and Atterberg Limit analyses is necessary to determine their engineering properties, suitability for construction, and susceptibility to erosion. The findings of such investigations will provide useful information for sustainable construction practices, erosion control, and land-use planning within the study area.

Methodology

Geology of the area

Ajali and its environs are located within southeastern Nigeria and form part of the Anambra Basin. The area lies within the tropical rainforest belt characterized by distinct wet and dry seasons. Annual rainfall ranges between 1800 mm and 2500 mm, with peak precipitation occurring between July and September. Temperatures are generally high throughout the year, averaging between 26 °C and 30 °C (Nigerian Meteorological Agency 2021).

Geologically, the area is underlain predominantly by the Ajali Sandstone Formation, consisting mainly of poorly consolidated, friable, and highly permeable sands. The formation is characterized by medium- to coarse-grained sands with minor clay intercalations, making it highly vulnerable to erosion processes (Egboka et al. 2020). The topography is undulating, with numerous gully erosion sites resulting from surface runoff and weak soil cohesion.

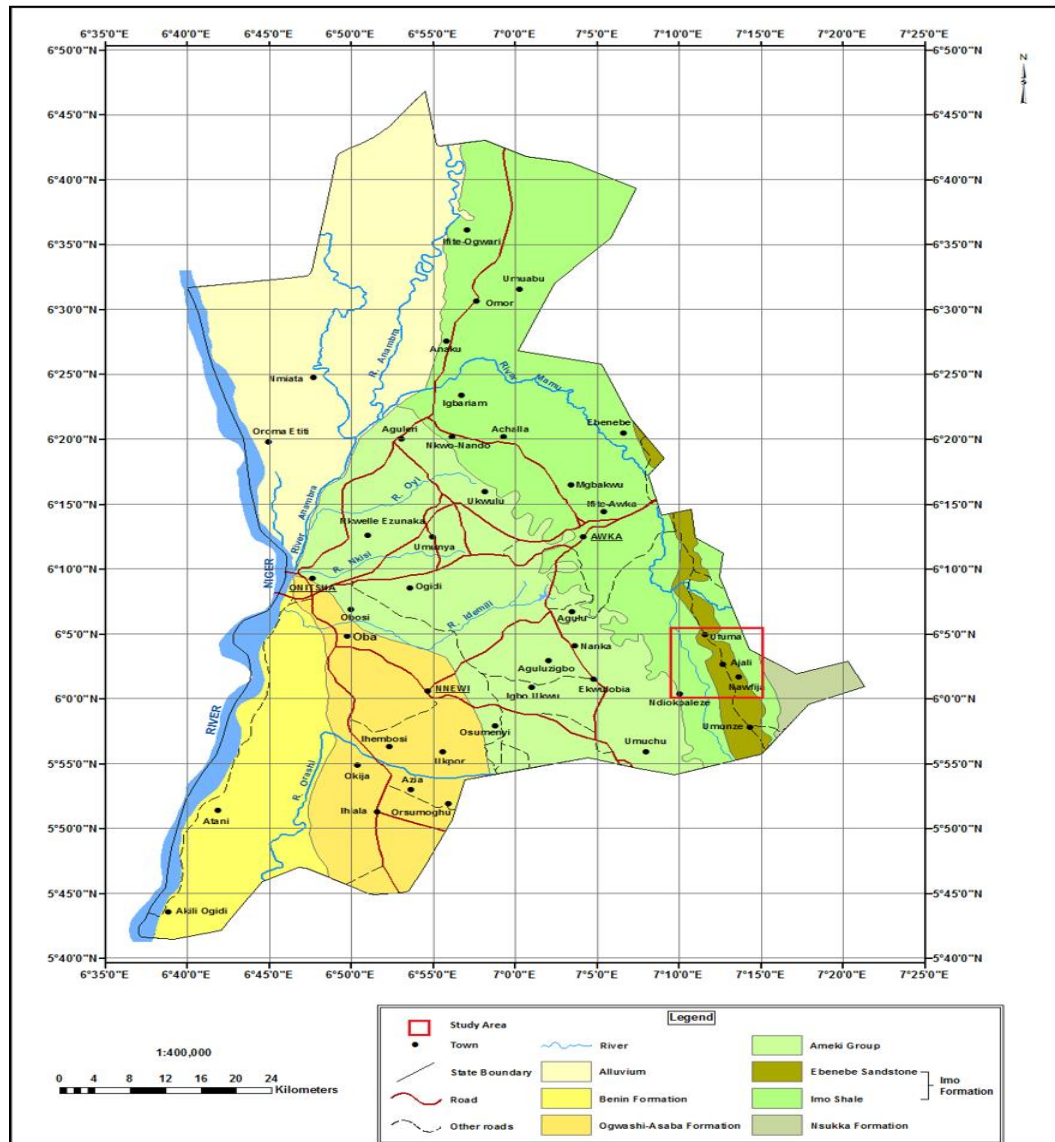


Fig. 1: Geologic map of Anambra State showing the study area (NGSA, 2010)

Soil Sampling

Six representative soil samples were collected from active borrow pits located at Ajali, Enugwu-Abo, Ufuma, Ndiowu, Isi-Ulo, and Ndikelionwu within the study area. These locations were selected because they serve as major sources of lateritic materials commonly utilized by construction companies for road construction and other civil engineering works in parts of Anambra State. The sampled soils were considered representative of the foundation and subgrade materials widely used within the region.

Laboratory Analysis

Laboratory analyses were conducted to determine the geotechnical properties of the soils. Particle Size Distribution analysis was carried out using sieve analysis in accordance with standardized procedures established by British Standards Institution (BSI) (2019). The test was used to determine the proportions of gravel, sand, silt, and clay-sized particles within the soil samples.

Atterberg Limit tests, including Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI), were also conducted following standard laboratory procedures. These tests were used to evaluate the consistency, plasticity, and moisture sensitivity of the soils.

Results And Discussion

Geotechnical Results and analysis

Grain size analysis

The grain size distribution analysis was carried out on six representative soil samples using a mechanical sieve shaker in order to evaluate the textural characteristics and engineering behavior of the soils within the study area. The results of the sieve analysis indicate that the soils are predominantly composed of medium- to coarse-grained sand, which accounts for approximately 85% by weight of the samples, whereas fine-grained sand and coarse silt constitute about 14% and 1%, respectively (Table 1). This predominance of sandy fractions reflects the sedimentary origin of the soils and is consistent with the lithologic characteristics of the Ajali Sandstone Formation underlying the area. Similar findings have been reported for sandy formations within southeastern Nigeria, where unconsolidated sandstone-derived soils are characterized by high sand content and low fines proportion (Akinwumi et al. 2022; Nwankwoala and Oborie 2023).

The grain size distribution curves further revealed noticeable variations in sorting characteristics among the samples. The soils range from very poorly sorted at Ufuma to moderately sorted at Ajali (Table 1 and Fig. 2). Sorting describes the uniformity of particle sizes within a soil mass and provides insight into the depositional environment and sediment transport history. Poorly sorted soils contain a wide range of particle sizes and generally indicate rapid or unstable depositional conditions, whereas moderately sorted soils suggest relatively more uniform sediment deposition (Nwankwoala and Warmate 2020). The observed variation in sorting within the study area may therefore be attributed to differences in sedimentary processes, weathering intensity, and localized erosion activities.

The index property analysis also showed that the soils possess an average specific gravity value of 2.67 (Table 1). This value falls within the typical range for lateritic and sandy soils developed from sedimentary parent materials in tropical environments (Eberemu and Nwofor 2021). Specific gravity is an important engineering parameter used in evaluating soil mineral composition, compaction characteristics, and suitability for construction purposes. The obtained values suggest that the soils contain predominantly quartz-rich sandy materials with moderate amounts of lateritic constituents.

The dominance of medium- to coarse-grained sand fractions indicates that the soils are highly permeable and possess relatively low interparticle cohesion. According to Akinwumi et al. (2022), sandy soils with low clay content generally exhibit weak binding forces between particles, making them more susceptible to erosion and structural instability under heavy rainfall conditions. The low percentage of fines within the soils reduces their cohesive strength and limits their ability to resist detachment by runoff water. Consequently, the soils can easily be loosened and transported during intense precipitation events, particularly on exposed slopes and poorly vegetated surfaces.

Furthermore, the poor sorting observed in some parts of the study area contributes significantly to the erodibility potential of the soils. Poorly sorted sandy soils often possess loose packing arrangements and high void ratios, which facilitate rapid infiltration and particle mobilization during storm runoff. Smaller and lighter particles require relatively low transport energy and are therefore easily detached and carried away by flowing water (Nwankwoala and Warmate 2020). This condition partly explains the widespread occurrence of gully erosion and land degradation within several communities in southeastern Nigeria underlain by similar sandy formations.

The combined influence of high sand content, poor sorting, low fines proportion, and weak cohesion therefore suggests that the soils within the study area possess moderate to high susceptibility to erosion and environmental degradation. Areas with limited vegetation cover, inadequate drainage systems, and intense anthropogenic activities are particularly vulnerable to accelerated soil erosion. These findings highlight the need for appropriate erosion control measures, proper land-use management, and geotechnical stabilization practices to minimize environmental hazards and improve the engineering performance of the soils within Ajali and its environs.

Result of Atterberg Limit Tests

The Atterberg limits test results obtained from the analyzed soil samples (Table 1) indicate average values of 63.45% liquid limit (LL), 19.13% plastic limit (PL), and 44.33% plasticity index (PI). These values suggest that the soils possess moderate to high plasticity with appreciable intergranular cohesive strength (Fig. 3 and Table 1). The results are consistent with similar findings reported for lateritic soils in southeastern Nigeria by recent studies such as Nwankwoala and Warmate (2020) and Eberemu et al. (2021).

The results further reveal the occurrence of both plastic and non-plastic soil units across the study area. Plastic soil materials were identified in Ajalli, Ndiowu, Ufuma, Enugwu-Abo, Isi-Ulo, and

Ndikelionwu, indicating the presence of appreciable clay fractions within the soil matrix. The moderate clay content enhances soil cohesion and binding characteristics, thereby improving resistance to particle detachment and reducing susceptibility to severe gully erosion in some parts of the area. According to Akinwumi et al. (2022), soils with moderate plasticity and sufficient clay content generally exhibit better structural stability and erosion resistance compared to cohesionless sandy soils.

Conversely, locations dominated by non-plastic or weakly plastic sandy materials are more vulnerable to erosion because of their low interparticle bonding and reduced shear strength. In such areas, runoff water can easily detach and transport soil particles, thereby accelerating gully development and land degradation. The predominance of non-cohesive sandy units in portions of the study area therefore explains the high incidence of erosion observed within the region.

Table 1: Index properties of collected soil samples within the study area

Property	Sample Description						Average (%)
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	
Specific Gravity	2.67	2.64	2.69	2.61	2.71	2.68	2.67
% gravel (> 2mm)	0	0	0	0	0	0	0
% Coarse grained sand (<2mm to 0.15mm)	86.43	78.02	85.88	87.43	86.89	87.06	85.29
% fine Sand (<0.15mm to 0.018mm)	12.55	21.53	12.81	11.7	12.13	12.856	13.93
% silt (<0.018mm)	1.02	0.45	1.31	0.87	0.98	0.084	0.79
Liquid limit (%)	64.62	60.74	67.71	64.21	63.42	60.00	63.45
Plastic limit (%)	21.04	21.02	17.04	18.05	19.10	18.50	19.13
Plasticity Index (%)	43.58	39.72	50.67	46.16	44.32	41.50	44.33

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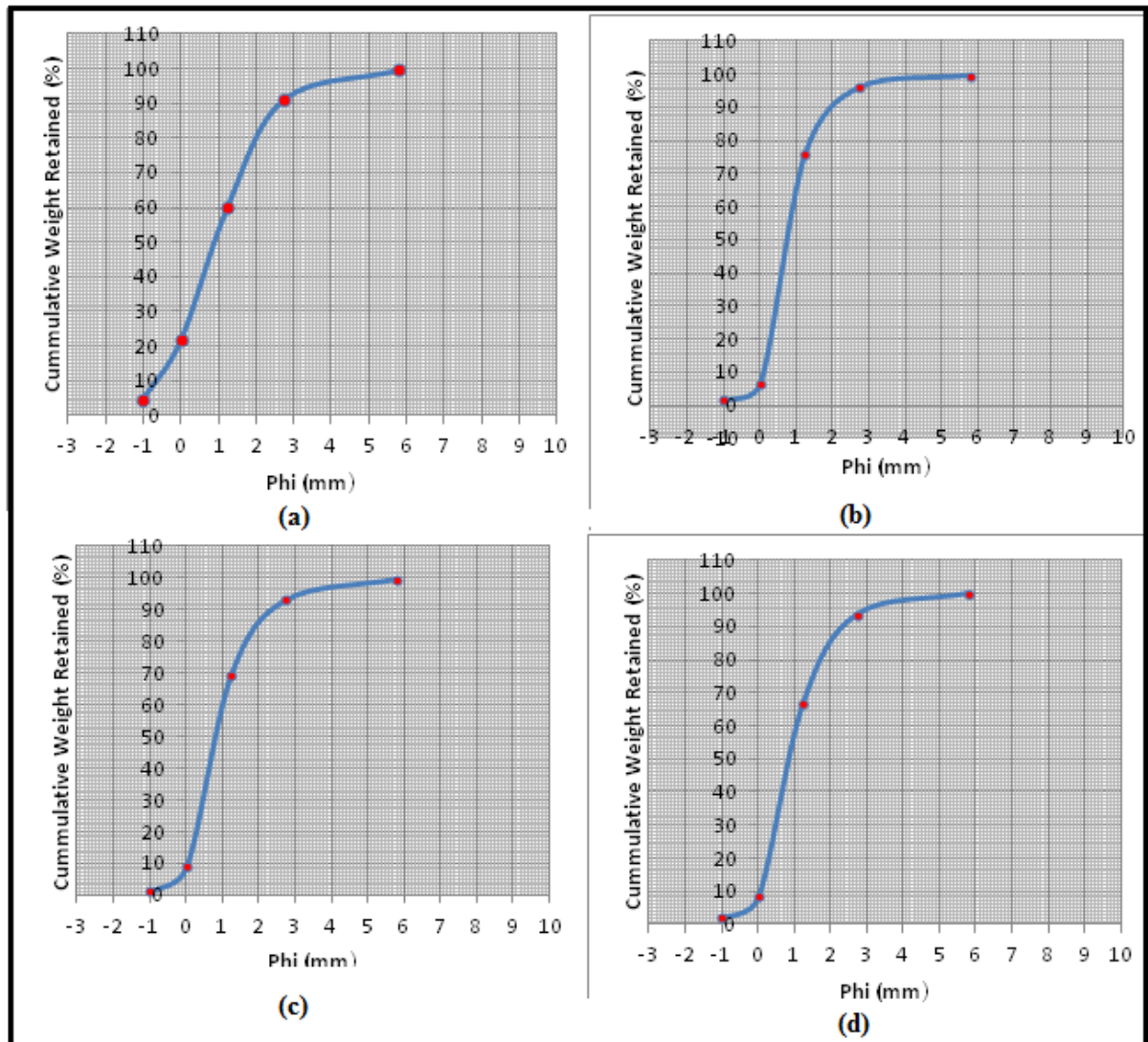


Fig.2 :A Cumulative frequency graph of sample 1-4 from the study area

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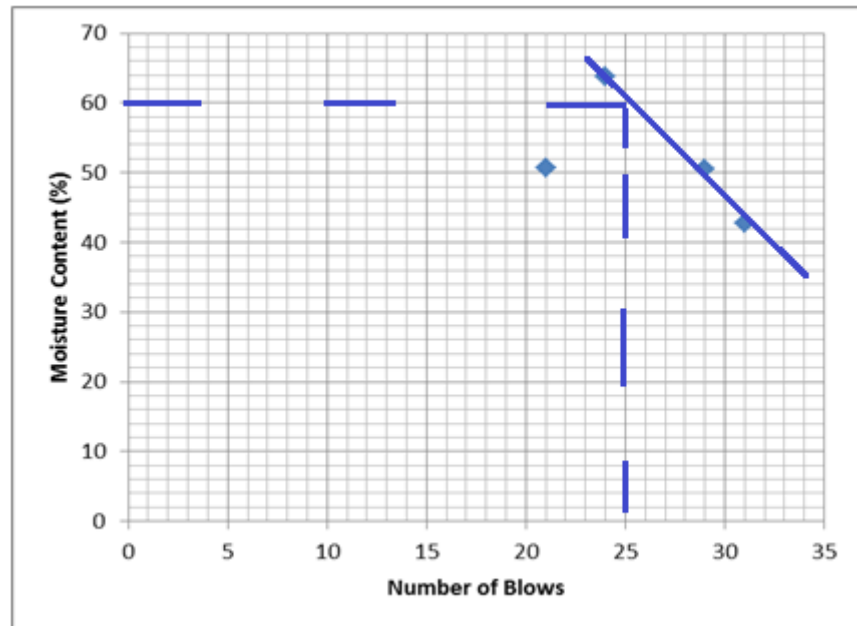


Fig. 3: A plot of moisture content against number of blows

Conclusion

The geotechnical evaluation of soils within Ajali and its environs using particle size distribution and Atterberg limit analyses has provided valuable insights into the engineering behavior and erosion susceptibility of the soils in the study area. The grain size analysis revealed that the soils are predominantly composed of medium- to coarse-grained sands with minor proportions of fine sand and coarse silt. The soils range from very poorly sorted to moderately sorted, indicating variability in depositional characteristics and particle arrangement.

The predominance of sandy materials suggests high permeability and low resistance to detachment by runoff water, thereby increasing the erodibility potential of the soils. This explains the widespread occurrence of soil erosion and gully development observed in several parts of the study area. The specific gravity values obtained indicate that the soils are typical lateritic and sandy materials derived from sedimentary formations.

Furthermore, the Atterberg limit results revealed moderate to high plasticity characteristics, indicating the presence of appreciable clay fractions within some of the soil units. The plasticity index values suggest that portions of the soils possess moderate intergranular cohesion, which contributes to improved soil stability and reduced erosion susceptibility in some locations. However, areas dominated by non-plastic or weakly plastic sandy soils remain highly vulnerable to erosion because of their low cohesive strength and poor particle bonding.

Overall, the study demonstrates that the engineering performance and erosion behavior of the soils are strongly controlled by their textural composition, grading characteristics, and plasticity properties. The combined influence of loose sandy materials, poor sorting, and varying cohesive strength contributes significantly to the instability of the soils within the study area. Finally, the following recommendations were made:

1. Comprehensive erosion control measures such as proper drainage systems, check dams, retaining structures, and slope stabilization techniques should be implemented in erosion-prone areas to minimize soil loss and gully expansion.
2. Vegetative cover and afforestation programs should be encouraged to improve soil binding capacity, reduce runoff velocity, and enhance slope stability within vulnerable locations.
3. Prior to the use of borrow pit materials for road construction and foundation works, detailed geotechnical investigations should be carried out to determine their suitability and required stabilization measures.
4. Soil stabilization techniques such as lime, cement, or bituminous stabilization should be adopted in areas where highly erodible sandy soils predominate in order to improve strength and durability.
5. Construction activities and land-use practices that expose loose sandy soils should be properly regulated to reduce accelerated erosion and environmental degradation.

6. Government agencies and environmental management authorities should establish continuous monitoring and maintenance programs for existing erosion sites within the study area.
7. Further studies involving shear strength, compaction characteristics, permeability, and mineralogical analyses are recommended to provide more comprehensive geotechnical information for sustainable engineering and environmental management practices.

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