SEDIMENTOLOGICAL AND GEOCHEMICAL CHARACTERIZATION OF PROBLEMATIC SOILS IN THE DAHOMEY BASIN OF NIGERIA. IMPLICATIONS FOR GEOLOGICAL AND ENGINEERING INFRASTRUCTURE

BY

Joanita Chidinma NWAOBI (Miss)

LSC2007318

DEPARTMENT OF SCIENCE LABORATORY TECHNOLOGY
(GEOLOGY AND MINING TECHNIQUES)
FACULTY OF LIFE SCIENCES
UNIVERSITY OF BENIN
BENIN CITY

NOVEMBER, 2025

SEDIMENTOLOGICAL AND GEOCHEMICAL CHARACTERIZATION OF PROBLEMATIC SOILS IN THE DAHOMEY BASIN OF NIGERIA. IMPLICATIONS FOR GEOLOGICAL AND ENGINEERING INFRASTRUCTURE

BY

Joanita Chidinma NWAOBI (Miss)
LSC2007318

PROJECT SUBMITTED TO THE DEPARTMENT OF SCIENCE LABORATORY TECHNOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF SCIENCE (BSc.) DEGREE IN SCIENCE LABORATORY TECHNOLOGY (GEOLOGY AND MINING TECHNIQUES).

NOVEMBER, 2025

CERTIFICATION

This is to certify that this thesis **SEDIMENTOLOGICAL AND GEOCHEMICAL CHARACTERIZATION OF PROBLEMATIC SOILS IN THE DAHOMEY BASIN OF NIGERIA. IMPLICATIONS FOR GEOLOGICAL AND ENGINEERING INFRASTRUCTURE** was carried out by **Joanita Chidinma NWAOBI (Miss)** with Matriculation Number LSC2007318 of the Department of Science Laboratory Technology (Geology and Mining Techniques), Faculty of Life Sciences, University of Benin, Benin-City, under the supervision of Dr. A. Ogbamikhumi.

Dr. A. Ogbamikhumi **Date**
Supervisor

Dr. P. O. Alonge **Date**
Project Coordinator

Prof. J. O. Osarumwense **Date**
Head of Department

5th November, 2025

External Examiner **Date**

DEDICATION

This research is dedicated to God almighty.

ACKNOWLEDGEMENTS

First and foremost I would like to express my sincere and uttermost gratitude to God almighty for his grace to complete this research work.

I am thankful to my project supervisor Dr. A. Ogbamikhumi and Dr. Godwin for their unwavering guidance and support throughout this research work.

I am also thankful to my HOD, lecturers and staff in the department of science laboratory technology for their support during this academic pursuit.

I owe a depth of gratitude to my family especially my father Mr. D. Nwaobi for his love, patience, encouragement, support and resources that facilitated the accomplishment of this research.

To my friends, my very special friends thank you for constant companionship and motivation, the shared moments of laughter, intellectual discussions and unwavering support made this academic pursuit worthwhile.

To everyone who supported me financially, emotionally and physically in one way or the other to the success of this endeavor may God bless and reward you all abundantly.

Finally, I would like to appreciate myself for not giving up, through all the struggles and sleepless nights you came on top.

TABLE OF CONTENTS

CONTENTS **PAGES**

LIST OF FIGURES

CONTENTS **PAGES**

]

LIST OF TABLES

CONTENTS **PAGES**

ABSTRACT

This study examined the sedimentological and geochemical characteristics of problematic soils within the Lagos segment of the Dahomey Basin, Southwestern Nigeria, to understand their composition, depositional setting, and engineering implications. Eight borehole samples (BH1–BH8) were analyzed for particle size distribution, water content, density, and plasticity characteristics, while representative samples (L2 and L5) underwent X-ray diffraction (XRD) analysis. The particle size distribution results showed that the soils are predominantly fine-grained comprising of clayey or silty materials to fine grained sand with mean grain sizes between 3.30ϕ and 6.83ϕ. Sorting values between 3.54 and 4.86ϕ classified them as very poorly sorted sediments deposited under fluctuating, low-energy coastal conditions. Water content ranged from 23.8 % to 36.9 %, density from 1.77 to 1.88 g/cm^3, and void ratios from 0.65 to 0.81, indicating moist, moderately compacted soils with high porosity. The liquid limit and plasticity index values, ranging from 37.7–58.2 % and 21.3–32.6 % respectively, revealed high plasticity and significant swelling potential. XRD results confirmed montmorillonite (41–42 %) as the dominant mineral, alongside quartz (33–39 %) and minor actinolite or albite. These properties collectively explain the soils' poor strength, high compressibility, and moisture sensitivity. The study concludes that the Lagos coastal soils are expansive and structurally unstable, requiring stabilization, effective drainage, or deep foundations to support safe and durable engineering development within the Dahomey Basin

CHAPTER ONE
INTRODUCTION

1.1 BACKGROUND OF THE STUDY:

Soil is referred to as loosely unconsolidated materials composed of mineral particles, organic matter, air and microorganisms which originate from the upper layers of rocks and organic decomposition. Problematic soils are soils which possess certain physical or chemical properties that make them unsuitable, unstable or hazardous for specific purposes without specialized management or engineering intervention.

Due to their ability to expand, collapse, disperse, undergo excessive settlement, and have a distinct lack of strength or solubility, many soils can prove to be problematic in geotechnical engineering. These characteristics may be attributed to their composition, nature of pore fluids, mineralogy or their fabric (Mohsen *et al*., 2012).

Problematic soils are found globally and pose challenges through expansive properties, structural instability and soil degradation. In Nigeria, problematic soils include structurally unstable lateritic soils in the south, expansive soils or swelling clay in the south-eastern and north-eastern parts, black cotton soils (BCS) and Sokoto soft clay shale in the north, and peaty clays in coastal areas like Lagos and Port-Harcourt. These soils are problematic due to their tendency to swell and shrink, leading to structural damage, or because of their inherent instability, which affects construction and agriculture (Bolarinwa and Ola, 2022).

Problematic soils are a recurring challenge in geotechnical engineering due to their unfavorable geomechanically and geochemical properties which render them unsuitable for construction without modification. These soils include expansive clays, collapsible sands, saline soils, and liquefiable sediments, all of which cause structural instability and increase construction and maintenance costs. Expansive soils, for example, undergo shrink–swell cycles driven by fluctuations in moisture content, which generate excessive heave pressures on foundations and pavements. Liquefiable soils, typically loose, saturated, cohesionless sands found in coastal and deltaic environments, may lose shear strength during seismic loading, leading to catastrophic infrastructure failures.

Globally, the economic implications of problematic soils are immense, with annual costs of damage to civil infrastructure reported to surpass those of natural disasters such as floods and earthquakes (Nelson and Miller, 1997; Kolay and Ramesh, 2016). In Nigeria, problematic soils are widespread, particularly within the Dahomey Basin, which underlies the Lagos coastal zone. The basin is characterized by sequences of unconsolidated sands, silts, clays, and peat that are highly susceptible to settlement, liquefaction, and other geotechnical failures. Recent studies in Lagos wetlands (Ikoyi, Badore, Okun-Ajah) reveal that loose silty sands with shear-wave velocities between 160–250 m/s and low cone penetration resistances are vulnerable to liquefaction, posing risks to roads, buildings, and bridges. Similarly, inland expansive clays with high plasticity indices and swelling potentials have been shown to induce heaving, cracking, and eventual failure of light structures.

The geochemical characteristics of these soils play a critical role in their engineering behavior. Expansive clays often contain minerals such as smectite, illite, and montmorillonite, whose layered structures promote high water absorption and swelling potential (Goodarzi *et al.,* 2016; Salimi *et al.,* 2018). Chemical compositions rich in alumina and silica further increase plasticity and compressibility, exacerbating engineering challenges. In contrast, coastal sediments of the Dahomey Basin often contain saline and organic-rich layers that weaken soil fabric and reduce shear strength, making them prone to sudden collapse or liquefaction under loading conditions.

Sedimentological and geochemical characterization offers a holistic framework for understanding and mitigating the risks associated with problematic soils. Sedimentological analysis provides insights into depositional history, grain-size distribution, and fabric, which control permeability and strength (Phanikumar *et al.,* 2021). Geochemical characterization, on the other hand, evaluates mineralogical and chemical compositions that influence reactivity, swelling, and collapsibility (Atemimi, 2020; Roy, 2013). Integrating these approaches enables geotechnical engineers to predict soil behavior accurately and to design stabilization strategies such as sand mixing, chemical additives, or drainage improvement.

In light of increasing urbanization in coastal and inland Nigeria, coupled with the rising demand for resilient infrastructure, there is a pressing need to understand the sedimentological and geochemical characteristics of problematic soils. This study, therefore, focuses on the Dahomey Basin and comparable terrains, providing an integrated assessment of soil behavior and its implications for geological and engineering infrastructure.

The findings will contribute to the development of sustainable construction practices and reduce the risks of infrastructure failures in problematic soil environments.

1.2 STATEMENT OF PROBLEM

Expansive soils, characterized by their significant volume changes in response to variations in moisture content, represent one of the most pervasive and damaging natural hazards to civil engineering infrastructure worldwide. These soils, often rich in clay minerals such as montmorillonite, illite, and kaolinite, undergo cyclic swelling and shrinking, leading to severe structural damage including foundation cracking, building collapse and road failures (Bell, 2005; Shi *et al*., 2002). The annual global economic cost attributable to expansive soil damage is estimated to be in the billions of dollars, a figure that surpasses the cumulative damage from natural disasters like floods and earthquakes in many regions (Nelson and Miller, 1997; Orazulike, 1992).

The core of the problem lies in the hydro-mechanical behavior of these soils. The swell-shrink potential is primarily governed by the clay minerals' ability to adsorb water into their lattice structure, a phenomenon explained by the diffuse double layer theory (Ikeagwuani and Nwonu, 2019). This behavior is intrinsically linked to the soil's mineralogical composition, geomorphological origin, and the climatic conditions of the region (Shi *et al.*, 2002; Rogobete and Grozav, 2013). For instance, in China, expansive soils of lacustrine origin (for example: Nanning and Pingdingshan) exhibit high montmorillonite content and severe swelling pressures, while in the semi-arid regions of Bauchi State, Nigeria, the combination of illite and montmorillonite in eluvial soils leads to widespread structural damage during seasonal rainfall cycles (Orazulike, 1992; Shi *et al.*, 2002).

Traditional soil stabilization techniques, such as mechanical compaction and the use of chemical additives like lime and cement, have been employed for decades. While often effective, these methods face significant limitations. The efficacy of traditional stabilizers can be inhibited by the presence of sulphates, leading to deleterious reactions, and their production carries a high environmental carbon footprint (Ikeagwuani and Nwonu, 2019). Furthermore, the application of these methods is often not standardized, leading to unpredictable performance in the field. The search for sustainable and efficient alternatives has led researchers to explore a vast array of materials, including industrial by-products, agricultural wastes and also fibres (Ikeagwuani and Nwonu, 2019; Alnnr and Ray, 2024). However, the results are often highly specific to the soil additive combination, lacking a generalized framework for prediction and application.

A promising yet underexplored avenue is the use of non-mechanical, simple additives like sand. Recent research has demonstrated that the systematic addition of sand can markedly improve the physical characteristics of expansive clays by reducing plasticity, altering compaction parameters, and increasing permeability and stiffness (Alnnr and Ray, 2024; Roy, 2013). However, the impact on key properties like shrinkage limit, longitudinal shrinkage and the hydraulic conductivity under varying sand percentages remains inadequately investigated. There is a pressing need for predictive models that can reliably estimate the engineering properties of sand-stabilized expansive soils based on their index properties, thereby reducing reliance on extensive and costly laboratory testing programs.

Therefore, the problem this research addresses is the lack of a standardized, sustainable and predictable methodology for stabilizing expansive soils using readily available additives like sand. The current situation is characterized by:

1. Widespread infrastructure damage caused by the inherent swell-shrink behavior of expansive soils.
2. Limitations and environmental concerns associated with traditional stabilization agents like lime and cement.
3. A fragmented understanding of the effects of sand addition, particularly on its impact on hydraulic conductivity and volumetric stability.
4. An absence of reliable empirical models to predict the final engineering properties of the stabilized soil mix based on its composition.

Consequently, there is a critical need to comprehensively investigate the efficacy of sand as a stabilizing agent, develop robust predictive equations for its performance, and establish optimal dosage guidelines to provide engineers with a cost-effective and sustainable solution for construction on expansive soils.

1.3 AIMS AND OBJECTIVES OF THE STUDY

AIM OF THE STUDY:

This research aims to undertake a comprehensive multi scale characterization of the genetically complex problematic soils of the Dahomey Basin, South West of Nigeria to decode the interplay between their depositional history, diagenetic alterations and resultant geomechanical behavior, thereby formulating a predictive framework for infrastructure risk assessment and the development of context-specific stabilization protocols.

OBJECTIVES OF THE STUDY:

The specific objectives of the study is to:

1. delineate the sedimentological architecture and provenance of the problematic soils through detailed granulometric analysis, mineralogical fingerprinting using X-Ray Diffraction (XRD) and micromorphological examination via Scanning Electron Microscopy (SEM) to establish a foundational genetic classification.
2. decipher the controlling geochemical signatures by quantifying the major and trace element geochemistry using X-Ray Fluorescence (XRF), determining the cation exchange capacity (CEC) and dominant exchangeable ions and also evaluating the pore water chemistry to identify the key parameters driving soil instability.
3. quantitatively evaluate the engineering geological properties by conducting a suite of geotechnical tests which includes Afterberg limits, free swell potential, collapse

potential and shear strength parameters, to precisely define the soil's problematic nature (expansivity, dispersivity, or collapsibility).

4. establish robust quantitative correlations between the geochemical proxies (e.g., Sodium Adsorption Ratio, presence of smectite clays) and engineering indices (e.g., Plasticity Index, swell pressure) using statistical modelling, thereby creating a predictive model for soil behavior based on its fundamental properties.
5. develop and validate genetically informed stabilization strategies by designing and testing the efficacy of chemical (e.g., lime-based additives) and mechanical (e.g., granular inclusion) treatment methods tailored to counteract the specific instability mechanisms identified, moving beyond empirical approaches to scientifically grounded solutions.

1.4 RESEARCH QUESTIONS

In order to address the issues observed and stated earlier, this study is guided by the following primary research questions.

1. What is the mineralogical composition, particularly the type and amount of clay minerals (e.g., smectite, kaolinite), of the selected soil samples from different locations in Lagos?
2. How do the basic geotechnical index properties (Afterberg Limits, particle size distribution, and free swell potential) of these soils classify them according to standard engineering systems (USCS, AASHTO)?
3. What is the relationship between the soil's chemical environment (pH, salinity, and cation exchange capacity) and its physical properties?

4. Is the observed soil behavior (e.g., cracking, heaving, and low strength) more strongly correlated with its sedimentological makeup (clay content) or its geochemical properties (e.g., presence of sodium ions)?
5. How does the seasonal high water table and coastal location of Lagos influence the expression of these problematic soil behaviors (e.g., promoting swelling or dispersion)?
6. What specific, practical recommendations can be made for construction practices and foundation design in Lagos to mitigate the risks posed by these soils?

1.5 JUSTIFICATION OF STUDY

The investigation of problematic soils in the Dahomey Basin, with particular focus on Lagos State represents a critical research imperative driven by substantial geotechnical challenges that constrain sustainable urban development. This study addresses multiple compelling justifications that merit rigorous scientific attention.

Lagos State serves as Nigeria's primary economic center, supporting extensive infrastructure networks that remain persistently vulnerable to sub-soil instability. The region's complex geological setting, characterized by expansive marine clays and alluvial deposits, generates significant engineering challenges. Recurrent infrastructure damage to building foundations, transportation networks and utility systems constitutes a substantial financial burden on municipal resources and private development. Nelson and Miller (1997) documented that economic losses from expansive soil damage frequently exceed those from natural disasters in developing regions, highlighting the critical need for improved geotechnical understanding.

Findings from this research will enable development of evidence based stabilization procedures and inform foundation design practices specific to Lagos geological conditions. The potential for utilizing local materials for soil improvement presents sustainable solutions that could significantly reduce construction costs and improve structural longevity. This approach aligns with contemporary geotechnical practice that emphasizes site-specific solutions based on detailed soil characterization.

1.6 SCOPE OF THE STUDY

The study concentrates specifically on the Nigerian sector of the Dahomey Basin, with detailed investigation of Quaternary deposits in Lagos State. Sample collection focuses on areas exhibiting pronounced soil-related infrastructure challenges, particularly those underlain by marine clay deposits and alluvial formations.

This research overs a detailed laboratory investigation through:

1. Detailed sedimentological analysis through particle size distribution and microfabric characterization
2. Mineralogical identification and quantification through X-ray diffraction analysis
3. Geochemical characterization including cation exchange capacity and exchangeable cation analysis
4. Standardized geotechnical testing of index properties and swell potential

1.7 DESCRIPTION OF THE STUDY LOCATION

The Dahomey Basin constitutes a significant cretaceous to tertiary sedimentary basin extending along the continental margin of West Africa from southeastern Ghana through Togo and Benin to southwestern Nigeria. The basin formed during the early cretaceous period following the separation of the African and South American plates, creating a typical passive margin basin structure. The Nigerian sector, particularly Lagos State, represents a critical area of the basin where complex sedimentary sequences overlie precambrian basement rocks of the West African craton fig (1.7.1). The basin's evolution involved multiple transgressive regressive cycles that deposited alternating marine and continental sediments, creating the complex stratigraphy observed today (Omatsola and Adegoke, 1981).

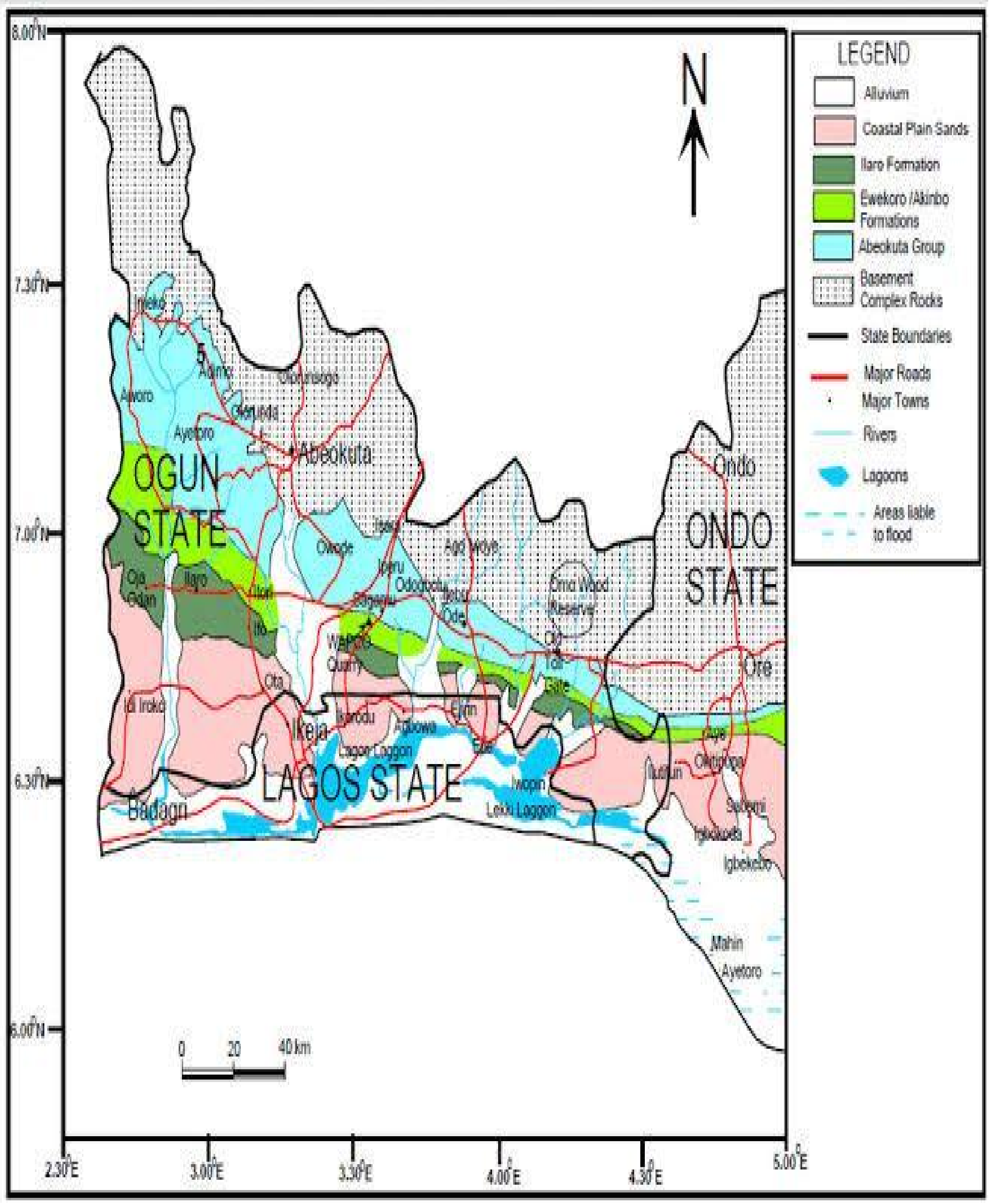

Figure 1.1: Geological map of the Dahomey Basin in the Nigerian sector and the states located in the basin (Aladejana *et al.,* 2021).

The basin's stratigraphy reveals a complex history of sedimentary deposition influenced by both marine and continental processes:

1. **Coastal Plain Sands (Benin Formation)**: Oligocene Miocene deposits consisting predominantly of poorly sorted sands with clay intercalations, representing fluvial and deltaic depositional environments
2. **Eocene Formations**: Including the Ilaro Formation (sandstones) and Akinbo Formation (clay sand sequences), deposited in transitional marine continental environments
3. **Paleocene Carbonates**: Ewekoro Formation limestone deposits representing shallow marine conditions
4. **Cretaceous Basal Sands**: Abeokuta Formation comprising coarse-grained sediments deposited during initial basin formation
5. **Quaternary Deposits**: This basin contains extensive quaternary deposits consisting of alluvial and coastal plain sediments derived from weathering and transport of older formations, marine clays and silt deposits associated with historical sea level fluctuations, beach sands and lagoon deposits reflecting contemporary coastal processes.

CHAPTER TWO

LITERATURE REVIEW

2.1 GEOLOGICAL SETTING

The long term stability and safety of civil engineering structures which range from buildings and bridges to roads and pipelines are primarily dependent on the performance of the ground upon which they are built. This relationship between foundation soil behaviour and structural integrity is an important part of geotechnical engineering (Bowles, 1996). In many regions of the world, the natural soil and rock conditions present significant obstacles to construction. This challenge presents itself most prevalently in the Dahomey Basin of Southwestern Nigeria. Here, engineers and developers consistently encounter a series of problematic soils that complicate development. These include loose, water saturated sands which are prone to liquefaction during seismic events, thick layers of highly compressible organic peat and soft clays as well as expansive clays that dramatically shrink and swell with seasonal changes in moisture content. The prevalent presence of these difficult materials creates a formidable and persistent barrier to sustainable and resilient urban growth, a concern documented by researchers over several decades, beginning with foundational work by Ola (1983) and further elaborated by Adeyemi and Oyediran (2011).

The consequences of building on these challenging geotechnical conditions can be seen visibly in the urban landscape across major cities within the basin, such as Lagos, Abeokuta and Ibadan. A common and distressing sight includes residential and commercial buildings marred by severe, often diagonal cracks in their walls and foundations, a sign of differential settlement where parts of a structure sink at different rates. Other frequent observations include the noticeable tilting of structures and the recurrent, premature failure of road pavements, which exhibit extensive cracking, potholing and undulations often shortly after construction (Oloruntola *et al*., 2018; Oladunjoye *et al*., 2024).

Addressing this cycle of infrastructure deterioration requires moving beyond superficial repairs and towards a foundational, scientific comprehension of the intrinsic properties that govern the behaviour of these soils. This understanding must be rooted in a detailed investigation of both the sedimentological and geochemical characteristics of the materials. Sedimentology provides crucial clues to the soil's origin and history, it reveals the source of the sediments (the parent rock), how they were transported (by wind, water, or ice) and the specific ancient environment in which they were finally deposited such as a river floodplain, a delta, a lagoon or a deep marine setting (Boggs, 2014). These depositional processes fundamentally determine the soil's texture, the size, shape and arrangement of its particles and its internal structure, which directly governs its engineering properties, including shear strength, stiffness and permeability (Das and Sobhan, 2018).

Geochemical investigation reveals the critical mineralogical composition of the soil, particularly the clay fraction. The presence of certain swelling clay minerals (like smectite or montmorillonite) is a primary driver of expansive soil behaviour as these minerals can absorb large quantities of water, leading to a significant increase in volume. Conversely, upon drying, they shrink, creating cycles of movement that wreak havoc on lightweight structures (Chen, 2012). Furthermore, the soil's ionic exchange capacity, a measure of its chemical reactivity and its ability to retain and swap charged particles affects its long term chemical stability and its interaction with construction materials like concrete and steel. However, studying these properties in isolation provides an incomplete picture. The true nature of these problematic soils can only be deciphered when their micro scale characteristics are put into context within the macro scale geological history of the Dahomey Basin. As established by early geological surveys (Jones and Hockey, 1964; Omatsola and Adegoke, 1981), the properties measured today are a direct result of the parent rocks from which the sediments were eroded, the tectonic events that shaped the basin, the ancient environments in which the strata were laid down millions of years ago and the post depositional chemical and physical alterations (diagenesis) they have undergone.

This literature review aims to synthesize existing knowledge to build a detailed geological and geotechnical framework for understanding the problematic soils of the Dahomey Basin. The first section will delve into the provincial geology of the basin, outlining its tectonic setting specifically, how it formed as a result of the Mesozoic breakup of the supercontinent Gondwana and the subsequent opening of the Atlantic Ocean, which created a series of linked sedimentary basins along the West African margin (Burke, 1972). This will be followed by a detailed examination of the basin's stratigraphy, which is the sequence of distinct rock and sediment layers, such as the Abeokuta Formation, that have accumulated over geological time. Each stratigraphic unit tells a story of a different depositional environment, from continental alluvial sands to shallow marine clays, which directly correlates to the types and variability of soils found at the surface today. The structural geology, including faults and folds that have deformed the strata, will also be discussed, as these features can create zones of weakness, influence groundwater flow pathways, and ultimately impact slope stability and soil behaviour.

The second section will survey key scientific works, from the foundational studies to contemporary research that have characterized the engineering behaviour of the basin's soils. This review will focus on the specific methodologies employed in both field and laboratory settings to assess critical geotechnical parameters such as compressibility, shear strength, permeability, plasticity, and swell potential. By comparing and contrasting findings from different locations and different stratigraphic units within the basin, patterns emerge that link soil behaviour to its geological origin, allowing for better predictive models of soil performance.

Finally, this chapter will integrate the geological context with the geotechnical data to discuss the profound practical implications for both geoscientists and civil engineers. For the geological community, this synthesis demonstrates the direct application of pure geological research such as paleo-environmental reconstruction and stratigraphic analysis to solving pressing societal problems. For the engineering community, it underscores the non-negotiable necessity of moving beyond standardized designs and towards thorough, geologically-informed site investigations. It is the central argument of this research that only through such an interdisciplinary approach can the persistent and costly challenge of infrastructure failure in Southwestern Nigeria be effectively mitigated. By interpreting the fundamental reasons why the soils behave as they do, this work justifies the critical need for the detailed investigation that follows and provides a scientific basis for developing locally appropriate and sustainable engineering solutions.

2.2 PROVINCIAL GEOLOGY OF THE DAHOMEY BASIN

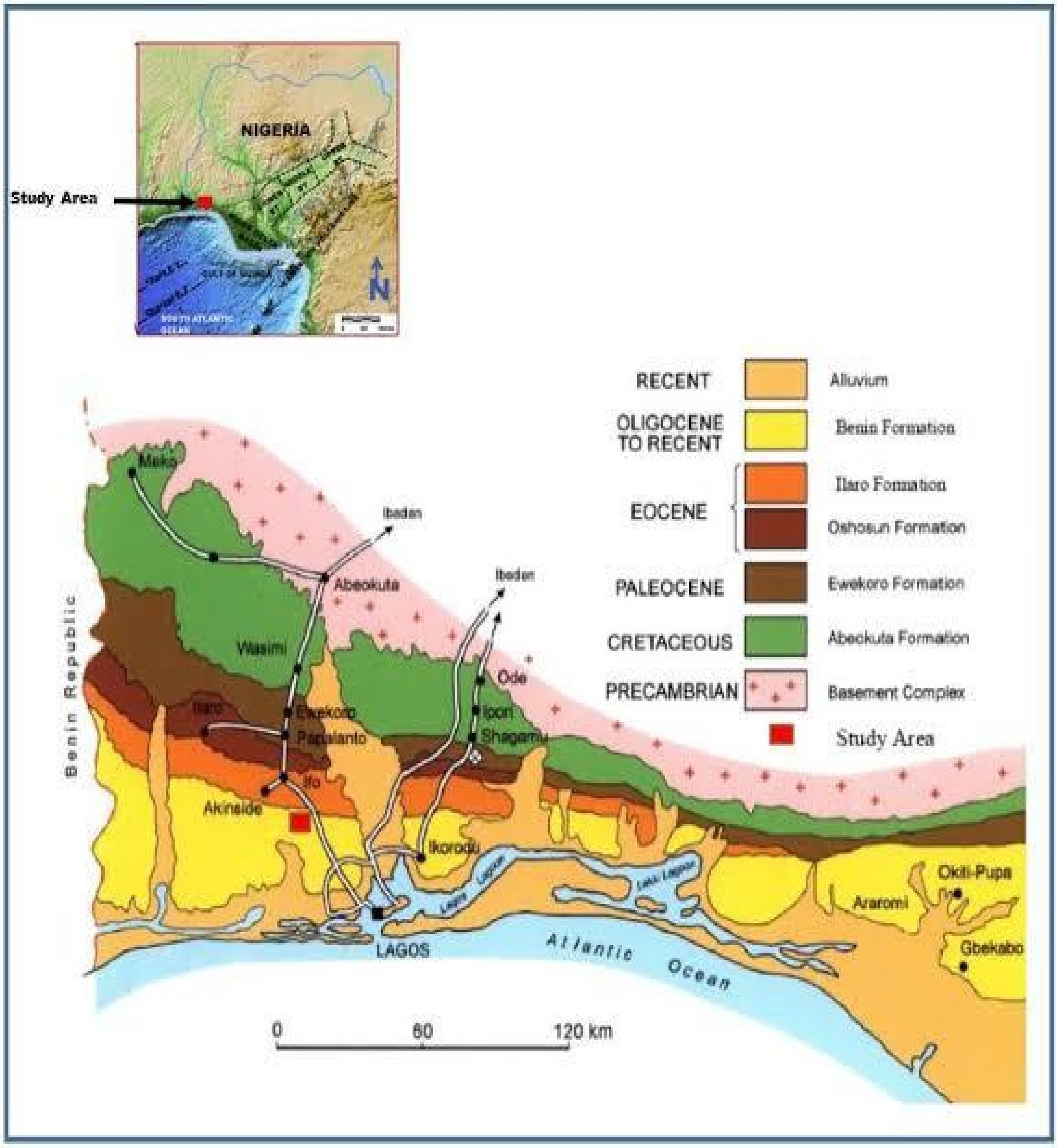

Figure 2.1: Showing study location and geological lithological units of the Dahomey basin (Bakere *et al.,* 2019).

The Dahomey Basin is a significant coastal sedimentary basin situated on the continental margin of the Gulf of Guinea, West Africa. It is one of a series of peri-cratonic basins that formed during the Mesozoic breakup of the Gondwana supercontinent. Geographically, the basin extends from southeastern Ghana (where it is referred to as the Keta Basin) through the coastal sectors of Togo and the Republic of Benin, into Southwestern Nigeria, where its eastern boundary is demarcated by the Niger Delta Basin (Omatsola and Adegoke, 1981; Obaje, 2009).

The basin's geological architecture comprises a thick sequence of Mesozoic to Cenozoic sedimentary rocks that unconformable overlie the Precambrian Basement Complex, which consists of igneous and metamorphic rocks such as granites, gneisses and magnetite (Rahaman, 1976; Jones and Hockey, 1964). The sedimentary fill, which can reach several kilometers in thickness, records a complex history of terrestrial and marine depositional environments. The most surficial and economically critical unit is the Coastal Plain Sands (Benin Formation), a vast expanse of largely unconsolidated sediments that forms the terrain for major urban and infrastructure development and is the primary host for the problematic soils that are the focus of this study (Adeyemi and Oyediran, 2011; Oloruntola *et al.*, 2018).

2.3 TECTONIC SETTING AND EVOLUTIONARY HISTORY

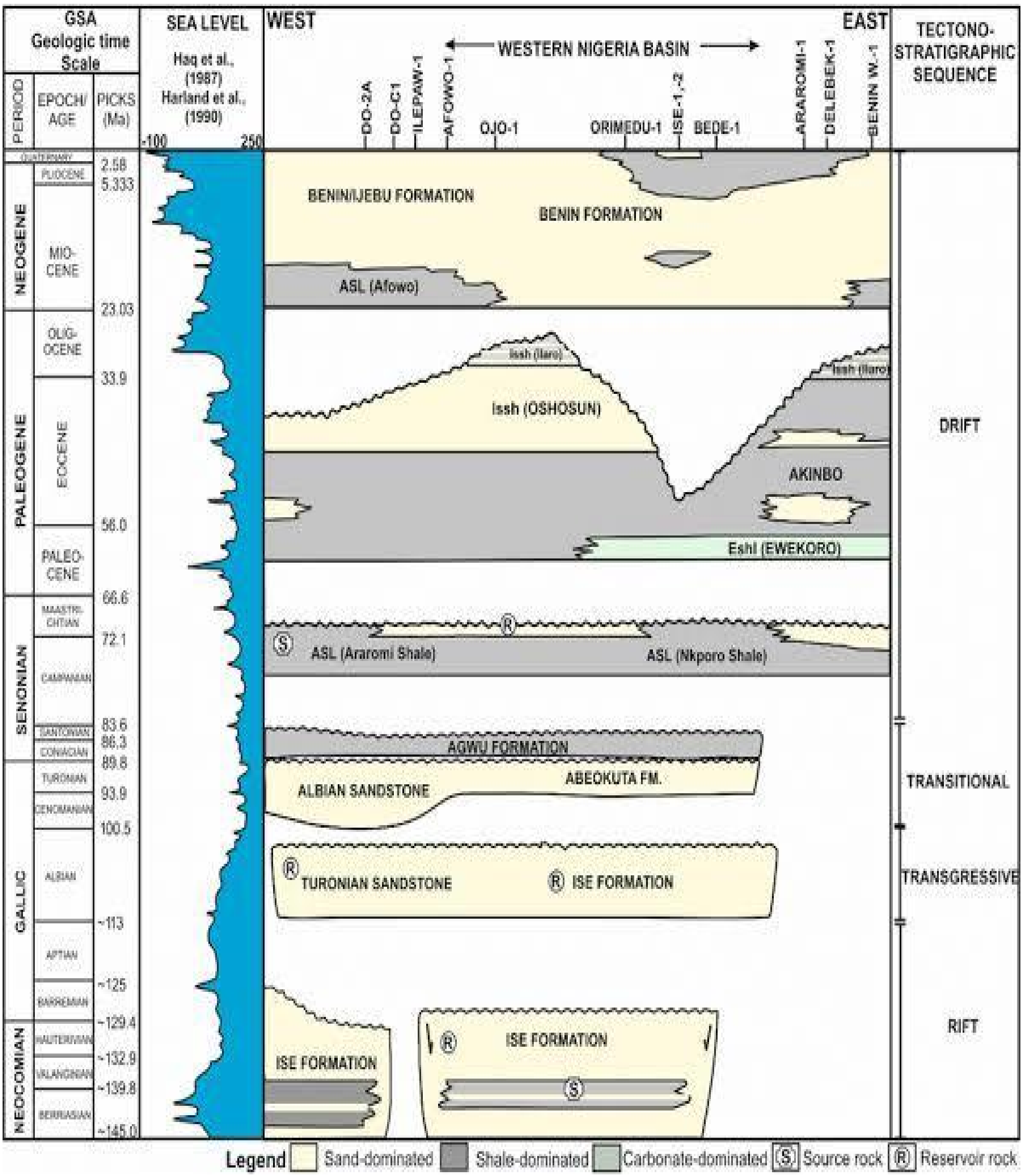

Figure 2.2: Showing the Tectonostratographic sequence and well as the evolutionary timescale of the Dahomey basin (Mosuro *et al.,* 2021).

The tectonic evolution of the Dahomey Basin (Fig 2.2) is a classic narrative of continental rifling and passive margin development, central to understanding its present day geology. This evolution can be chronologically segmented into three primary phases:

1. **Pre-Rift Phase (Pre-jurassic)**: The basin area was part of the stable African craton, underlain by the Precambrian Basement Complex.

2**. Syn-Rift Phase (Neocomian - Aptian)**: This phase initiated in the Early Cretaceous, driven by the extensional forces associated with the disintegration of Gondwana and the subsequent opening of the South Atlantic Ocean. Crustal extension led to the formation of NE-SW trending rift systems, consisting of a series of horsts and grabens (Burke *et al*., 1971). These rift valleys became the initial depocenters, accumulating continental fluvial and lacustrine sediments of the Abeokuta Formation (Omatsola and Adegoke, 1981). This phase was characterized by block faulting and significant crustal thinning.

3. **Post-Rift (Drift) Phase (Albian - Recent)**: Following the continental rupture and the onset of seafloor spreading, the tectonic regime transitioned to a passive margin. The primary driver of subsidence shifted from mechanical extension to thermal subsidence, where the stretched and thinned lithosphere cooled and contracted (McKenzie, 1978). This led to a major marine transgression from the south, flooding the basin and depositing the shallow marine carbonates of the Ewekoro Formation and the overlying marine shales of the Akinbo and Oshosun Formations (Agagu, 1985). The continued subsidence throughout the Tertiary period allowed for the pro-gradation of the extensive deltaic and alluvial sands of the Ilaro Formation and the Coastal Plain Sands (Obaje, 2009).

A crucial tectonic element influencing the basin is its proximity to major oceanic fracture zones, particularly the Romanche and Chain Fracture Zones. These transform faults, which offset the Mid-Atlantic Ridge, extend into the continental crust and have been implicated in the transmission of tectonic stresses (Ajakaiye *et al*., 1987). This relationship offers a plausible mechanism for the recorded intraplate seismicity in Southwestern Nigeria (Akpan *et al*., 2014), a factor that critically amplifies the liquefaction hazard of the basin's loose sandy deposits (Oladunjoye *et al*., 2024).

2.4 STRATIGRAPHY OF THE DAHOMEY BASIN

The stratigraphic succession of the Dahomey Basin provides a chronological record of its tectonic and depositional history. The sequence, from the oldest to the youngest, is as follows:

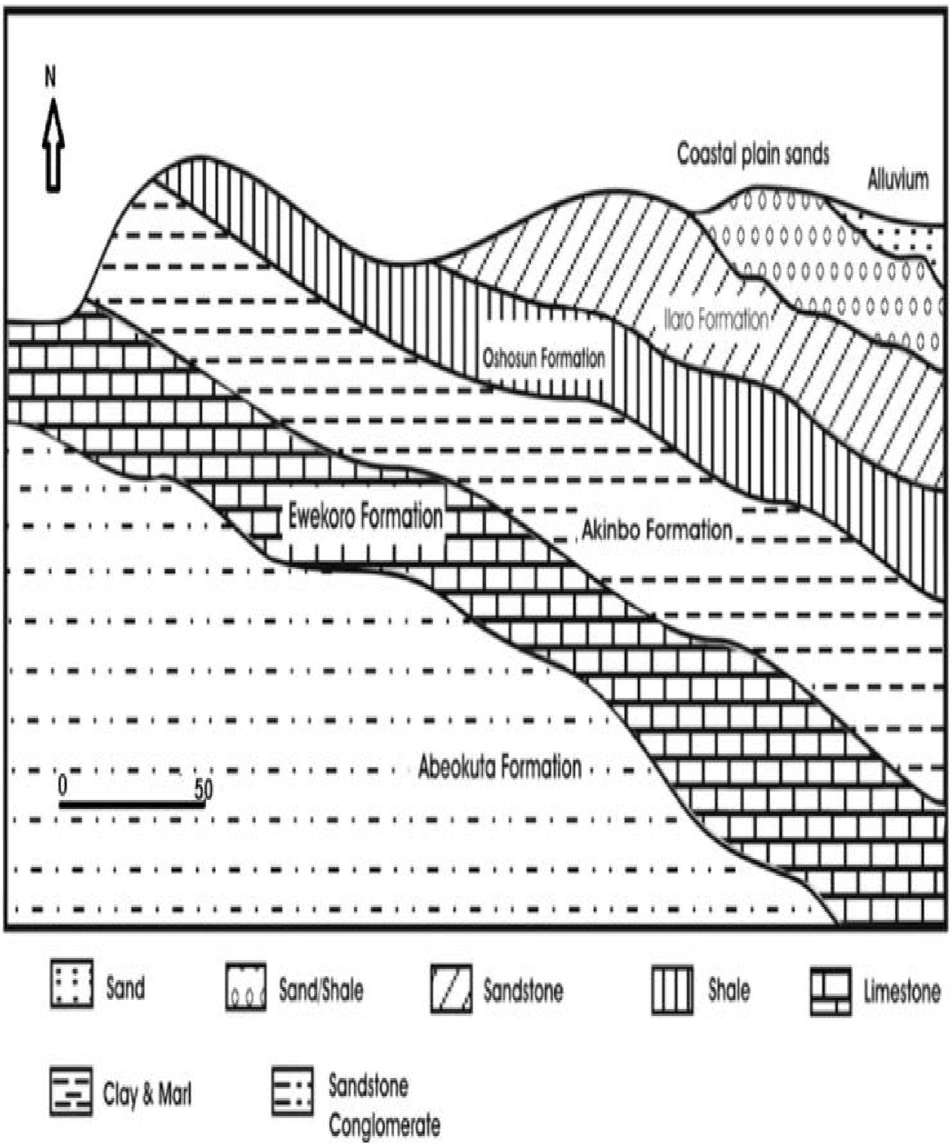

Figure 2.3: Showing the stratigraphic configuration of the Dahomey basin (Omatsola and Adegoke, 1981)

1 **Abeokuta Formation (Neocomian - Albian)**: This is the basal sedimentary unit, deposited in the syn-rift grabens. It consists of coarse-grained, poorly sorted sandstones, conglomerates and variegated kaolinitic clays. Its composition indicates a high-energy fluvial (river) to deltaic depositional environment (Omatsola and Adegoke, 1981).

2 **Ewekoro Formation (Middle Cenomanian)**: Representing the peak of the marine transgression, this formation is a prominent, fossiliferous limestone unit deposited in a shallow, open marine environment. It is a major economic resource for cement production (Jones and Hockey, 1964).

3 **Akinbo Formation (Late Cenomanian)**: Conformably overlying the Ewekoro limestone, this unit consists of dark-grey, fossiliferous shales and clays, indicating a continuation of deep marine, anoxic conditions (Agagu, 1985).

4 **Oshosun Formation (Late Campanian - Maastrichtian)**: This formation comprises predominantly greenish-grey, phosphatic and kaolinitic clays and shales, often with intercalations of sandstone and limestone. Its distinctive geochemistry is critical as it weathers to form clay-rich soils that can be highly expansive (Ogundana and Talabi, 2011).

5 **Ilaro Formation (Maastrichtian Paleocene)**: Marking a return to terrigenous (land-derived) sedimentation, this formation consists of massive, poorly sorted, cross-bedded sandstones with minor shale interbeds. It is interpreted as a deltaic front deposit, signifying a regressive phase (Obaje, 2009).

6 **Coastal Plain Sand (Eocene - Recent)**: This is also known as Benin formation. It is the most surficial, widespread and economically relevant formation which consists of several hundred meters of unconsolidated, fine to coarse grained sands, frequently interbedded with lenses of clay, silt and, crucially, thick deposits of organic peat (Oloruntola *et al.,* 2018; Fatoba and Olorunfemi, 2004). The unconsolidated nature and variable composition of this

formation are the direct source of the most severe geotechnical challenges in the region, including liquefaction, excessive compressibility and low bearing capacity.

2.5. STRUCTURAL GEOLOGY OF THE DAHOMEY BASIN

The structural architecture of the Dahomey Basin is a complex pattern interlinked through its protracted tectonic history, spanning from the Mesozoic rifting to recent neotectonic influences. This framework is not merely of academic interest; it fundamentally controls the distribution of geological units, influences geomorphic expression (topography), governs groundwater flow and contributes to the geotechnical vulnerability of the region.

2.5.1 Major Structural Features and Trends:

The primary structural grain of the basin was established during the syn-rift phase of the Early Cretaceous. This phase was characterized by NE-SW to NNE-SSW trending normal faults, which are parallel to the continental margin of the Gulf of Guinea (Omatsola and Adegoke, 1981; Ola *et al*., 2015). These are typically listric faults that flatten with depth, creating a series of horsts (uplifted blocks) and grabens (down-dropped blocks). The main depocenters of the initial Abeokuta Formation were controlled by these grabens (Olatinsu *et al*., 2009).

A significant feature often associated with the basin's margin is the Ifewara-Zungeru Fault system, a major NNE-SSW trending shear zone in the Basement Complex. This deep-seated crustal weakness is believed to have influenced the location and orientation of the basin-bounding faults (Adetoyinbo and Ogunyele, 2019). The continued activity along these and related structures into the Tertiary period influenced the deposition of the younger Coastal Plain Sands, with thickness variations often correlating with underlying fault blocks.

2.5.2 Folding and Later Deformation:

While extensional faulting dominates, subsequent tectonic events have imposed compressional and transgressional stresses. In the eastern part of the basin, closer to the Niger Delta hinge line, gentle E-W to NW-SE trending folds have been identified within the Cretaceous strata (Agagu, 1985). These folds are likely the result of the same Santonian tectonic event that caused the folding and uplift of the Abakaliki Anticlinorium in the adjacent Benue Trough. This event represents a period of regional compression that inverted previous rift structures.

Furthermore, the influence of the nearby Chain and Romanche Fracture Zones cannot be overstated. These major oceanic transform faults have transmitted transgressional and trans-tensional stresses into the continental crust, potentially reactivating ancient fault lines in a strike-slip manner. This mechanism is the leading hypothesis for the recorded low-level seismicity in Southwestern Nigeria (Ajakaiye *et al.*, 1987; Akpan *et al.*, 2014), which has direct implications for liquefaction triggering.

2.6 TOPOGRAPHIC EXPRESSION AND GEOMORPHOLOGY

The structural framework is directly expressed in the topography and geomorphology of the Dahomey Basin:

2.6.1. The Eastern Escarpment and Idanre Hills:

The NE-SW trending fault systems have created a distinct, though subdued, escarpment that separates the sedimentary terrain of the basin from the Precambrian Basement Complex to the north and east. The Idanre Hills represent a spectacular geomorphic feature; they are inselbergs (monadnocks) of Basement Complex rocks that were likely uplifted and exposed due to faulting and subsequent erosion of the surrounding softer sedimentary rocks (Burke and Dessen, 1994). This topography directly influences drainage patterns and sediment transport into the basin.

2.6.2. Coastal Plains and Lagoons:

The vast, low-lying topography of the Coastal Plain Sands is a direct result of the post-rift thermal subsidence that created accommodation space for thick, flat-lying sedimentary accumulations. The Lagos Lagoon and other coastal water bodies are themselves structural features, often occupying depressions controlled by underlying fault trends. The poor drainage characteristic of these low-lying areas is a primary factor in the high saturation of near-surface soils, a critical precondition for both liquefaction and the formation of organic peat (Oloruntola *et al*., 2018).

2.6.3. Drainage Patterns:

The drainage network of Southwestern Nigeria shows strong structural control. Major rivers often follow fault lines or the trends of weaker sedimentary strata. The alignment of certain river courses along NE-SW directions is a clear testament to this structural guidance (Olatinsu *et al*., 2009). This, in turn, controls the modern distribution of alluvial deposits and influences areas of peat formation.

2.7. RECENT WORKS ON PROBLEMATIC SOILS IN THE DAHOMEY BASIN

Recent research has significantly advanced beyond general description, employing integrated, multi-disciplinary approaches to quantitatively characterize soil hazards, map their spatial distribution and develop robust risk assessment models.

2.7.1. Liquefaction Susceptibility of Loose Saturated Sands:

The coastal and wetland areas of Lagos, underlain by the Coastal Plain Sands, have been a focal point for liquefaction studies. Oladunjoye *et al.*, (2024) conducted a pioneering integrated study in Ikoyi, Badore and Okun-Ajah, combining Multichannel Analysis of Surface Waves (MASW), Cone Penetration Tests (CPT) and Standard Penetration Tests (SPT). Their research quantified the dangerous state of the sands. MASW-derived Shear Wave Velocity (V_s) values for the critical layers ranged from 160-250 m/s, firmly within the range indicative of highly liquefiable soils. CPT measurements recorded very low cone tip resistance (q_e) values (often < 30 kg/cm^2), confirming low density and strength. Most critically, the calculated Factor of Safety (FS) against liquefaction was less than 1.0 at depths between 2.5m and 18m across the study sites. The Liquefaction Potential Index (LPI), which integrates the thickness and depth of vulnerable layers, classified these areas as having "High" to "Very High" risk severity. This work provides a quantitative, rather than qualitative, assessment of liquefaction hazard. It serves as a clear warning for infrastructure development and a model for similar assessments elsewhere in the basin. It explicitly links the geological setting (coastal, saturated sands) to a specific, catastrophic engineering failure mode.

2.7.2 Spatial Variability and Hazards of Compressible Peats and Clays:

The work of Oloruntola *et al*., (2018) in the Kosofe area of Lagos masterfully demonstrated the application of integrating 48 geotechnical boreholes with 9 Vertical Electrical Sounding (VES) points to map the high spatial variability of compressible soils. The study revealed a complex subsurface where peat layers reached a maximum thickness of 18.25 meters and clay units varied dramatically from 2.50 m to 28.50 m. They established a clear correlation between peat accumulation and proximity to streams, highlighting palaeo-depositional control. They also defined resistivity ranges for these materials: <20 Ωm for peat and 20–65 Ωm for clay, providing a valuable tool for preliminary geophysical screening. In addition, the extreme lateral and vertical heterogeneity of these weak layers over very short distances. This variability makes traditional site investigation based on sparse boreholes, highly unreliable and risky. It forcefully argues for the use of geophysical methods to interpolate between boreholes and create a continuous 3D understanding of the subsurface before design begins.

2.7.3 Geochemical and Mineralogical Controls on Expansive Soils:

While located in the Bauchi Basin, the study by Orazulike (1992) on expansive soils is a perfect analogue for understanding the geochemical underpinnings of clay related problems. His work chemically analyzed soils causing severe structural damage. The problematic soils were rich in expansive clay minerals, specifically montmorillonite (60-75%) and illite (20-35%), with a lower content of kaolinite. These smectite-group minerals have a high cation exchange capacity (CEC) and can absorb large volumes of water, leading to significant swelling pressure. This was reflected in a high Plasticity Index (PI > 13.4%), a direct measure of expansive potential. This study underscores that the engineering problem is not merely the presence of "clay," but its specific mineralogy. This understanding is crucial for predicting soil behaviour and selecting appropriate mitigation strategies, such as chemical stabilization with lime or phosphate additives to flocculate the clay particles and reduce their plasticity, as suggested by Orazulike (1992).

Other works have contributed to the broader understanding. Adeyemi and Oyediran (2011) detailed the geotechnical properties of lateritic soils, common in the basin, linking their engineering behaviour to their formation processes. Jegede (1998) provided an extensive overview of the engineering geological characteristics of the Coastal Plain Sands, highlighting issues of erosion and low shear strength. Ola (1983) established the fundamental link between the sedimentary history of Nigerian soils and their resulting geotechnical properties.

This literature unequivocally establishes that the Dahomey Basin is a geologically complex region where an intricate history of tectonism and sedimentation has resulted in a substrate containing highly problematic soils. The recent works reviewed herein, particularly those by Oladunjoye *et al*. (2024) and Oloruntola *et al.* (2018), represent a significant leap forward. They employ integrated, quantitative methodologies to move from simple soil description to sophisticated hazard mapping and risk quantification. They confirm that the risks from liquefaction induced collapse to gradual settlement induced cracking are severe, spatially variable and directly attributable to the geological environment.

This extensive review underscores the absolute necessity for comprehensive, site specific geotechnical and geophysical investigations as the non-negotiable foundation for all engineering projects in Southwestern Nigeria. It is within this critical context that the present study on the sedimentological and geochemical characterization of problematic soils in the Dahomey Basin is positioned, aiming to contribute further data and insight to this vital field of study and practice.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

Apparatus / Equipment

i. Hand auger
ii. Core cutter
iii. Shelby tube sampler
iv. GPS device
v. Thermometer
vi. Stainless steel spatula
vii. Measuring tape
viii. Labeling materials
ix. Polythene sample bags
x. Sealing wax
xi. Field notebook
xii. Oven (up to 110°C)
xiii. Mechanical sieve shaker
xiv. Set of standard sieves (2.00 mm–0.063 mm)
xv. Mortar and pestle (agate or porcelain)
xvi. Analytical balance (0.001 g precision)
xvii. Desiccator
xviii. Drying trays
xix. Glass beakers
xx. Sample trays
xxi. Mechanical stirrer
xxii. Hydrometer
xxiii. Graduated cylinders (50 mL and 1000 mL)
xxiv. Pipettes
xxv. Funnels
xxvi. Pycnometer
xxvii. Polarizing microscope

xxviii. Scanning Electron Microscope (SEM)
xxix. Epoxy resin
xxx. Glass slides
xxxi. X-ray Diffractometer (XRD)
xxxii. Muffle furnace (1000°C capacity)
xxxiii. Centrifuge
xxxiv. Mechanical shaker
xxxv. Direct shear box apparatus
xxxvi. Stopwatch

Reagents / Chemicals

i. Sodium hexametaphosphate (Calgon)
ii. Ammonium acetate (1 M, pH 7)
iii. Potassium chloride (1 M KCl)
iv. Ethanol (absolute)
v. Lithium tetraborate flux
vi. Ethylene glycol
vii. Nitric acid (10%)
viii. Distilled water
ix. Deionized water
x. Kerosene
xi. Ammonium solution (NH_4^+ source)

3.2 Methodology

3.2.1 Study Area

The study locations lie between 6^{0} 26^{I} N – 6^{0} 29^{I} N to 3^{0} 25^{I} E – 3^{0} 29^{I} E in the Dahomey Basin, Nigeria

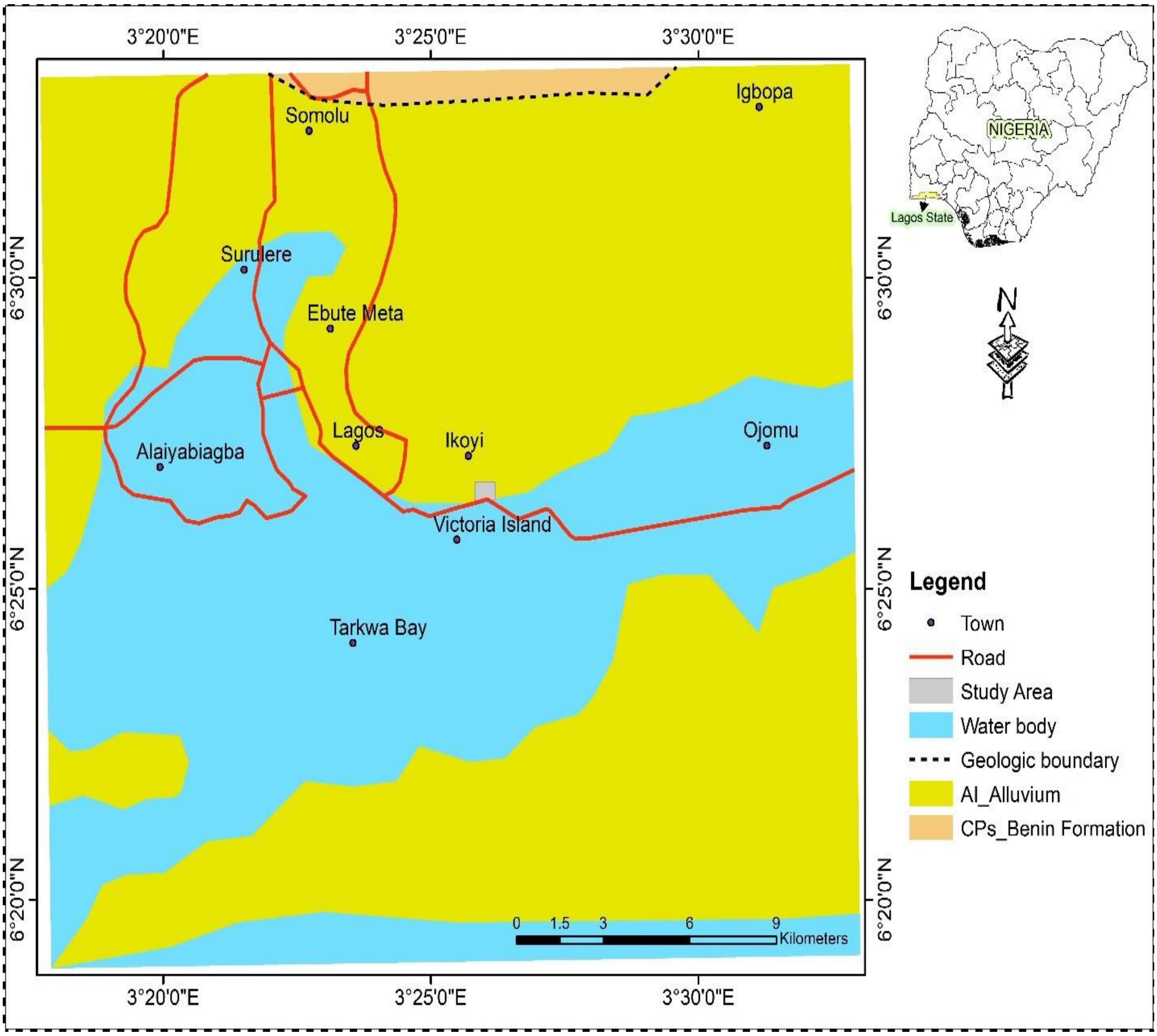

Figure 3.1: Map showing the study area of the Coastal Regions of Victoria Island in Lagos State, Nigeria.

3.2.2 Fieldwork and Sampling Procedure

Soil sampling was conducted at five locations in the Lagos segment of the Dahomey Basin — Ikoyi, Badore, Lekki, Ajah, and Epe — based on evidence of structural failures, poor drainage, and visible foundation cracks that indicated problematic soil behavior. At each site, a test pit of 1.5–3.0 m depth or a borehole up to 5.0 m was excavated using a hand auger and light drilling rig. The soil profiles were logged at 0.1 m intervals, noting color, texture, plasticity, and moisture. Both disturbed and undisturbed samples were collected. Disturbed samples were taken at 0.5 m intervals using clean augers, while undisturbed specimens were extracted with thin-walled Shelby tubes for strength and compressibility testing.

Each sample was packed in airtight, labeled polythene bags to preserve natural moisture, showing site code, depth, and date. Approximately 1 kg of soil was collected per depth for sedimentological and geochemical tests, and undisturbed samples were sealed with wax at both ends. The average field temperature during collection was 29 ± 2°C, with groundwater levels observed between 0.8 and 2.4 m. Samples were transported to the laboratory within 48 hours of collection.

3.2.3 Sample Preparation

In the laboratory, soil samples were air-dried at 27°C for 72 hours to prevent alteration of clay minerals. Dried soils were gently crushed with a wooden mallet to avoid particle breakage, and organic materials, stones, and roots were removed manually. The dried samples were sieved through a 2.00 mm mesh to obtain the fine fraction for testing. Subsamples were divided into three categories: one portion for sedimentological analysis, one for geochemical characterization, and one for geotechnical testing. For X-ray analyses, a representative portion was pulverized to pass through a 75 μm mesh using an agate mortar and pestle to obtain a homogeneous powder.

3.2.4 Sedimentological Analysis

Water content (natural moisture content)

Natural water content was determined by oven drying in accordance with ASTM D2216. Approximately 50 g of the field sample was placed into a pre-weighed aluminium dish and the wet mass (Ww) was recorded to 0.001 g on a calibrated analytical balance (±0.001 g). The dish and sample were dried in a convection oven at 105°C until constant mass was reached (typically 16–24 hours). After cooling in a desiccator the dry mass (Wd) was recorded. Water content was calculated as $w= \frac{Ww-Wd}{Wd} \times 100\%$. Each test was run in duplicate and the mean value was reported.

Bulk density (dry density)

Bulk density (ρb) was measured using the core cutter method on undisturbed samples. A cylindrical core of known volume (100 cm^3) was trimmed flush, weighed wet to obtain wet mass, then oven-dried at 105°C to constant weight and re-weighed to get the dry mass. Dry density was computed as $\rho b= \frac{Mdry}{Vcore}$ and expressed in g/cm^3. Where undisturbed core samples were not available, compacted laboratory samples of known mould volume were used following the same drying procedure. All mass measurements used the same calibrated analytical balance.

Specific gravity (particle density, Gs)

Specific gravity of solids (G_s) was determined by the pycnometer method following ASTM D854. About 10 g of oven-dried (<40°C) fine soil was used for each run. The dry soil mass was recorded, then placed in a 100 mL pycnometer. Deionized water at 20°C was added, the assembly was degassed by gentle vacuum and sonication to remove entrapped air, and the pycnometer volume was determined. The pycnometer was re-weighed and Gs was calculated using the standard pycnometer equation. Each sample was measured in duplicate and the mean value reported to two decimal places.

Void ratio (e_0)

Void ratio was calculated from the measured dry density (ρb) and specific gravity (Gs) using the relationship $\rho_b = \frac{Gs\rho w}{1+e}$ where ρ_w is the density of water taken as 1.00 g/cm^3 at the test temperature. Rearranged, the initial void ratio e_0 was computed as $e_0 = \frac{Gs\rho w}{1+e} - 1$. Values were reported to two decimal places. The same G_s and ρ_b values used in the table produced the void ratios quoted.

Liquid limit (LL)

Liquid limits were obtained by the cone penetrometer method according to ASTM D4318 (cone penetrometer option). Representative samples passing a 0.425 mm sieve were mixed with distilled water to produce a homogeneous paste. Approximately 100 g portions were placed under a 30° cone penetrometer fitted with an 80 g cone. Penetration readings were taken at multiple water contents to construct a flow curve. The liquid limit was taken as the water content corresponding to 20 mm penetration. Each sample was tested at least twice and the LL reported was the average of the consistent runs.

Plastic limit (PL)

Plastic limits were determined by rolling threads in accordance with ASTM D4318. About 10 g of soil passing the 0.425 mm sieve was moistened and rolled on a glass plate until the thread crumbled at 3.2 mm diameter. The soil from the crumbled threads was collected, oven-dried at 105°C and weighed to determine water content at the plastic limit. Tests were repeated twice and the mean PL recorded.

Plasticity index (PI)

Plasticity index was calculated as the difference between liquid and plastic limits: $PI = LL - PL$.

Particle Size Distribution

This Standard Operating Procedure (SOP) is based on ASTMD 422-63 Standard Test Method for Particle Size Analysis of Soils. This SOP covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes coarser than 0.063mm is determined by sieving, while the distribution of particle sizes finer than 0.063mm is determined by a sedimentation process using a hydrometer to secure the necessary data

The sample was oven dried at a temperature of 105°C and a representative sample was taken for category A and B below

A. Sieve Analysis (for coarse-grained soils): The sample was oven-dried and passed through a stack of standard sieves ranging from 0.063-4mm, the retained on each sieve was weighed and recorded.

B. Hydrometer Analysis (for fine-grained soils): In accordance with standard sedimentological procedures, particles of silt and clay were determined in a 1000ml cylinder containing the sample and distilled water with the use of dispersing agent (sodium hezametaphosephate), measurement of density suspension over time was taken using hydrometer and particle size was calculated using sedimentation theory

3.2.5 Geochemical Analysis

X-Ray Diffraction (XRD) Analysis

The mineralogical composition of the soils was determined using an X'Pert Pro X-ray diffractometer with Cu-Kα radiation ($\lambda = 1.5406$ Å) operating at 40 kV and 30 mA. Samples were scanned from 2° to 40° 2θ at 1° per minute. The <2 μm clay fraction was separated by sedimentation and mounted on glass slides as oriented aggregates. Each slide was scanned in three states — air-dried, glycolated (exposed to ethylene glycol vapor for 24 hours), and heated to 300°C — to distinguish smectite, illite, and kaolinite. Diffraction peaks were identified using the JCPDS database.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Particle Size Distribution (PSD) Analysis

The particle size distribution data presented in Table 4.1 showed clear variation in grain-size composition among the eight borehole samples (BH1–BH8) obtained from different locations within the Dahomey Basin, Lagos. The statistical parameters derived from the Folk and Ward (1957) method mean grain size, sorting (standard deviation), skewness, and kurtosis provided insight into the depositional environment, sediment maturity, and textural character of the soils.

Table 4.1: *Statistical Parameters of Particle Size Distribution of Soil Samples from the Dahomey Basin (Lagos State)*

	MEAN	SD	SKEWNESS	KURTOSIS
BH 1	4.83	4.53	-0.38	0.66
BH 2	3.3	5.2	-0.04	0.50
BH 3	5.57	3.84	-0.37	0.63
BH 4	6.83	2.31	-0.10	0.93
BH 5	5.54	4.17	-0.39	0.56
BH 6	5.53	4.05	-0.39	0.61
BH 7	4.1	3.77	-0.17	0.70
BH 8	4.43	4.00	-0.27	0.64

Across all boreholes, the results indicated dominance of fine-grained sediments, mostly within the silt and very fine sand range (mean grain size between 3.30ϕ and 6.83ϕ, equivalent to 0.1–0.009 mm). This texture is typical of low-energy depositional environments, such as floodplains, lagoons, and estuarine plains, which characterize much of the Lagos segment of the Dahomey Basin. The soils' fine texture directly influences their water retention, drainage behavior, and engineering performance.

The mean grain size values varied between 3.30ϕ (BH2) and 6.83ϕ (BH4), corresponding to fine sand and silt, respectively. From table 4.1, Boreholes BH1, BH3, BH4, BH5, BH6, BH7, and BH8 all had mean sizes above 4.0ϕ, confirming a predominance of silt-grade material. BH2, with a mean of 3.30ϕ, contained more fine sand, suggesting slightly higher energy or localized reworking.

The variation in mean size indicated spatial textural heterogeneity, which may result from alternating depositional regimes for instance, fluvial inputs alternating with marine or lagoonal sedimentation. Such alternations are common in the coastal plain sands and alluvial–marine clays of Lagos. From an engineering standpoint, the fine-grained nature of most samples suggests low permeability, high compressibility, and slow drainage, which collectively make the soils prone to settlement and instability under load.

The sorting values were generally high, ranging from 3.54 to 4.86ϕ, which classified the sediments as very poorly sorted according to Folk's classification. Poor sorting indicates a wide range of particle sizes, showing that the sediments were deposited under fluctuating or non-uniform energy conditions. This condition is common in deltaic and estuarine environments, where sediment supply and hydraulic energy vary seasonally or with tidal influence.

Poorly sorted soils have inconsistent packing and pore structures, which reduce compaction efficiency and increase susceptibility to differential settlement. In the Dahomey Basin context, this explains the patchy bearing capacities and uneven foundation behavior frequently observed in coastal infrastructure. The variability of grain sizes also contributes to irregular moisture movement, promoting localized zones of saturation and shrink–swell activity when expansive clays are present.

The skewness values were mostly negative to near-symmetrical, ranging from −0.04 to −0.39. Negative skewness indicates a dominance of coarser particles relative to fines in the tails of the distribution curve. This implies that deposition occurred in an environment with slightly fluctuating hydrodynamic energy, capable of introducing occasional coarser materials such as fine sand or silty sand into a dominantly fine matrix.

Such conditions are consistent with transitional depositional settings — for example, the interface between tidal flats, backswamps, and floodplains common in Lagos' coastal sediments. The slight coarse skew also suggests that while fine particles dominate, coarser grains intermittently interrupt the sequence, producing local strength contrasts that can complicate subgrade uniformity during construction.

Kurtosis values ranged from 0.50 to 0.93, generally indicating platykurtic distributions (flatter curves than normal). Platykurtic distributions reflect sediments that have undergone multiple reworking events or deposition from mixed sources. Instead of being sharply peaked (well-defined size range), these soils contained particles distributed across several size classes.

This flatness further supports the inference of variable energy conditions and reworking. In engineering terms, such soils do not compact uniformly; some particles fill voids effectively, while others leave microvoids that contribute to low bulk density and high compressibility.

These textural irregularities are directly linked to the soils' problematic nature when loaded or saturated.

Overall, the PSD data classified the soils as fine-textured, very poorly sorted, slightly coarse-skewed, and platykurtic. Such characteristics are diagnostic of low-energy depositional systems with episodic inputs of coarser material — typical of the coastal and deltaic sediments of the Dahomey Basin. These sediments likely formed under fluctuating energy conditions, alternating between calm sedimentation (lagoonal/marine clays and silts) and brief higher-energy inputs (fluvial fine sands).

This depositional pattern reflects the transitional coastal environment of Lagos, where tidal influences, river flooding, and marine incursions interact. The textural immaturity (poor sorting and mixed sizes) suggests that the sediments are young, weakly consolidated, and have not undergone significant diagenetic alteration. Such geological youth correlates strongly with the poor engineering properties observed in these problematic soils — including high compressibility, low shear strength, and instability under fluctuating moisture.

From a geotechnical standpoint, the fine-grained and poorly sorted character of these soils poses significant challenges for construction. High silt and clay content imply low permeability and slow drainage, causing extended pore pressure dissipation and differential settlement under loads. The broad particle size distribution leads to non-uniform compaction, reducing achievable dry densities during field compaction.

Additionally, the slightly coarse skewness observed means that while some coarse fractions exist, they are insufficient to create continuous drainage paths; hence, the soils retain water for long periods. Combined with expansive clay minerals identified elsewhere in the study, this results in volume instability, swelling during wet seasons, and shrinkage during dry periods. These characteristics are consistent with field observations of foundation cracks, pavement distress, and subgrade failure within the Lagos area.

Table 4.2: Showing Water Content, Density, and Plasticity Characteristics

Sample No.	Water Content (%)	Density (g/cm³)	Specific Density (g/cm³)	Void Ratio (e_0)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
BHI	30.3	1.88	2.72	0.74	55.0	26.3	28.7
BH2	24.1	1.87	2.71	0.65	52.9	20.6	32.3
BH3	26.1	1.82	2.72	0.74	53.3	20.7	32.6
BH4	23.8	1.82	2.72	0.70	37.7	14.3	23.4
BH5	36.9	1.80	2.71	0.76	58.2	26.4	31.4
BH6	27.5	1.81	2.72	0.77	39.4	15.7	23.7
BH7	24.7	1.82	2.71	0.71	37.7	16.4	21.3
BH8	27.5	1.77	2.72	0.81	40.4	14.4	26.0

The results in Table 4.2 show variations in water content, density, specific gravity, void ratio, and plasticity characteristics of the soil samples (BH1–BH8) collected from different boreholes in the study area. These parameters describe the physical state and behavior of the soils and help explain their engineering performance. The natural water content of the samples ranged from 23.8% (BH4) to 36.9% (BH5). Most samples had values above 25%, showing that the soils were generally moist and fine-grained, typical of coastal and alluvial deposits in Lagos.

The high water content observed in BH1 (30.3%) and BH5 (36.9%) suggests that these locations are poorly drained, possibly influenced by a high groundwater table or fine clayey texture that retains moisture. In contrast, lower values in BH2 (24.1%) and BH4 (23.8%) indicate relatively drier or coarser materials with better drainage.

The bulk density values ranged from 1.77 to 1.88 g/cm³, while specific gravity (Gs) remained consistent at about 2.71–2.72, which is typical for mineral soils rich in quartz, feldspar, and clay minerals.

The small variation in density suggests that the soils have similar composition but differ slightly in compaction and porosity. The higher density in BH1 (1.88 g/cm³) implies a more compact structure, while BH8 (1.77 g/cm³) shows lower compaction and possibly higher pore space.

The specific gravity values confirm that the solid particles are mainly silicate minerals, as supported by the XRD results showing quartz, albite, and montmorillonite. These minerals contribute to the soils' high moisture retention and swelling potential.

Void ratio values ranged between 0.65 and 0.81, indicating moderate to high porosity. The highest void ratio (0.81) in BH8 suggests a loosely packed soil with many air or water-filled voids, while BH2, with the lowest (0.65), is denser and less porous. Generally, higher void ratios are found in soft, clayey soils with high water content, explaining why BH5 and BH8 (both moist) have larger voids. Such soils tend to compress easily under load, leading to settlement problems in buildings and road foundations.

Liquid limit values ranged from 37.7% (BH4 and BH7) to 58.2% (BH5). Soils with LL values above 50% (such as BH1, BH2, BH3, and BH5) are classified as high plasticity clays, while those below 50% are low to medium plasticity soils. The higher LL in BH5 and BH1 indicates the presence of active clay minerals like montmorillonite, which absorb water and expand, making them highly plastic and sensitive to moisture changes. Lower LL values in BH4, BH6, and BH7 suggest less clay content or dominance of silt-sized particles, leading to less swelling.

Plastic limit values varied from 14.3% (BH4) to 26.4% (BH5), while the Plasticity Index (PI) ranged from 21.3% (BH7) to 32.6% (BH3). The PI, calculated as the difference between LL and PL, reflects the soil's plasticity range—that is, the range of moisture content over which the soil remains plastic and moldable.

Most of the samples had PI values above 20%, meaning they are highly plastic soils. BH3 and BH2 recorded the highest PIs (32.6% and 32.3%), showing that these soils can undergo large volume changes with varying moisture. BH4 and BH7, with lower PI values (23.4% and 21.3%), are less plastic and less prone to expansion.

In practical terms, soils with high PI tend to be problematic for engineering works because they shrink and swell significantly when wet or dry, leading to foundation movement and cracking.

From the combined results, the soils in the study area are fine-grained, moderately to highly plastic, and moisture-retentive. Their high water content, low density, and high plasticity index indicate that they are weak, compressible, and prone to volume changes.

These properties are consistent with the mineralogical findings that show dominance of montmorillonite, a clay mineral known for its swelling behavior. Such characteristics explain the poor bearing capacity, settlement, and pavement failure commonly observed in the Lagos area of the Dahomey Basin.

4.2 The XRF and XRD Analysis

From the figure 4.1 and 4.2, the XRF and XRD analyses of the coastal soil samples L2 and L5 reveal a mineralogical composition dominated by montmorillonite, quartz, and accessory minerals such as actinolite and albite, which collectively influence the geotechnical and engineering behavior of the soil. In sample L2, montmorillonite constitutes about 41%, quartz 33%, and actinolite 26%, while in sample L5, montmorillonite makes up 42%, quartz 39%, and albite 19%. The presence of these minerals indicates that the soils have developed in a coastal depositional environment characterized by alternating marine and terrestrial sedimentation, high groundwater influence, and a humid tropical climate that favors chemical weathering and clay mineral formation. The predominance of montmorillonite, a smectitic clay mineral, is of particular engineering concern because of its high surface area, high cation exchange capacity, and extreme sensitivity to changes in moisture and ionic concentration.

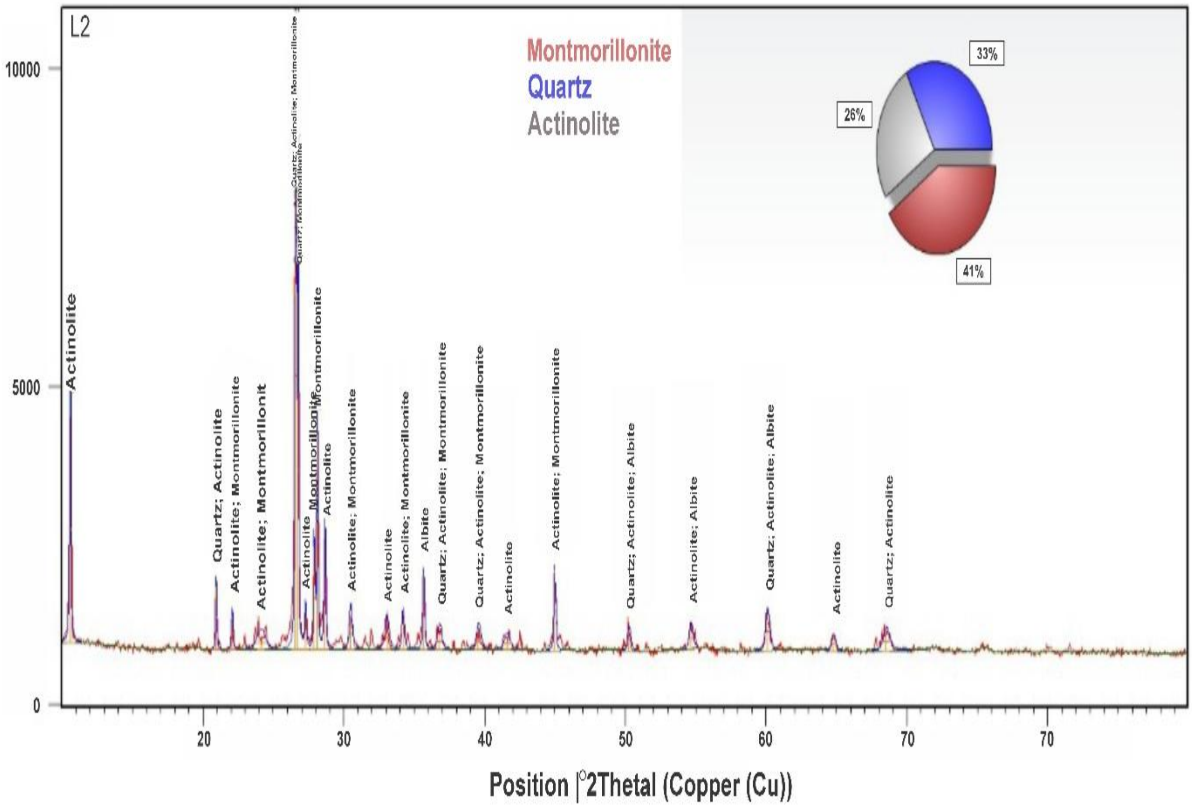

Figure 4.1: A diagram showing the XRF and XRD of location 2

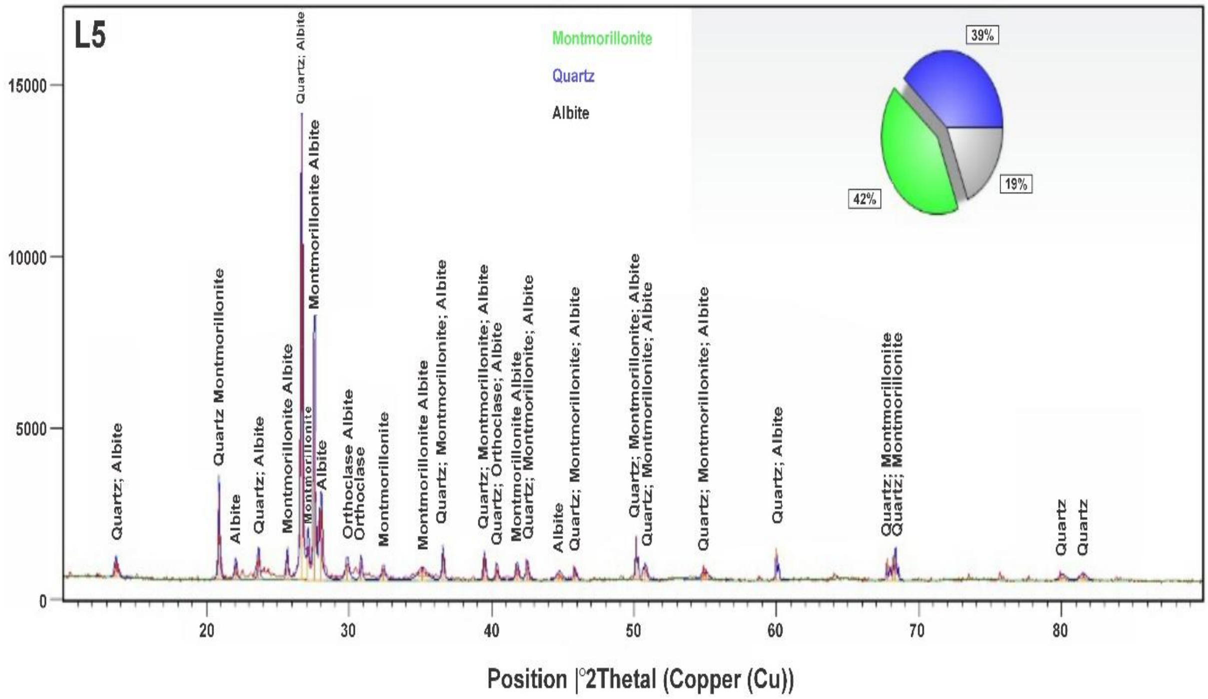

Figure 4.2: A diagram showing the XRF and XRD of location 5

When exposed to water, montmorillonite undergoes interlayer swelling due to the absorption of polar water molecules between its crystal sheets, causing a significant increase in soil volume. Conversely, during drying, the mineral contracts, resulting in shrinkage. This cyclic swelling and shrinkage process leads to volume instability, which causes ground movement, cracking of foundations and pavements, tilting of light structures, and differential settlement. In coastal settings where the groundwater table fluctuates and where periodic wetting and drying are common due to tidal influences, these effects are magnified. The saline nature of coastal groundwater further complicates the behavior of montmorillonitic soils. High salinity enhances cation exchange processes, whereby sodium, calcium, and magnesium ions alter the clay structure, changing its swelling characteristics. Sodium-dominated montmorillonite, for instance, tends to exhibit higher swelling potential than calcium-dominated varieties, making soil behavior unpredictable if not properly treated or stabilized.

Quartz, the second major constituent, is a stable, hard, and chemically inert mineral that contributes to the soil's strength and stiffness. Its presence improves the mechanical stability of the soil, increases bearing capacity, and reduces overall plasticity. However, the stabilizing effect of quartz in these samples is insufficient to counterbalance the dominant montmorillonitic fraction. In coastal soils, quartz is often associated with sandy deposits that improve permeability and drainage, but excessive sand content can also lead to erosion and instability, particularly when underlain by expansive clay layers that respond differently to moisture variations. This combination of quartz and montmorillonite produces a stratified soil system that is mechanically heterogeneous, where the upper sandy or silty layer behaves differently from the expansive clayey layer beneath, increasing the risk of uneven settlement during loading.

Actinolite, present in L2, is an amphibole mineral containing iron, magnesium, and calcium, typically formed from the metamorphism of mafic rocks. Although actinolite itself is not expansive, its presence suggests that the soil has inherited materials from metamorphic terrains. Under prolonged exposure to moisture and coastal salinity, actinolite can weather into fine-grained products that increase the plasticity and decrease the permeability of the soil. The partial decomposition of actinolite may also contribute to the release of ions that enhance the chemical activity of the clay fraction, subtly influencing the swelling potential of the soil over time. In contrast, the L5 sample contains albite, a sodium feldspar that commonly weathers to form secondary clay minerals such as kaolinite and montmorillonite. Albite's chemical instability in saline and humid environments makes it an important precursor for clay mineral formation, indicating ongoing geochemical alteration within the soil profile. The progressive breakdown of albite releases silica and sodium, which can further increase the sodium content of montmorillonite, thus enhancing its expansive characteristics.

From an engineering standpoint, the high montmorillonite content makes these coastal soils highly problematic for construction. Such soils exhibit low shear strength, high plasticity index, poor drainage characteristics, and significant susceptibility to volume change. Structures built on untreated expansive soils often experience foundation distress due to heaving and settlement, which can lead to cracking of walls and pavements, tilting of light buildings, and even complete foundation failure in severe cases. In addition, the cyclic wetting and drying typical of coastal areas accelerate fatigue within the soil matrix, leading to progressive degradation of the foundation-bearing layer. These soils also have low bearing capacity due to the weak interparticle bonding and reduced effective stress when saturated. The high salinity in coastal zones can further weaken soil structure by promoting the dissolution of bonding agents and altering the electrochemical balance within clay minerals, thereby increasing the risk of liquefaction under dynamic loading such as wave action or vibrations.

To mitigate these geotechnical challenges, several improvement techniques are essential. Chemical stabilization using lime, cement, or fly ash remains one of the most effective methods for improving expansive soils. Lime treatment induces pozzolanic reactions that convert clay minerals into stable cementitious compounds like calcium-silicate-hydrates (C–S–H) and calcium-aluminate-hydrates (C–A–H), reducing plasticity and swelling potential. Cement stabilization similarly increases strength and durability, while fly ash can be used as an additive to enhance binding properties and reduce shrinkage. In coastal environments, salt stabilization using calcium chloride or sodium chloride has been used to achieve ionic equilibrium within the clay mineral structure, thus reducing further swelling. Mechanical stabilization techniques, including deep compaction and dynamic consolidation, help reduce void ratios and limit water movement through the soil. In critical areas, soil replacement with well-graded granular materials such as sand, gravel, or crushed rock provides a stable, non-expansive foundation layer. Proper drainage systems are also vital to control groundwater fluctuations, while surface protection measures such as concrete pavements, geomembranes, or impermeable liners can limit water infiltration and reduce seasonal moisture variations.

In cases where ground improvement is insufficient, the use of deep foundation systems such as driven piles, drilled shafts, or piers ensures that loads are transferred to deeper, more stable strata below the active zone of volume change. Preloading and surcharging methods can also be applied to accelerate consolidation and minimize post-construction settlement. Additionally, geosynthetic materials such as geotextiles, geogrids, and geomembranes can be incorporated to reinforce the soil, enhance drainage, and prevent excessive deformation.

From an engineering geology perspective, the mineralogical composition revealed by the XRD and XRF analysis demonstrates that these coastal soils have developed under dynamic geological and environmental conditions involving both marine deposition and terrestrial weathering. The mixture of stable quartz and reactive clay minerals signifies a soil that is mechanically anisotropic and chemically active. The dominance of montmorillonite indicates that the soils are highly expansive, moisture-sensitive, and chemically reactive, characteristics that render them unsuitable for shallow foundations without prior stabilization or modification. The presence of feldspathic and amphibole minerals also implies ongoing weathering, which may further deteriorate soil stability over time. Therefore, when designing engineering structures in such environments, it is crucial to integrate geotechnical investigation with mineralogical and chemical characterization to predict soil behavior accurately.

In conclusion, the XRD and XRF results for samples L2 and L5 reveal that the coastal soils under study are predominantly montmorillonitic, with secondary contributions from quartz, actinolite, and albite. These mineralogical components produce a soil profile that is expansive, compressible, and highly sensitive to moisture and salinity variations. Such soils pose major challenges for foundation stability, but with appropriate soil improvement methods such as chemical stabilization, drainage control, mechanical densification, and the use of deep foundations their adverse effects can be minimized. A sound understanding of the engineering geology of these coastal soils is therefore essential for the safe and sustainable design of engineering structures in coastal environments, ensuring long-term durability and performance despite the inherent mineralogical and geotechnical limitations of the soil.

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSION, AND RECOMMENDATIONS

5.1 Summary of Findings

This study focused on the sedimentological and geochemical characterization of problematic soils in the Lagos portion of the Dahomey Basin to understand their origin, composition, and engineering implications. The main analyses carried out were particle size distribution (PSD), Atterberg limits, density and water content determination, and mineralogical analysis (XRD/XRF).

The particle size distribution results showed that the soils are predominantly fine-grained, consisting mainly of silt and very fine sand with mean grain sizes between 3.30ϕ and 6.83ϕ. Sorting values indicated that the soils are very poorly sorted, confirming that they were deposited in a low-energy depositional environment such as a coastal plain, lagoon, or estuarine setting. The negative to near-symmetrical skewness and platykurtic distributions further reflect fluctuating depositional conditions, likely influenced by alternating marine and fluvial processes. These characteristics indicate texturally immature sediments, consistent with recent deposition and limited diagenetic alteration typical of Lagos coastal formations.

The physical and plasticity properties also revealed that the soils are moist, highly plastic, and compressible. Water content ranged from 23.8% to 36.9%, indicating that most of the soils retain high moisture, while bulk density ranged between 1.77 and 1.88 g/cm^3, reflecting moderate compaction. The specific gravity values (2.71–2.72) suggest mineralogical uniformity dominated by silicate minerals. Void ratios ranged from 0.65 to 0.81, showing moderate to high porosity typical of soft, fine-grained coastal soils.

The liquid limit values (37.7–58.2%) and plasticity index values (21.3–32.6%) classified most of the soils as highly plastic clays. These soils are moisture-sensitive and tend to undergo significant volume change (swelling and shrinkage) when exposed to fluctuations in moisture content. The high plasticity values correspond with the mineralogical results, which identified montmorillonite as the dominant clay mineral responsible for the soils' expansive behavior.

The XRD results for representative samples (L2 and L5) confirmed a mineral composition dominated by montmorillonite, quartz, and accessory minerals such as actinolite and albite. Montmorillonite accounted for about 41–42% of the total mineral content, followed by quartz (33–39%) and minor actinolite or albite. The dominance of montmorillonite explains the high plasticity and low strength of the soils, while quartz contributes to the granular fraction that slightly improves strength and stiffness. Albite and actinolite indicate sediment derivation from both igneous and metamorphic sources and ongoing chemical weathering in a humid tropical coastal environment.

Overall, the findings show that the soils in the Lagos segment of the Dahomey Basin are fine-grained, poorly sorted, and montmorillonite-rich. These properties collectively make the soils problematic for engineering purposes, leading to low shear strength, high compressibility, and poor foundation stability. The geological and environmental conditions of the basin promote the formation of such expansive and moisture-sensitive soils.

5.2 Conclusion

The study concludes that the problematic nature of soils in the Lagos area of the Dahomey Basin arises primarily from their fine-grained texture, poor sorting, and high montmorillonite content. These soils have developed under alternating marine and terrestrial depositional conditions that favor the accumulation of clayey sediments rich in smectitic minerals.

From both the sedimentological and geochemical perspectives, the soils are young, unconsolidated, and texturally immature, making them mechanically weak and highly sensitive to moisture changes. Their high plasticity and water-retaining capacity cause swelling and shrinkage during wet and dry seasons, resulting in foundation heave, pavement cracking, and structural instability.

The results confirm that engineering projects in the Lagos coastal zone must consider both the textural and mineralogical characteristics of the soil before design and construction. Without proper soil treatment or foundation design, structures built on these materials are at high risk of differential settlement and long-term failure.

5.3 Recommendations

Based on the findings of this study, the following recommendations are proposed to reduce the geotechnical challenges associated with the soils of the Dahomey Basin:

Soil Stabilization:

Expansive soils containing montmorillonite should be stabilized before construction using chemical methods such as lime, cement, or fly ash treatment. These stabilizers reduce plasticity and swelling potential by forming cementitious compounds that improve soil strength and durability.

Improved Drainage Design:

Proper surface and subsurface drainage systems should be installed to control groundwater fluctuations and reduce water infiltration. This will limit seasonal volume changes in the soil and minimize settlement problems.

Use of Deep Foundations:

For heavy structures, pile or pier foundations should be adopted to transfer loads to more stable layers beneath the active expansive zone. Shallow foundations should be avoided unless the soil has been adequately stabilized.

Mechanical Compaction and Replacement:

In areas where stabilization is not feasible, mechanical densification or replacement with well-graded sand or gravel can improve bearing capacity and reduce void ratio. This is especially useful for road subgrades and lightly loaded structures.

Periodic Monitoring:

Engineering sites located on these soils should undergo regular monitoring of moisture variation and ground movement, especially during the wet season. Continuous observation helps in early detection of expansion-related damage.

Integrated Geotechnical and Geochemical Investigations:

Future construction projects should combine sedimentological, mineralogical, and geotechnical studies during site investigations to accurately assess the risk of soil instability and to select appropriate foundation or stabilization methods.

5.4 Summary

In summary, the soils of the Lagos area in the Dahomey Basin are fine-grained, expansive, and moisture-sensitive, with dominant montmorillonitic clay minerals that make them unsuitable for direct foundation support. Their poor sorting, high void ratio, and high plasticity result in low strength, poor drainage, and high compressibility. However, with appropriate stabilization, compaction, drainage control, and foundation design, these problematic soils can be effectively managed for safe and sustainable engineering development.

REFERENCES

Adetoyinbo, A. A. and Ogunyele, A. C. (2019). Geophysical investigation of the Ifewara-Zungeru fault system, southwestern Nigeria, using aeromagnetic and remote sensing data. *Journal of African Earth Sciences* **151**: 225-237.

Adeyemi, G. O. and Oyediran, I. A. (2011). Geotechnical investigation of foundation failure of a building in Lagos, Nigeria. *Journal of Earth Sciences and Geotechnical Engineering* **1**(1): 1-12.

Adeyemi, G. O. and Oyediran, I. A. (2011). Geotechnical properties of lateritic soil developed over quartz schist in Ishara area, Southwestern Nigeria. *Journal of Earth System Science* **120**(5): 889–897.

Agagu, O. K. (1985). *A geological guide to Bituminous Sediments in Southwestern Nigeria. Unpublished Report*, Department of Geology, University of Ibadan, Nigeria. pp 135.

Ajakaiye, D. E., Daniyan, M. A., Ojo, S. B. and Onuoha, K. M. (1987). The July 28, 1984 Southwestern Nigeria earthquake and its implications for tectonics and evolution of Nigeria. *Journal of Geodynamics* **7**(3-4): 205–214.

Akpan, O. U., Isogun, M. A., Yakubu, T. A., Adepełumi, A. A., Okereke, C. S., Oniku, A. S. and Oden, M. I. (2014). An evaluation of the 11th September, 2009 earthquake and its implication for understanding the seismotectonics of South Western Nigeria. *Open Journal of Geology* **4**(11): 542-550.

Bakere K. M., Aozeboekhai P. A. and Oyeyemi K. (2019). Investigating groundwater pollution at an open dumpsite using 2D geoelectrical resistivity imaging and vertical electrical sounding. *Journal of Physics: Conference Series* **1299**(1): 1742 - 6596.

Boggs, S. (2014). Principles of sedimentology and stratigraphy (*5th edition*). Pearson Education. Pp. 120-124.

Bowles, J. E. (1996). Foundation analysis and design (*5th edition*). McGraw-Hill. Pp. 12-48

Burke, K. (1972). Longshore drift, submarine canyons, and submarine fans in development of Niger Delta. *AAPG Bulletin* **56**(10): 1975-1983.

Burke, K. and Dessen, C. (1994). *Africa's environmental and climatic past: A resource for research and teaching.* University of Virginia Press. pp. 189.

Burke, K., Dessauvagie, T. F. J. and Whiteman, A. J. (1971). The opening of the Gulf of Guinea and the geological history of the Benue depression and Niger Delta. *Nature Physical Science* **233**(38): 51–55.

Chen, F. H. (2012). Foundations on expansive soils (*2nd Edition*). Elsevier Science. Pp. 23-26.

Das, B. M. and Sobhan, K. (2018). *Principles of geotechnical engineering* (*9th edition*). Cengage Learning. pp. 45-60.

Fatoba, J. O. and Olorunfemi, M. O. (2004). Subsurface sequence delineation and saline water mapping of Lagos state, south western Nigeria. *Global Journal of Geological Sciences*, **2**(1): 111-123.

Jegede, G. (1998). Engineering geological characteristics of the soils of the Coastal Plain Sands of Western Nigeria. *Bulletin of the International Association of Engineering Geology* **57**(1): 107-114.

Jones, H. A. and Hockey, R. D. (1964). The geology of part of Southwestern Nigeria. *Geological Survey of Nigeria Bulletin* **31**: 1-101.

McKenzie, D. (1978). Some remarks on the development of sedimentary basins. Earth and Planetary Science. *Letters* **40**(1): 25-32.

Mosuro, G. O., Adebisi, N., Ariyo, S. O., Omosanya, K. O., Bayewu, O. O. and Oloruntola, M. O. (2021). Redefining the boundary between crystalline and sedimentary rock of Eastern Dahomey Basin. Scientific reports, **11**, 5016

Obaje, N. G. (2009). *Geology and mineral resources of Nigeria* (2nd ed.). Springer-Verlag Berlin Heidelberg. pp. 221.

Ogundana, A. K. and Talabi, A. O. (2011). Geotechnical assessment of some clay soils in southwestern Nigeria as raw material for the ceramic industry. *Ife Journal of Science* **13**(2): 281-290.

Ola, P. S., Alausa, A. W. and Adeyemi, G. O. (2015). Structural controls on the drainage network of the Precambrian Basement Complex of Southwestern Nigeria: A GIS approach. *Journal of Geography and Geology* **7**(2): 1-12.

Ola, S. A. (1983). Geotechnical properties of some Nigerian soils related to sedimentation. *Bulletin of the International Association of Engineering Geology* **28**(1): 413–417.

Oladunjoye, H. T., Ishola, K. S., Oyedele, K. F. and Adeoti, L. (2024). Multi-parameters approach to assessment of soil liquefaction vulnerability in wetland areas of Lagos, Southwestern, Nigeria. *Discover Applied Sciences* **6**: 50-56.

Oladunjoye, O. T., Akinlabi, I. A. and Adediran, A. A. (2024). Assessment of pavement failure along the Lagos-Abeokuta expressway, Southwestern Nigeria: A geotechnical perspective. *Journal of African Earth Sciences* **209**: 105-118.

Olatinsu, O. B., Olorunfemi, M. O. and Oladapo, M. I. (2009). Geophysical evaluation of the engineering foundation conditions of a site in Iwo, Southwestern Nigeria. *Journal of Geology and Mining Research* **1**(5): 102-115.

Oloruntola, M. O., Adeyemi, G. O. and Ola, S. A. (2018). Geotechnical evaluation of subgrade soils for road construction in parts of Ibadan, Southwestern Nigeria. *Ife Journal of Science* **20**(2): 287-299.

Oloruntola, M., Bayewu, O., Kehinde, K., Obasaju, D. O. and Mosuro, G. O. (2018). Profiles of problematic soils and spatial distribution: Implication on foundation construction in parts of Kosofe Lagos, Southwestern Nigeria. *GeoScience Engineering* **64**(4): 11-22.

Omatsola, M. E. and Adegoke, O. S. (1981). Tectonic evolution and Cretaceous stratigraphy of the Dahomey Basin. *Journal of Mining and Geology* **18**(1): 130-137.

Orazulike, D. M. (1992). Expansive soils: the silent hazard in Bauchi State, Nigeria. In: Freeth, S. J., Ofoegbu, C. O. and Onuoha, K. M. (*1st edition*) *Natural Hazards in West and Central Africa*. Friedr. Vieweg and Sohn, Braunschweig/Wiesbaden, pp. 163-171.

Rahaman, M. A. (1976). Review of the basement geology of Southwestern Nigeria. In Kogbe, C. A. (Ed.), *Geology of Nigeria*. Elizabethan Publishing Company, Lagos, pp. 41-58.

APPENDIX

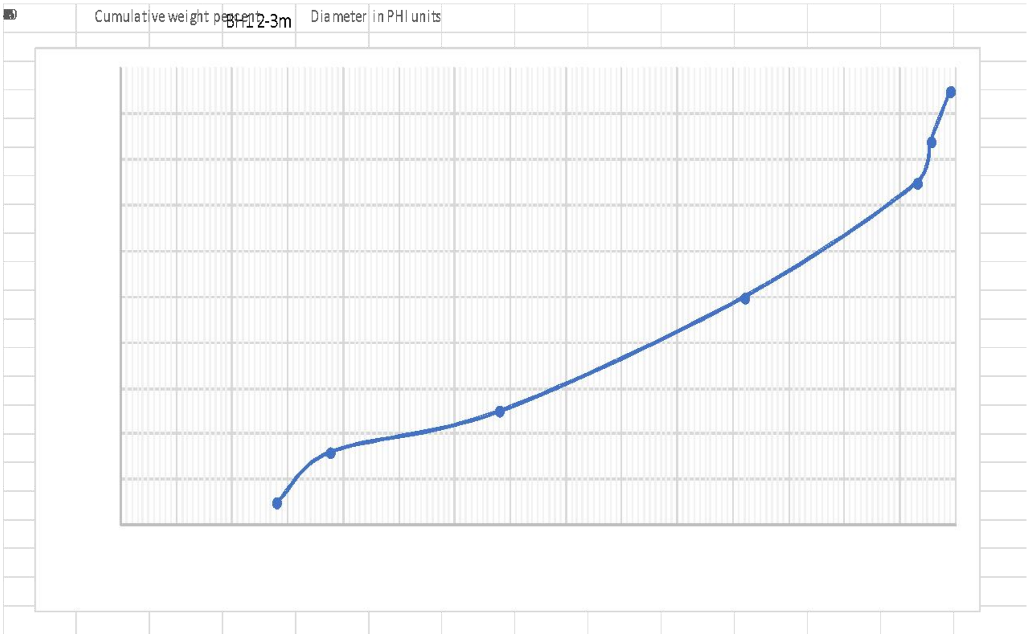

Figure 1: *Grain Size Distribution Curve for Borehole 1 (BH1)*

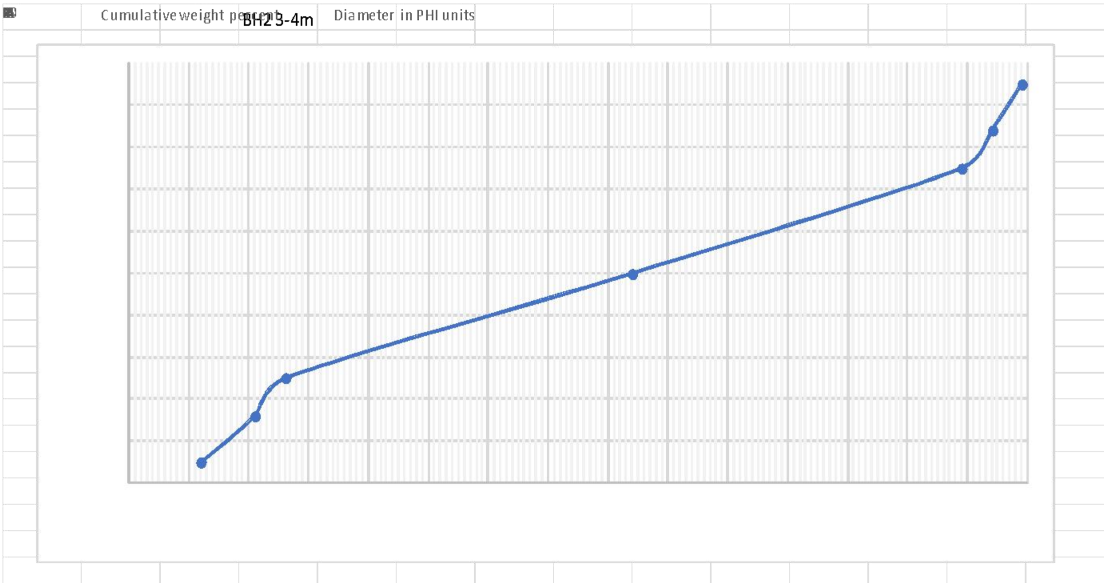

Figure 2: *Grain Size Distribution Curve for Borehole 2 (BH2)*

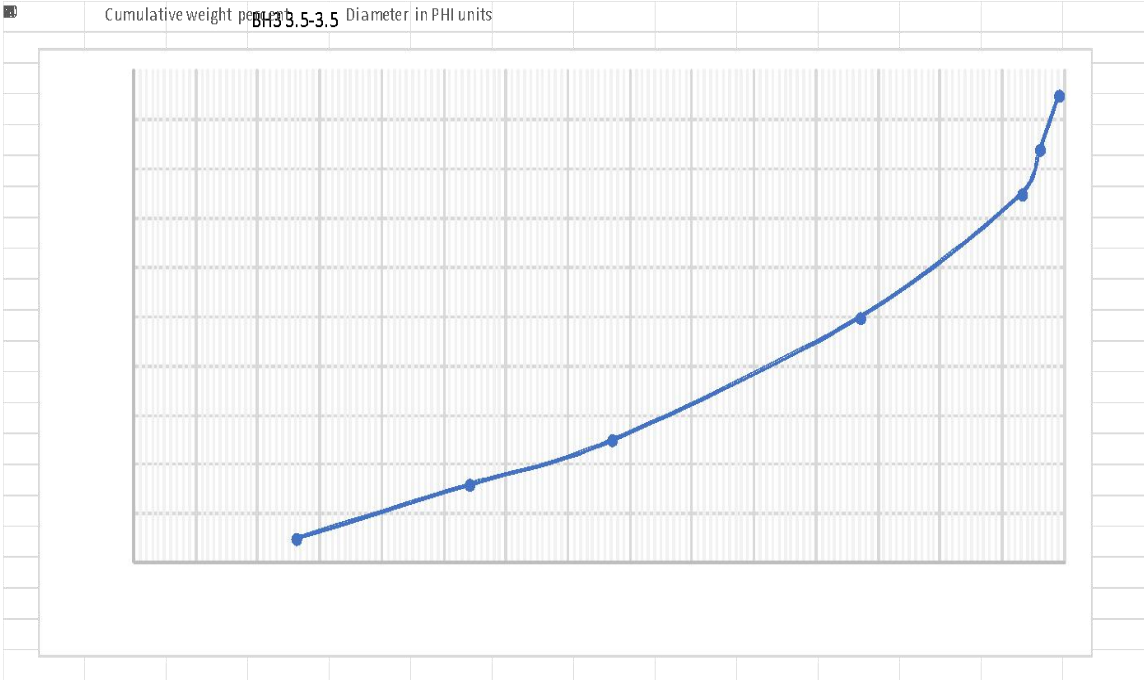

Figure 3: *Grain Size Distribution Curve for Borehole 3 (BH3)*

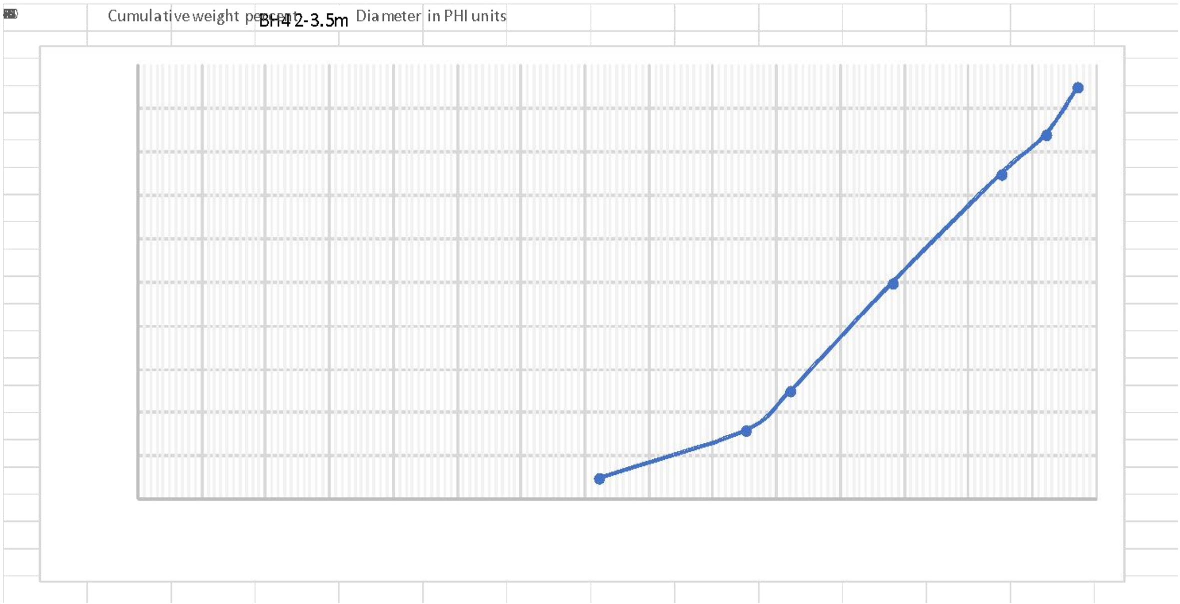

Figure 4: *Grain Size Distribution Curve for Borehole 4 (BH4)*

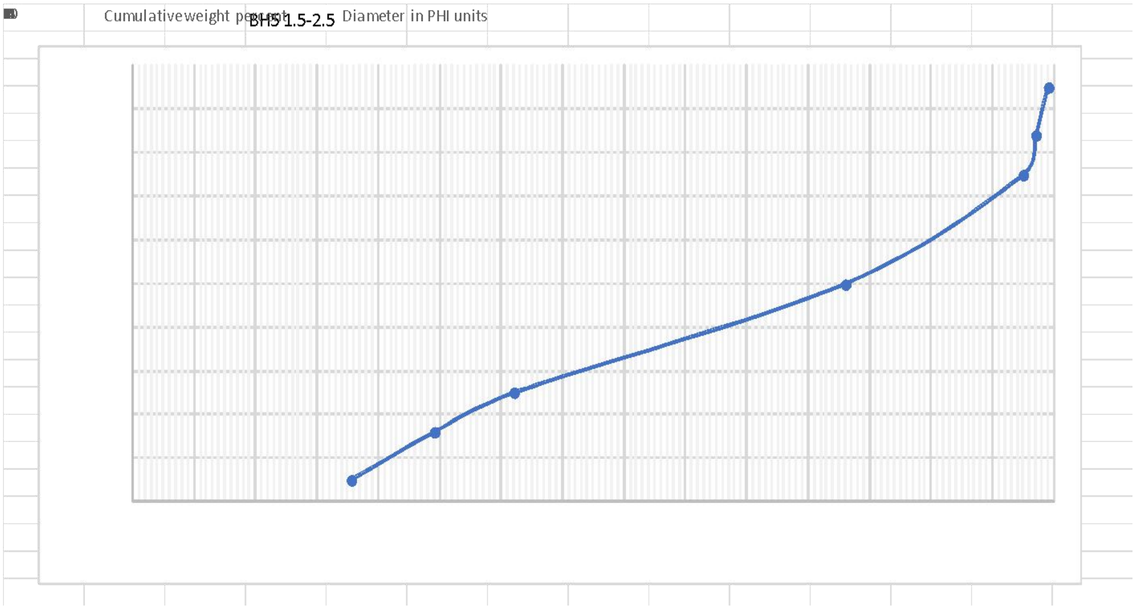

Figure 5: *Grain Size Distribution Curve for Borehole 5 (BH5)*

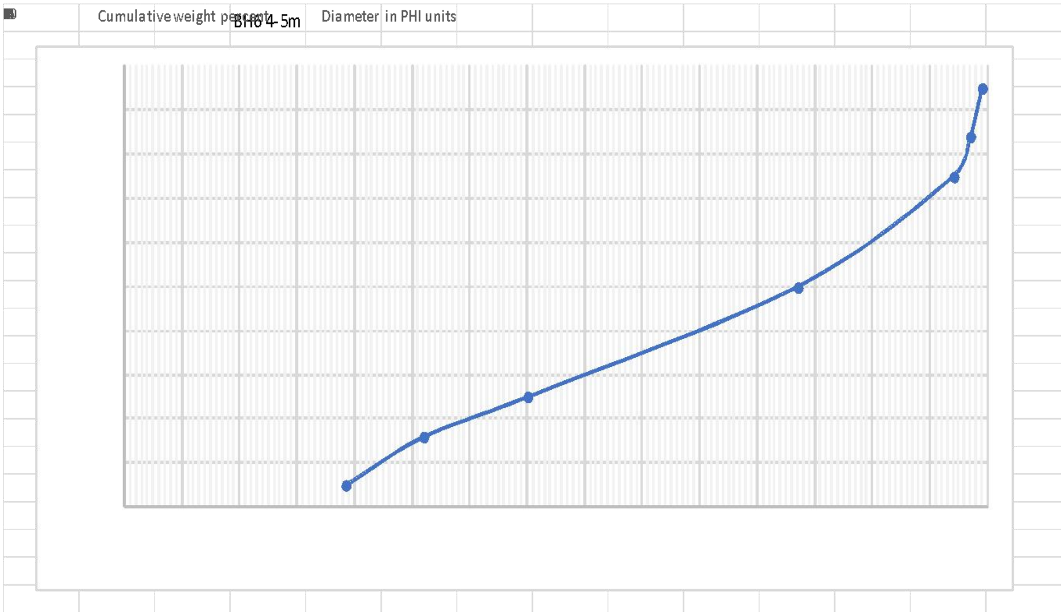

Figure 6: *Grain Size Distribution Curve for Borehole 6 (BH6)*

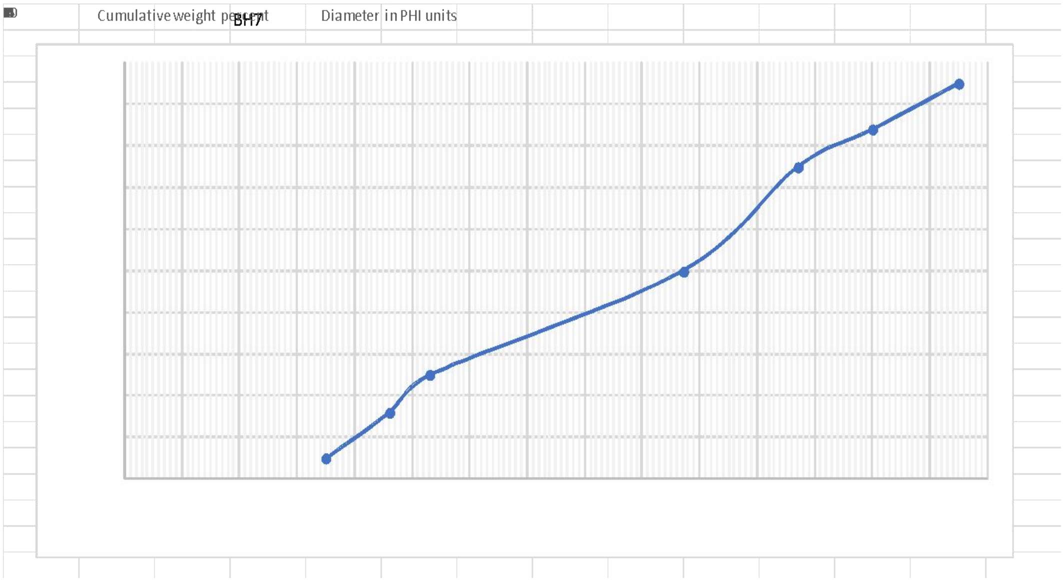

Figure 7: *Grain Size Distribution Curve for Borehole 7 (BH7)*

Figure 8: *Grain Size Distribution Curve for Borehole 8 (BH8)*

Plate A: Hydrometer Setup

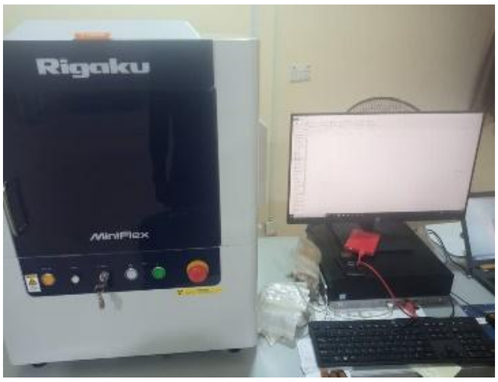

Plate B: Powder X-Ray Diffractometer (P-XRD, SmartLab RIGAKU 9 kW)

Plate C: Ohaus Scout Pro SP402 Digital Balance

Plate D: High Precision Test Sieves (ASTM Standard)

Plate E: Analytical Test