UNIVERSITÀ DEGLI STUDI DI PADOVA
DIPARTIMENTO DI INGEGNERIA CIVILE, EDILE E AMBIENTALE
Department Of Civil, Environmental and Architectural Engineering

Corso di Laurea Magistrale in Environmental Engineering

Master Thesis

Development of a hydrogeological model of Lagos, Nigeria

Elham Ashrafi
2072035

Supervisor
Prof. Eng. Pietro Teatini

Academic year 2024 / 2025

Acknowledgements

With deep gratitude, I wish to thank my professor for his unwavering support, generous guidance, and the time and effort he dedicated to this work. His mentorship has been a constant source of encouragement and inspiration.
To Francesco, my boyfriend and the love of my life — thank you for being my rock. Your love, patience, and belief in me have carried me not only through this thesis but through everything. I am endlessly grateful for you, always.
Lastly, my heart goes to the courageous women of Iran who continue to rise, speak, and fight for their rights with unbreakable strength. Your voices echo in the hearts of many, and your bravery lights the way for generations to come.

ABSTRACT

Groundwater is a very important resource for Lagos, Nigeria, both in domestic, industrial, and agricultural use. The fast rate of urbanization and growth in the population of Lagos City has exposed the aquifer system to huge pressure therefore, the characterization of its aquifer systems is of paramount importance.
This thesis focuses on the 3D reconstruction of the Lagos aquifer system using geological and hydrogeological data. Leapfrog software was used to develop the model, based on lithological data collected from previous studies and institutional sources.

The final 3D model reveals that the Lagos aquifer system is primarily composed of thick sandy layers, with interbedded clay and intermediate units. These formations define both confined and unconfined aquifer conditions across the study area. Particular attention is given to zones at risk of land subsidence due to thick compressible clays, and to coastal areas vulnerable to sea-level rise and saltwater intrusion. The model provides a useful framework for future groundwater planning and hydrogeological analysis in Lagos.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Background

Water is one of the most essential means and sources of sustaining life, economic development, and maintaining public health. In the last three decades, due to rapid urbanization, population growth, and rapid industrialization, stress on water resources has increased globally, greatly impacting the quantity and quality of available water supplies, especially in emerging megacities (Gu et al., 2021). By 2050, 60–68% of the global population is projected to reside in megacities, with the largest growth occurring in Asia and Africa (Marlier et al., 2016).
It is difficult to estimate the importance of water resources for megacities' economic growth. Many megacities mainly rely on groundwater to supply the growing demand for water. Lagos, Nigeria, is expected to become the world's largest city by 2100 (Desjardins, 2018) and is frequently referred to as "the city that won't stop growing" (Hoornweg & Pope, 2017).

It is expected to surpass all other cities in the world in size by the year 2100 (Desjardins, 2018). It is one of the fastest-growing cities in the world, surpassing places like New York, Los Angeles, Istanbul, and Tehran with an annual growth rate of 3.5% (Desjardins, 2018; Faisal Koko et al., 2021).
At the same time, this growth has been attributed to industrialization, commercialization, and the development of seaport facilities that have generally added up towards increased employment opportunities and a noteworthy contribution of Lagos to the economies of Nigeria and West Africa.

While the city of Lagos increases economically, it faces an increasing water crisis, driven by physical scarcity, economic constraints, and unsafe water conditions on a global scale. Groundwater is the most important source of freshwater for domestic and industrial use, especially in coastal areas where public water infrastructure is underdeveloped and surface waters are highly polluted. In most developing countries, like Nigeria, freshwater is scarce, and a large percentage of the population does not have access to potable water.
Groundwater has become the major source of good-quality potable water supply to households, industries, and agriculture in Lagos, especially since public water systems reach 10%–30% of the population only (Healy et al., 2020; IGRAC, 2021). Thus, groundwater access comes with challenges. Boreholes are the most reliable method of accessing uncontaminated water, their high cost makes them inaccessible to most residents. As a result, many rely on shallow boreholes or hand-dug wells, which are often poorly constructed and highly contaminated with harmful substances (Jimoh et al., 2018).

Therefore, there is a dire need for sustainable groundwater management in improving access to safe water. The increased problem due to urbanization results in impervious surfaces increasing recharge rates while also causing stress in the aquifer systems (Abiodun et al., 2017). On the other hand, despite this threat to the sustainability of the resource, it is the most reliable source of water in many regions. It thus makes the problem double-edged (Balogun et al., 2017).

1.2 Problem Statement

Lagos's excessive reliance on groundwater has been difficult for sustainable water resource management. Over-extraction, progressive declines in water table levels, widespread contamination, and saltwater intrusion into the aquifers have been recorded, especially along the coastal region of Apapa (Jimoh et al., 2018).

Over-extraction of groundwater, particularly in coastal areas, has caused land subsidence, with subsidence rates ranging from 2 mm/year to 87 mm/year in regions like Apapa, Ikoyi, and Lekki (Ikuemonisan & Ozebo, 2020). The excessive pumping has caused compaction of sediments beneath the surface, increasing flooding, coastal erosion, and the city's vulnerability to sea level rise.

Lagos as a low-lying coastal city is even more vulnerable due to the expected sea level rise by up to 1m by 2100.

In addition to land subsidence and rising sea levels, contamination from sewage disposal, industrial effluents, and surface runoff has proven to be a significant issue along the shallow aquifers on the other hand deep aquifers which are the main source of freshwater, remain inaccessible due to high drilling costs.

1.3 Objectives

This thesis aims to develop a general three-dimensional hydrogeological model for the aquifer systems of Lagos. It should integrate both lithological and spatial data to visualize subsurface structures, delimit the extent of the aquifers, and identify zones important to their management. This study tries to provide a foundational framework that may help in the sustainable management of groundwater and inform future hydrogeological research in Lagos.

Chapter 2

Study area

2.1 Location and Geography

Lagos is the largest city in Nigeria and one of the busiest commercial and industrial centers in West Africa. Lagos is located in southwestern Nigeria along the narrow coastal line of Bight of Benin, between longitudes 2°42' and 3°42' East and between latitudes 6°23' and 6°41' North. (Figure 2.1)
Lagos has a total land area of 3,577 km² and around 22% is occupied by water bodies in the form of wetlands and lagoons.
Moreover, it is characterized by a low-lying topography with most areas lying below 15m above mean sea level, making it vulnerable to flooding, saltwater intrusion, and sea-level rise impacts.

Lagos is known for having a high urbanization rate, which has witnessed its coastal regions extending through land reclamation. The city is one of Africa's most urbanized cities, with an estimated 17 million people, and still suffers from immense pressure from expanding populations and urban demands. (Figure 2.2)
In about 25 years, at the rate Nigeria is currently growing, it will have a population of 300 million, or the same as the present-day United States, all living in an area with the size of Nevada, New Mexico, and Arizona. With the population doubling over the last 15 years, living standards across Nigeria remain poor. Today, 25% of Africans are Nigerian (World Population Review, 2024).

Figure 2.1. The map of Lagos Source: Tajudeen et al., 2022

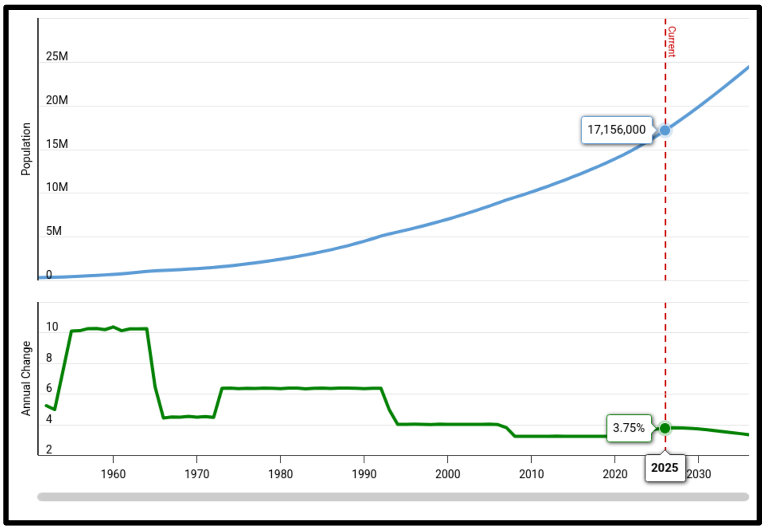


Figure 2.2. Population growth and annual change for Lagos (1950-2025). Retrieved from https://www.macrotrends.net/global-metrics/cities/22007/lagos/population

2.2 Climate and Rainfall Patterns

Lagos has a well-defined dry and wet season climate. April to October is regarded as the wet season while November to March is the dry season. It has a high yearly rainfall with a value ranging from 1,500 mm to 2,000 mm and a highest rainfall between May and July (Figure 2.3).

Rainfall is extremely intense between this period and results in frequent flooding in lowlands (Oteri, 2003; Oyedele, 2009).

The Rainy season is marked with heavy rains that have a major impact on groundwater recharge, while the dry season marked with low rainfall and low humidity may lead to a decrease in groundwater recharge, especially in areas with no water infrastructure (Ikuemonisan & Ozebo, 2020).

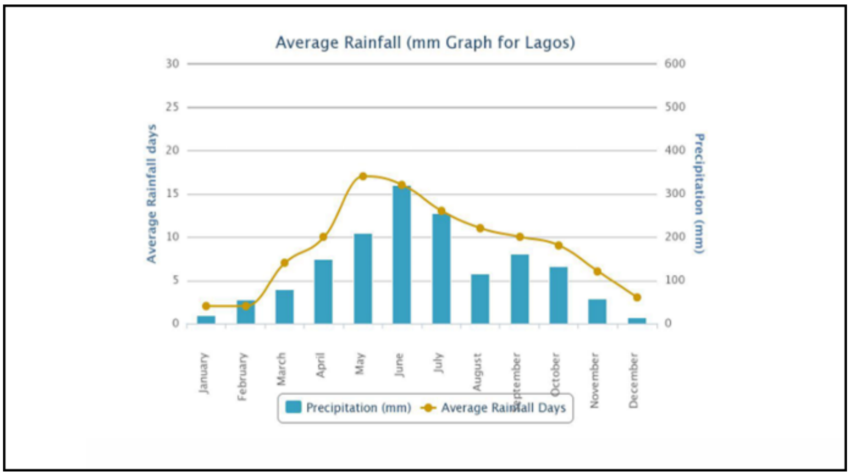


Figure 2.3. The average monthly rainfall over the years 2000 to 2012. Source: Oteri, 2003

Lagos temperature is typically constant throughout the year with a range of daily mean highs between 29°C and 31°C and lows between 23°C and 24°C (Figure 2.4).
Consistently high relative between 75% and 85% contributes to year-round elevated humidity levels. (Weatherspark, 2025).
Lagos's tropical climate is similarly prone to climate change, which will increase rainfall frequency and severity and increase flood vulnerabilities in the city. Sea level rise and storm surges will further stress water management systems in the area, and effective flood controls and groundwater management will be all the more important (Cian, 2019). High rainfall and humidity similarly influence the regional hydrology system, with high rates of evapotranspiration in the wet season influencing surface and groundwater resources (Oteri, 2003).

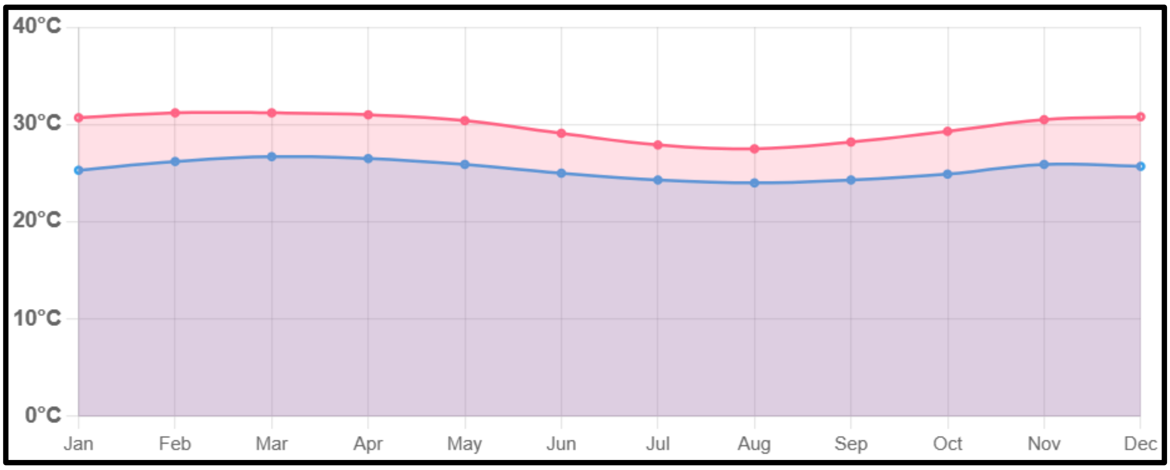


Figure 2.4. Average monthly temperature in Lagos, Nigeria.

Retrieved from https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,lagos-ng,Nigeria

2.3 Hydrology of Lagos

The hydrology of Lagos is defined by its rivers, lagoons, and coastal characteristics. Some of the principal water bodies include the Lagos Lagoon, Ogun River, and Yewa River, all of which drain into the Atlantic Ocean. These water bodies, besides supplying surface water, recharge groundwater, mostly in coastal areas (Oyedele, 2015; Balogun, 2017). High urbanization in the city and a lack of proper drainage systems, has led to increased flooding and contamination of both surface water and groundwater resources (Oteri, 2003; Akinlalu & Afolabi, 2018). Groundwater resources in Lagos are significant due to the lack of public water supply infrastructure. The region's primary aquifers are the shallow unconfined Coastal Plain Sands aquifers, which are prone to contamination, and the deeper semi-confined and confined aquifers, which yield high-quality water but are more susceptible to saltwater intrusion and over-abstraction, particularly in coastal areas such as Victoria Island, Lekki, and Apapa (Ikuemonisan & Ozebo, 2020; Oyedele, 2009).

Figure 2.5. Map of Lagos State showing Local Government Areas (LGAs), including coastal areas such as Apapa, Victoria Island, and Lagos Island

2.4 Study Area

This research is centered on the specific area in Lagos, shown in Figure 2.5.
The area of study covers most of the southwestern part of the city, which comprises Victoria Island, Lekki, Ikoyi, and Apapa, and other coastal towns along the Lagos Lagoon and Ogun River. Borehole locations, indicated by BH in Figure 2.5, are distributed throughout these areas and provide important data required for the comprehension of the groundwater resource, the aquifer characteristics, and the manner in which the development process in these vulnerable areas influences their status (Oyedele, 2015).

By focusing on such regions, the study aims to highlight the challenges faced by Lagos's coastal and urban regions due to urbanization at rapid levels, emphasizing the need for sustainable water management to improve long-term development of groundwater control (Ikuemonisan & Ozebo, 2020; Oyedele, 2009).

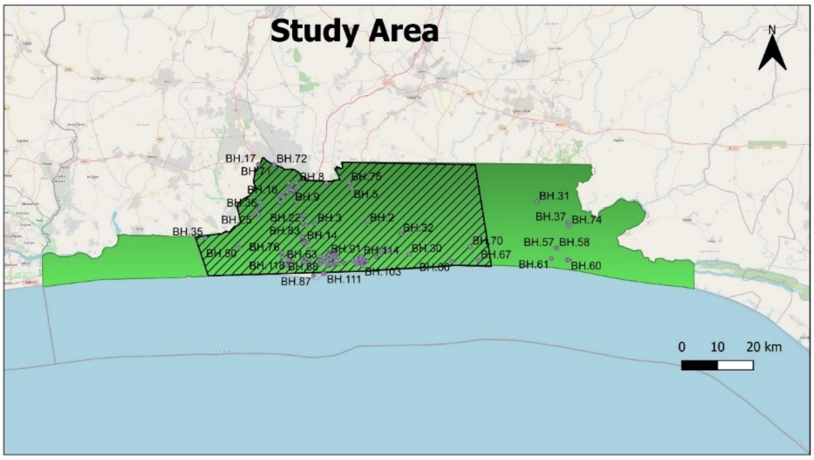


Figure 2.6. Study area with the most number of boreholes reported.

Chapter 3

Lagos Hydrology

3.1. Geological Setting of Lagos

Lagos is situated within the Dahomey Basin, a coastal sedimentary basin with a complicated geological structure that extends from the eastern part of Ghana to the western side of the Niger Delta, passing through Togo and the Benin Republic.
The sedimentary rocks of the Dahomey Basin provide the geological foundation for the hydrogeological systems in Lagos which also have an impact on groundwater storage and flow.
The region is dominated by sedimentary rocks including clays, sandstones, and Quaternary deposits of alluvium (Adelana et al., 2008).
These deposits are a consequence of millions of years of deposition and erosion that have created a layered subsurface with a number of aquifer systems.

The geological setting of Lagos is dominated by Tertiary and Quaternary sedimentary sequences (Figures 3.1 and 3.2), which account for the majority of Lagos State's geology. The Benin Formation, which underlies the majority of the coastal city, consists of thin interbedded shale, clay, and highly porous sandy gravels (Oteri & Atolagbe, 2003). These sediments are composed of silt, clays, and sands with varying grain sizes,
making them highly significant for groundwater storage and flow in the region. The absence of any outcrops of the basement is remarkable, such that the entire geological framework is sedimentary in nature.

The geological formations of the coastal basin were primarily formed during the recent geological period (post-Cretaceous). The Benin Formation (Miocene to Recent), recent coastal alluvial, lagoon, and Coastal Plain Sands (CPS) deposits represent the surface geology (Longe et al., 1987). The sub-surface is made up of the semi-permeable to impermeable geological formations (Akoteyon et al., 2011).
In addition to the CPS, other formations like the Ilaro Formation and Abeokuta Formation provide groundwater from deeper aquifers, although the use of such water may require deeper boreholes in addition to advanced drilling technology (Omosuyi et al., 1999). These deeper aquifers, such as the Abeokuta Formation, are productive but require heavy investment in drilling facilities and are, therefore, less accessible than the shallower CPS aquifers.

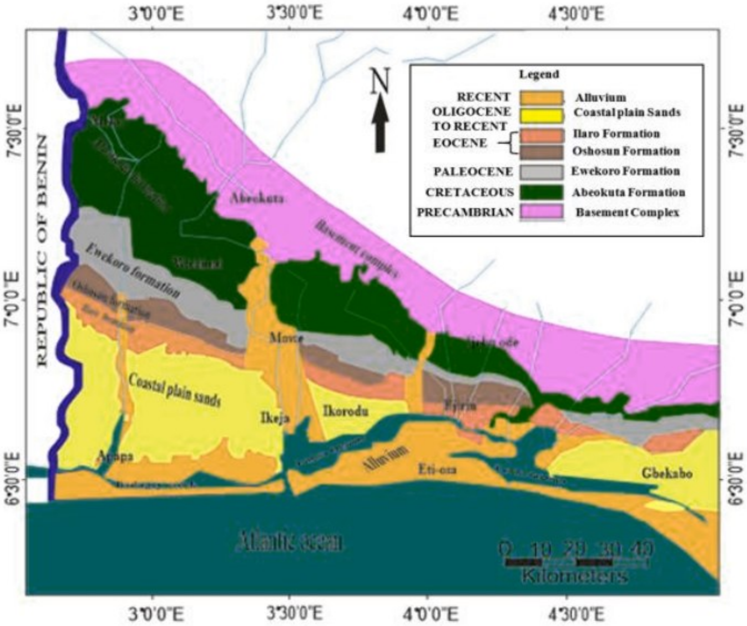


Figure 3.1. Geological map of Lagos area. After Billman (1976).

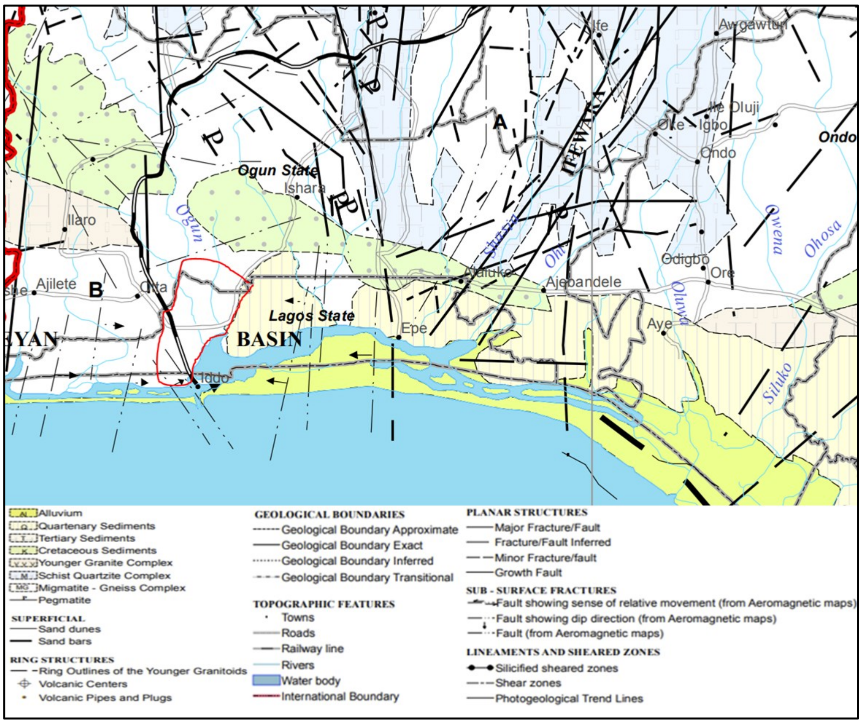


Figure 3.2. Geological map of Nigeria cropped to the Lagos area including faults

3.2. Stratigraphy of Lagos and Dahomey Basin

Several studies have been carried out on the stratigraphy of the Lagos Metropolitan Area and its surrounding regions, including works by Ako et al. (1981), Omatsola and Adegoke (1981), and Adekeye (2005). These studies have discovered and identified five major lithostratigraphic formations, from the Cretaceous to Tertiary periods, that are important for understanding groundwater movement and availability in the region.

3.2.1. Abeokuta Group

It's the Dahomey Basin's oldest sedimentary sequence. The formation consists mainly of siltstone, poorly sorted ferruginous grit siltstone, and mudstone with shale-clay layers. The Abeokuta Group is divided into three sub-formations: Ise Formation, Afowo Formation, and Araromi Formation (Omatsola & Adegoke, 1981).

- **The Ise Formation**

It consists of basal conglomerate with interbedded coarse to medium-grained loose sands and sandstones, which are highly productive for groundwater due to their high porosity (Nton, 2001).

- **The Afowo Formation**

It features coarse to medium-grained sandstones with interbedded siltstones and clays. It was deposited in a littoral or estuarine environment (Billman, 1976).

- **The Araromi Formation**

It is marked by fine- to medium-grained sandstones overlaid by shale and siltstone, with occasional interbedded limestones (Ogbe, 1970).

3.2.2. Ewekoro Formation (Paleocene)

The Ewekoro Formation is mostly made up of fossiliferous limestone and is located conformably above the Abeokuta Group (Adegoke, 1969). It is widely distributed across the Dahomey Basin (Adegoke et al., 1980). While it is important for a regional geological understanding, it is not a significant source of groundwater in Lagos, because of its low permeability and low fossil material.

3.2.3. Akinbo Formation

The Akinbo Formation overlies the Ewekoro Formation and it is identified by its glauconitic composition. The upper part of the Akinbo Formation is identified by pure grey, gritty sand, lacking red mottling, and with minor clay (Oke et al., 2016).
The formation is not considered a major aquifer.

3.2.4. Oshosun Formation

The Oshosun Formation, which is quite varied in both lateral and vertical lithology, is found overlying the Akinbo Formation and is composed of greenish-grey clays, sandstone, and clayey shale (Okosun, 1998). The upper part of the formation is an unconsolidated and loosely compacted mixture of sandstone and clay while the basal bed comprises facies of sandstone, mudstone, claystone, and shales.

3.2.5. Ilaro Formation

This formation is above the Oshosun formation and mainly consists of coarse sand stones (Slansky, 1962). It is a highly aquiferous formation with an average thickness ranging from 30 m to 60 m (Oke et al., 2016), making it significant for groundwater supply, particularly in the central and western parts of Lagos.

3.2.6. Coastal Plain Sands / Benin Formation

The primary aquifer system in Lagos is the CPS, the youngest geological succession in the Dahomey Basin. It consists of poorly stored sands and clayey layers. The CPS is well-noted for its groundwater resource; however, this resource is vulnerable to saltwater intrusion (Akinlalu & Afolabi, 2018). The thickness of the formation increased from north to south with reports of up to 400 m of CPS deposits near the coast (Agagu, 1985).

3.2.7. Recent sediments / alluvial deposits

Recent sediments, which include unconsolidated sands, clays, and muds, are found along the coastal area. Because of their closeness to urban areas and industrial waste, these sediments are the most vulnerable aquifers along the coast (Nton, 2001). But during the rainy season, they also contribute to groundwater replenishment.
Figure 3.3 shows the generalized stratigraphy of the Dahomey Basin.

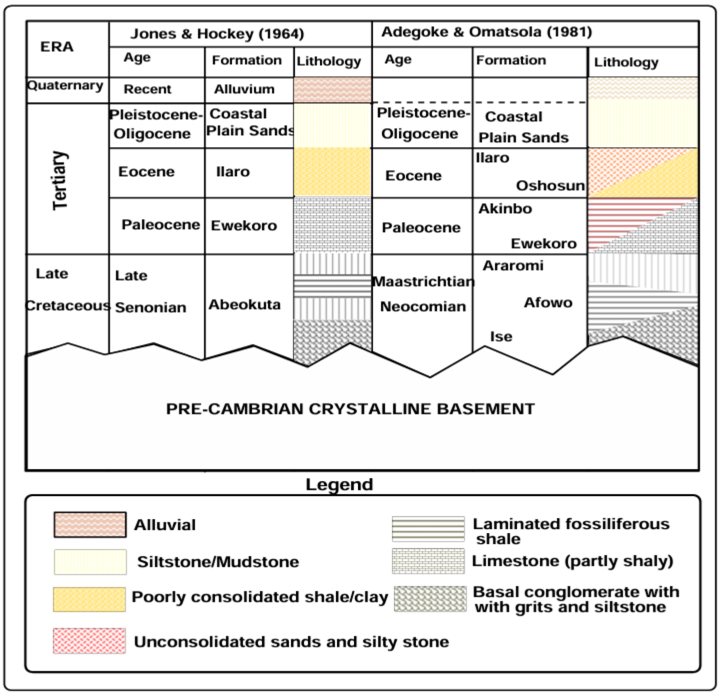


Figure 3.3. Generalised stratigraphy of the Dahomey Basin

3.3. Lagos Hydrogeological Setting

The hydrogeological setting of Lagos is characterized by its aquifer systems that are critical in providing freshwater to Lagos.

Numerous geophysical studies carried out throughout the Lagos megacity to define the development of groundwater resources included borehole lithologic correlation and aquifer delineation in parts of the coastal basin of Southwest Nigeria. (Longe et al., 1987). These studies have highlighted the complexity and significance of the aquifer systems in Lagos. Lagos has a multilayer aquifer system which are varying from unconfined to confined in places and depths and made up of four hydrostratigraphic units. (Figure 3.4)

These aquifers are mostly composed of sand, gravel, clay, and silt, and vary in their permeability and susceptibility to contamination.

The superficial alluvial aquifer, the Upper Coastal Plain Sands (UCPS) aquifer, the Lower Coastal Plain Sands (LCPS) aquifer, and the deeper confined Abeokuta Sands aquifer are the main aquifers, classified from shallow to deeper (Coode-Blizzard et al., 1996; Bale et al., 2004; Longe et al., 1987).

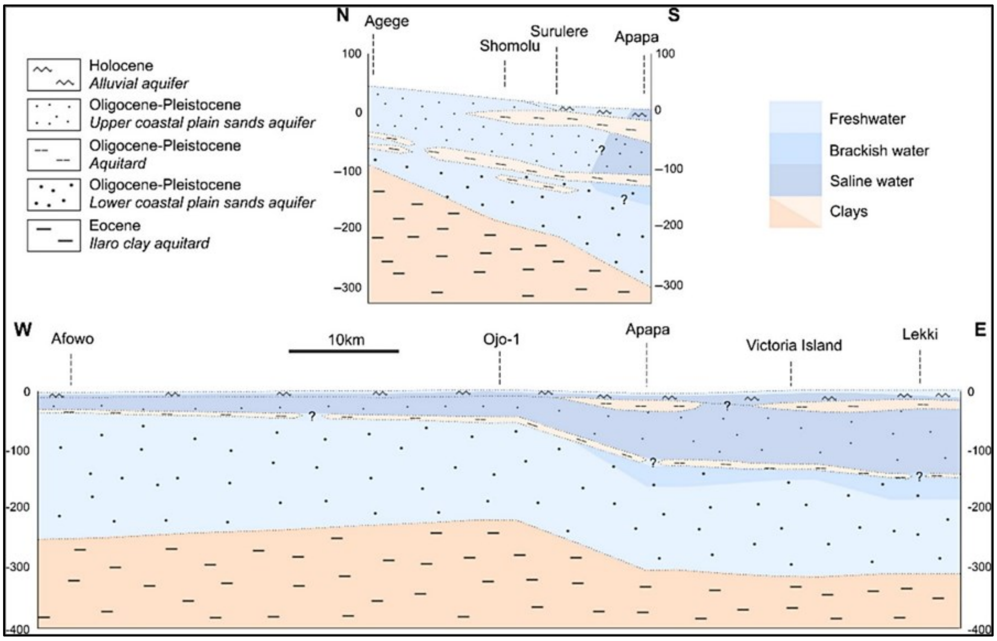


Figure 3.4. North to South and West to East Hydrogeological cross-sections of Lagos aquifer system, showing the main aquifers units and the distribution of fresh, saline, and brackish waters in 1995 (modified after Coode-Blizzard et al., 1996).

The Coastal Plain Sands (CPS) aquifer is the most accessible and widely used aquifer in Lagos. It consists of medium to coarse sands with a very high permeability, making it a significant source of groundwater in the region.

The CPS aquifer is extremely vulnerable to saltwater intrusion in coastal areas such as Lekki, Victoria Island, and Apapa, because of over extraction and its location close to the ocean. (Akinlalu & Afolabi, 2018; Adelana et al., 2008).

In addition to CPS, the Ilaro and Abeokuta Formations supply groundwater from deeper aquifers. Even though these aquifers provide high-quality water and they play a major role in the water supply of the area, their utilization is still restricted to industrial applications and they are less accessible because of the high cost of drilling.

For example, deep boreholes are necessary to access the groundwater resources of the Abeokuta Formation, which is situated in the northern regions of Lagos at a depth of around 750m (Adelana et al., 2008; Adeleye, 1975).

The hydrogeological characteristics of the Lagos coastal aquifers are influenced by Tertiary and Quaternary sediment deposits, with shale and clays acting as impermeable layers that separate the aquifers. Shallow unconfined aquifers, which are less than 30m deep below ground level, are typically found around the coastline (United Nations, 1988). The CPS aquifer is subdivided by clayey or silty layers into three primary horizons: the Upper Coastal Plain Sands aquifer, the Lower Coastal Plain Sands aquifer, and the first horizon, which consists of recent alluvial sediments (Kampsax & Shwed, 1977; Longe et al., 1987). The Ilaro and Ewekoro Formations are not considered key aquifers in Lagos due to their predominantly shale and clay composition.

Figure 3.5 shows a schematic hydrogeological cross-section along the coastal area of Lagos State.

There are notable variations in the water quality and susceptibility to contamination in Lagos' aquifer system. The unconfined aquifers in the coastal fringe are made up of superficial alluvial deposits that are between 10 and 30m thick, with freshwater found inland and saltwater close to the coast. With a depth of 10 to 100m, the UCPS aquifer is mostly made up of coarse, unsorted sands and is normally unconfined inland but semi-confined along the coast. Similar to the CPS, the coastal margin of this aquifer is susceptible to saltwater intrusion (Adiat, 2019; Longe et al., 1987; Oloruntola et al., 2017).

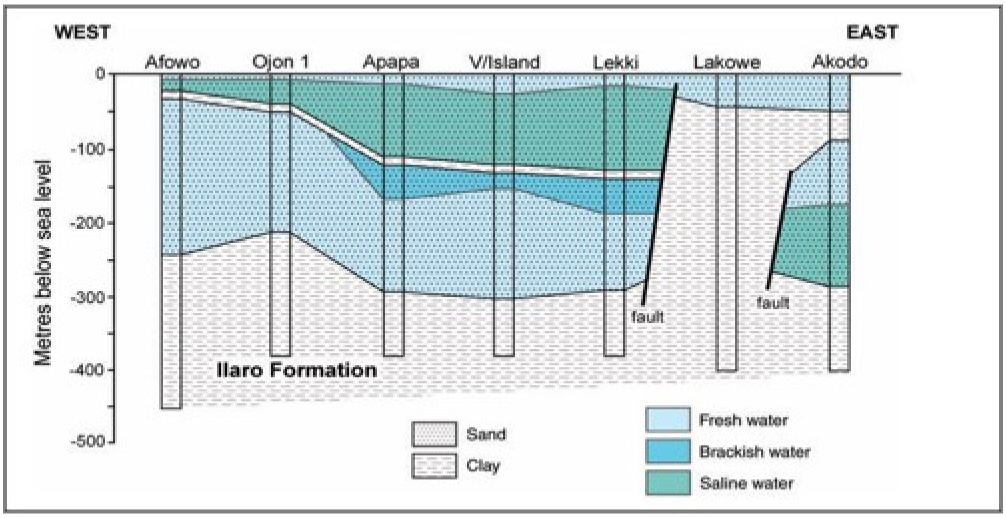


Figure 3.5. Hydrogeological cross-section in Lagos. Modified after Adelana et al. (2008)

3.4. Aquifer Systems in Lagos

In Lagos, the aquifers' depths differ significantly. The first aquifer extends from the surface to about 12 m below the ground and is made of clay and sand. It is generally considered to have minor importance for large-scale water supply purposes and it is prone to pollution because of its limited depth. The second aquifer, found between 20 m and 100 m below sea level, is more important.

Central Lagos is home to the third aquifer, which is found at depths of 130 to 160 m. A thick layer of shale called the Ewekoro Formation divides the third aquifer from the fourth, the Abeokuta Formation, which is situated at a depth of roughly 450 m (Hockey, 1964). Although the Abeokuta Formation offers excellent groundwater, its depth makes it costly and challenging to extract.

A summary of the main features of the aquifer system is provided in the following:

1. **Recent Sediments Aquifer (0–20 m, Unconfined)**

- Lithology: Fine sands, silty clay, and organic materials.
- Hydrology: This shallow aquifer experiences rapid recharge from rainfall, especially during the wet season. However, it is highly vulnerable to contamination due to its proximity to surface activities, such as industrial waste and urban runoff. This aquifer is typically found in coastal regions like Lekki and Apapa, which are prone to increased pollution risks.

2. **Coastal Plain Sands (CPS) Aquifer (20–150 m)**

- Lithology: Medium to coarse sands interbedded with clay.
- Hydrology: The CPS aquifer is the primary source of municipal and industrial water supply in Lagos. Despite its high permeability, over-extraction has led to saltwater intrusion in several coastal zones. This aquifer is heavily exploited, particularly in central and coastal areas like Lekki, Victoria Island, and Badagry.

3. **Ilaro Formation Aquifer (150–250 m, Confined)**

- Lithology: Fine sand, silty clay, and ferruginous sandstone.
- Hydrology: The Ilaro Formation is a confined aquifer, typically found in the central parts of Lagos, such as Ikeja and Alimosho. It is less prone to contamination due to its large depth and the confined nature. However, it experiences slow recharge rates, making it less susceptible to rapid recovery, and is primarily tapped for industrial and municipal water supply.

4. **Abeokuta Formation Aquifer (250–400 m, Deep Confined)**

- Lithology: Gravelly sands, sandstones, and fractured rocks.
- Hydrology: The Abeokuta Formation is an important source of high-quality groundwater in northern Lagos, including areas like Ikorodu and Epe. This aquifer, however, has very slow recharge rates due to its depth and the

geological barriers surrounding it. Despite its high-quality water, it is generally only accessible through deep drilling, making it expensive to exploit and limiting its use to industrial applications.

Chapter 4

Data Collection & Processing

4.1 Data Collection

The data for this study was collected from multiple sources, including previous studies, published articles, the Lagos State Water Corporation, and the ENGULF project. The initial step involved gathering all available borehole data, including borehole names, coordinates, and lithology information, regardless of whether the lithological data was fully reported or not. A complete list of all boreholes collected before filtering is provided in Table A1 (Appendix A).

Significant gaps existed in the dataset, particularly in the lithological information of some boreholes. While several boreholes were recorded, their lithological descriptions were either incomplete or entirely missing. Since the primary goal of this study is to construct a 3D model that is supposed to represent the aquifer system's behavior, data processing and filtering was necessary to select and keep only usable and more relevant boreholes.

4.2 Data Processing

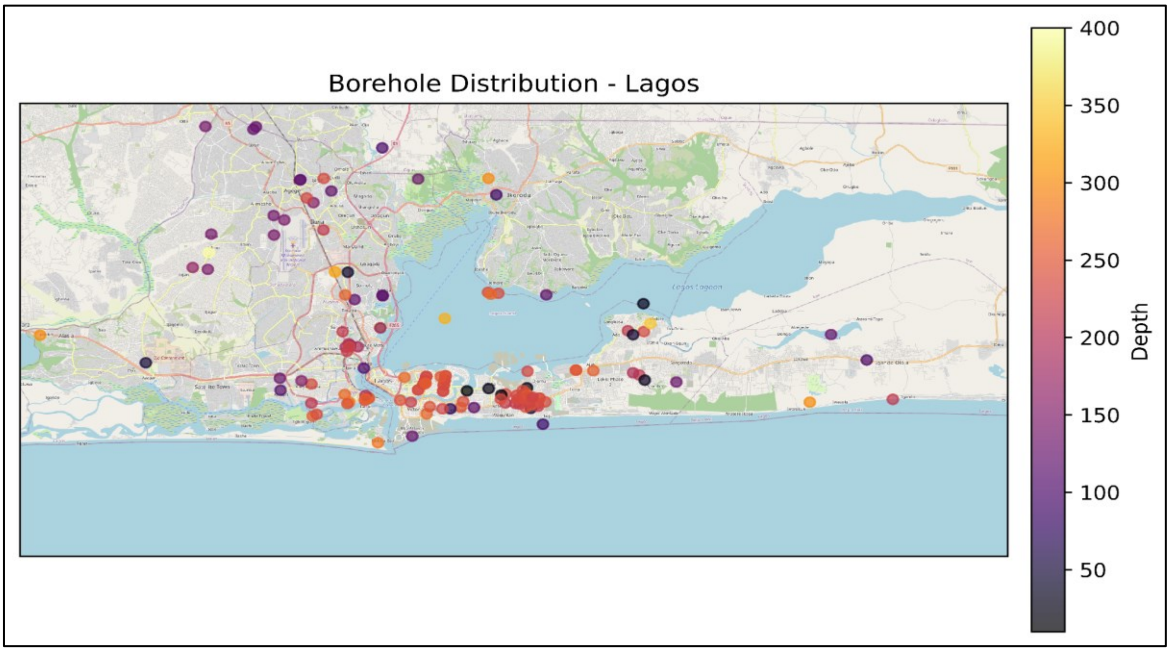
Once all data was collected, the next step was to focus on the data that contained complete and reliable information. As the goal of this study is to construct a 3D model that represents the aquifer system's behavior, boreholes without lithology data were excluded from the dataset. The processed data, now containing only boreholes with lithology information, is shown in Table A2 (Appendix A).

To gain a better understanding of the borehole distribution, boreholes were imported to QGIS. Figure 4.1 shows the distribution of the boreholes and their corresponding depths.

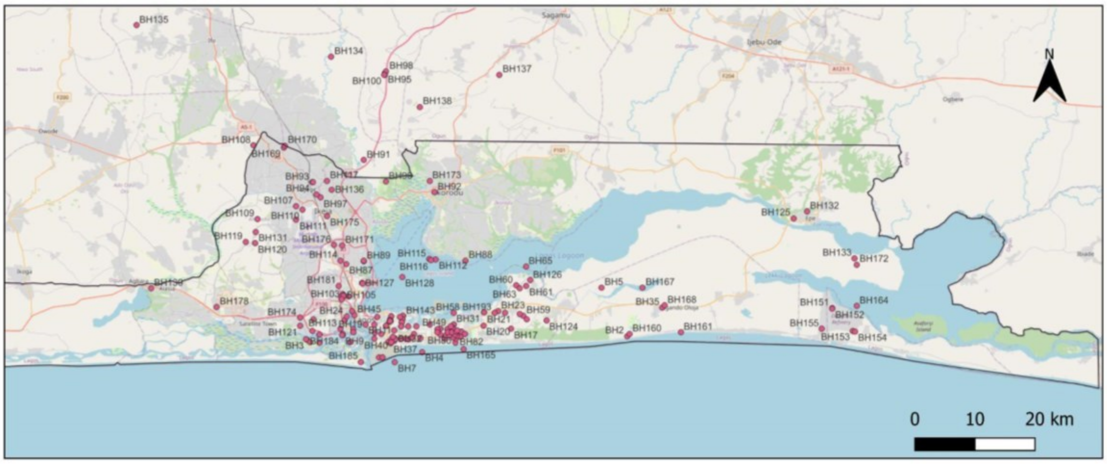
Upon analyzing the data in Figure 4.1, several issues became apparent. Some boreholes were placed in the lagoon or outside the Lagos area, which indicated either incorrect data entry or gaps in the dataset. These boreholes were removed from the study, as they could potentially distort the 3D model.

Additionally, several boreholes are clustered in the same locations. In such cases, only one borehole was kept, while the others were excluded to prevent overlap (shown in Figure 4.2) during the import process into Leapfrog software. Furthermore, there were a few boreholes that, despite being in the same area, showed differing lithological trends compared to others nearby. These inconsistencies were addressed by excluding the outliers to ensure a more coherent dataset.

The final borehole distribution, with validated coordinates and depths, is presented in Figure 4.3. This subset of boreholes was retained for further analysis and modeling.



(a) Zoom in view of distribution of boreholes and their depth



(b) Borehole distribution in Lagos

Figure 4.1. Borehole distribution with (a) depth and (b) ID code for identification

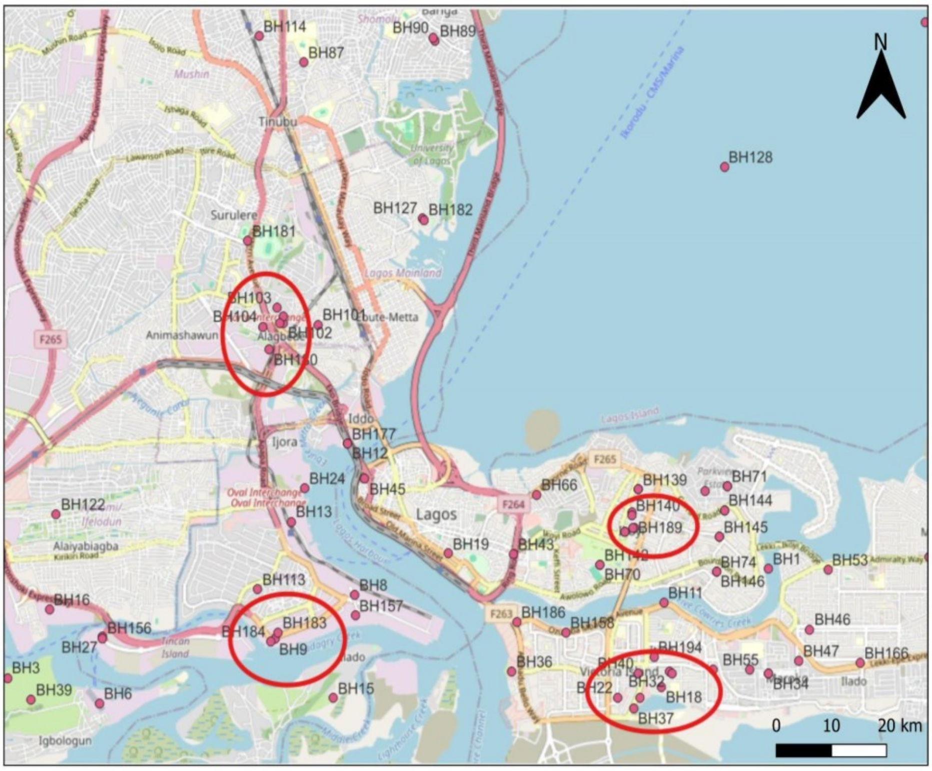


Figure 4.2. Map showing overlapping boreholes in some specific area

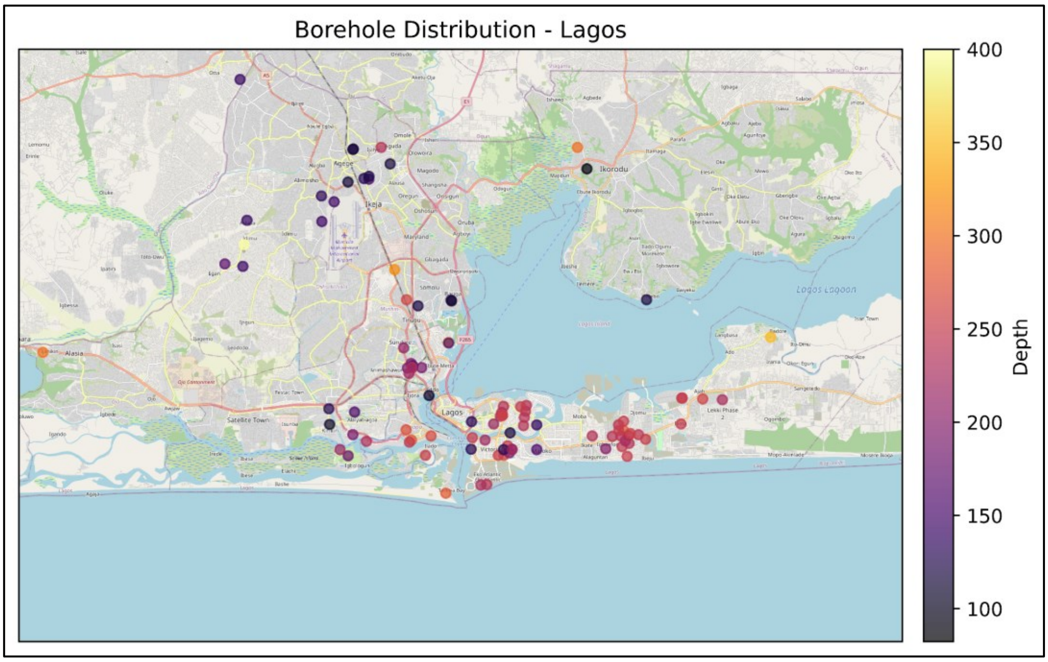


Figure 4.3. Distribution of boreholes after filtering and excluding useless data

4.3 Lithological Data Simplification

Lithological data in the collected boreholes were reported by various studies, each with its own interpretation and classification. To ensure consistency and facilitate the creation of the 3D model, the data was categorized into three main groups due to the complexity and diversity of the lithologies found across the research area:

1. **Sand**: Representing permeable layers, these sands are highly permeable and allow for significant groundwater flow.
2. **Clay**: Representing impermeable layers, which restrict groundwater movement and storage.
3. **Intermediate**: These layers, including sandy clay, clayey sands, and similar materials, exhibit mixed permeability characteristics and influence groundwater flow in a more complex manner.

The categorization of lithological data was essential for creating a 3D model with Leapfrog software. This method of classifying the lithologies made the dataset more manageable while remaining comprehensive enough to represent actual geological conditions. The idea was to make the data simpler without losing important details so that the model could accurately represent the subsurface layers of Lagos.

This method was created especially to maintain the greatest degree of accuracy to the real geology, ensuring that the simplified categories matched the observed features of the aquifer system. The classification was carried out in a way that maintains similarity to actual conditions so that the model closely simulates the aquifer system behavior. This simplification helped the model to demonstrate realistic and reliable groundwater flow behavior, aquifer response, and interaction between different geologic layers.

One example of the lithology data used in this study is shown in Figure 4.4. The remaining lithological profiles and borehole data can be found in the Appendix B. Such profiles, together with the depth intervals and corresponding lithological materials, were used to validate and refine the classification of sand, clay, and intermediate layers so that the simplifications were as realistic as possible. Thus, the model built in this study is a realistic representation of the geological structure and behavior of the Lagos aquifer system.

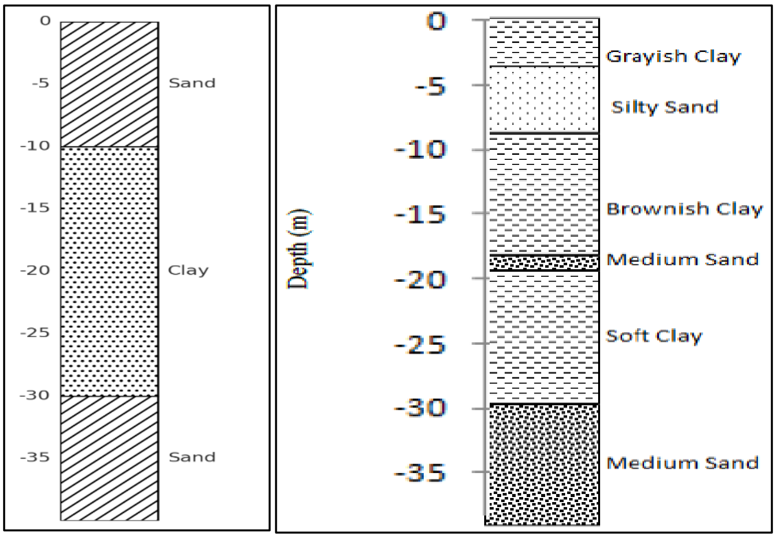


Figure 4.4. Typical lithology for the area around the lagoon (borehole 11) and as re-classified to build-up the 3D hydrogeological model

Chapter 5

Constructing 3D model in Leapfrog

5.1 Introduction to Leapfrog and modeling approach

The main goal of this thesis is to use the geological and hydrogeological data that is currently accessible to develop a 3D reconstruction of the Lagos aquifer system. Leapfrog was used for developing the 3D model, which provides a comprehensive understanding of the structure and behavior of the aquifer system based on lithological profiles, drill data, and other geological information.

For many years, the presentation of geological structures has been limited to a 2D environment. The development of powerful software for 3D geological modeling has been a significant breakthrough in the field of geology. 3D geological modelling tools have several advantages, such as the fact that they are fast in big data processing, they use predefined geological features (i.e., faults, intrusions, deposits) when evaluating data and enable later adjustment, in order to build a geological model as close as possible to the real model in nature.

Leapfrog was chosen for this study due to its advanced 3D modeling features, which allowed the creation of an accurate and dynamic representation of the Lagos aquifer system.

5.2 Data importation on Leapfrog

After completing the data collection, borehole selection, and lithological simplification, the final dataset, consisting of selected boreholes with known coordinates and simplified lithologies, was imported into Leapfrog. A snapshot of the scene showing the imported boreholes is provided below to give a visual representation of the model setup. Figure 5.1 shows the Leapfrog 3D environment from two different perspectives. This figure shows how the boreholes were placed in the software, serving as the foundation for the subsequent modeling steps.

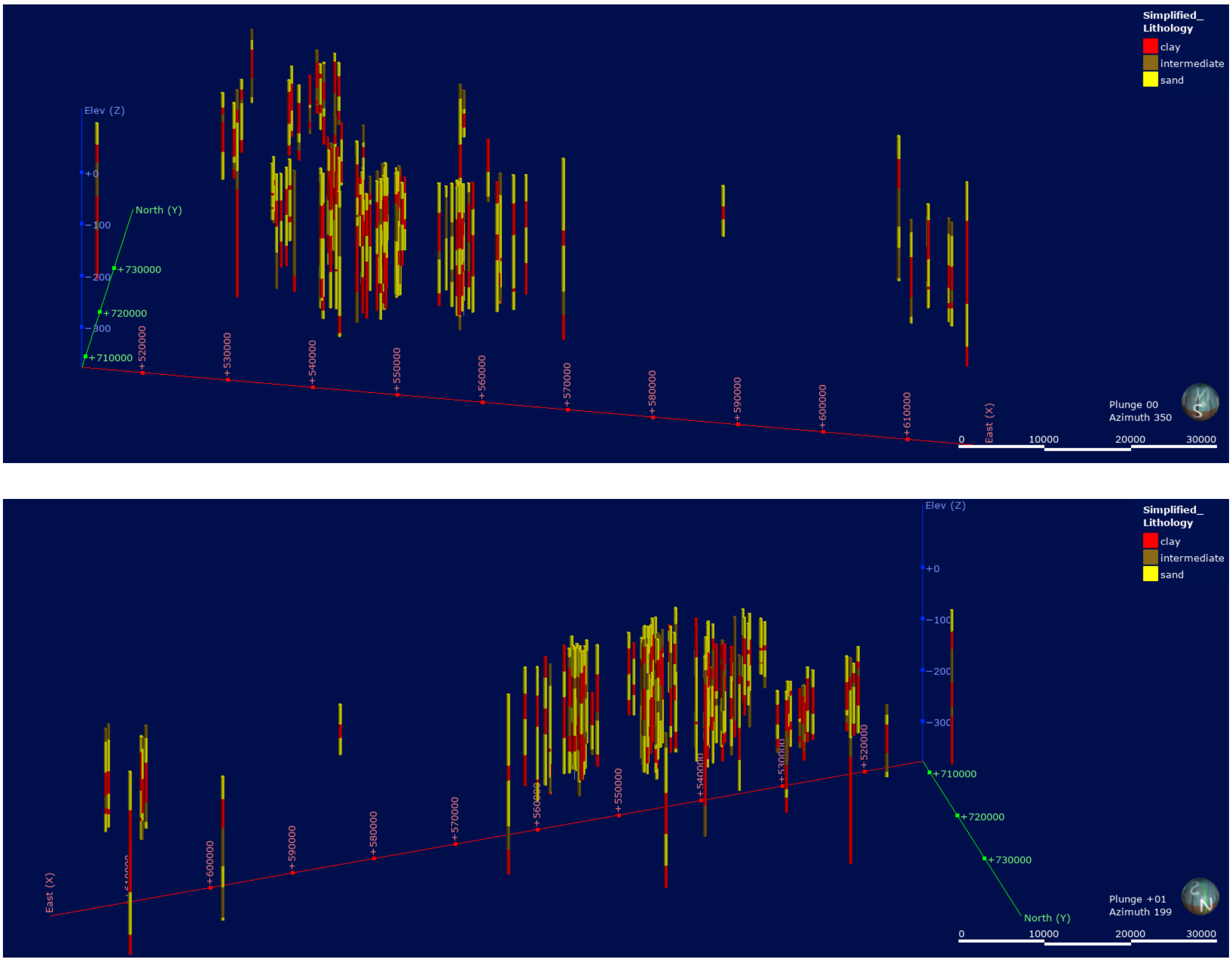


Figure 5.1. Leapfrog 3D view of imported boreholes with simplified lithological categories

Importing the data into Leapfrog also allowed for the detection of any last-minute inconsistencies which were not visible during earlier QGIS filtering stages.
Certain issues became apparent upon visualizing the boreholes in 3D:

- Some boreholes were significantly shallower than others, and thus excluded in order to maintain a consistent depth range across the dataset.

- Other boreholes overlapped spatially with nearby ones but had entirely different lithological sequences, likely due to conflicting data sources, different interpretation, or representing local-scale heterogeneities, which are worth smoothing in a regionals-scale model.

In this stage, boreholes that overlapped or conflicted with the broader stratigraphic trend were visually re-evaluated. In a few cases, boreholes were further excluded due to spatial overlap or isolated lithological behavior, as previously described in the data filtering process. These boreholes are shown in Figure 5.2.

These additional checks and exclusions helped ensure that only the most reliable and geologically coherent data were used in the 3D reconstruction. With the refined borehole dataset in place, the next step was to analyze geological trends by generating cross-sections, which guided the stratigraphic classification process and model construction.

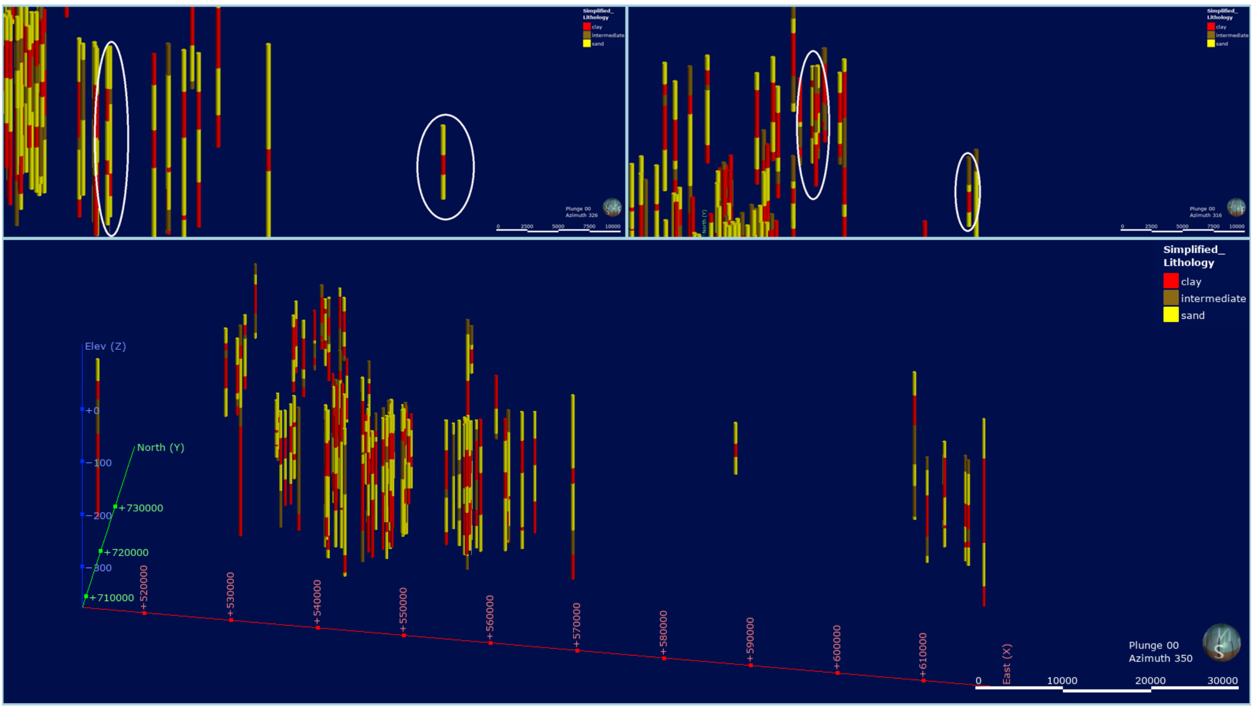


Figure 5.2. Zoomed-in views highlighting boreholes with inconsistencies

5.3 3D Modeling process

Once the data was imported into Leapfrog, several cross-sections were created from North to South, East to West, and along the coastline. These cross-sections were generated using Leapfrog's 2D visualization tools "drillhole correlation" to provide an initial understanding of the spatial distribution of lithologies across the study area. The cross-sections allowed to analyze the geological trends and structures, helping to identify how the different lithological layers were distributed in the subsurface. (Figure 5.3)

Based on the analysis of these 2D views that are shown in Figures 5.4a & 5.4b 5.4c, the next step was to classify the lithologies based on their stratigraphy. The layers were named starting with **D1** for the youngest layers, and this naming continued through **Dn** for the oldest. This stratigraphic classification was essential to organizing the geological layers and building an accurate 3D model.

The process of classifying the stratigraphy was one of the most challenging aspects of the modeling. I created three to four models, each with slightly different interpretations of the stratigraphy. Ultimately, the model that was the most detailed and appeared to best represent the real-world conditions was chosen and used in this thesis. This model was refined and provided the closest approximation of the subsurface structure of the Lagos aquifer system.

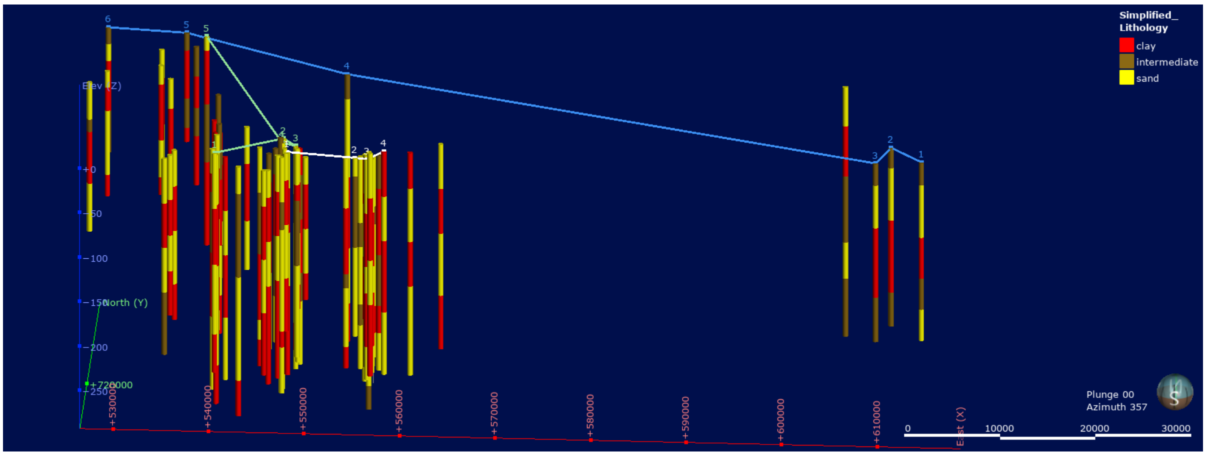
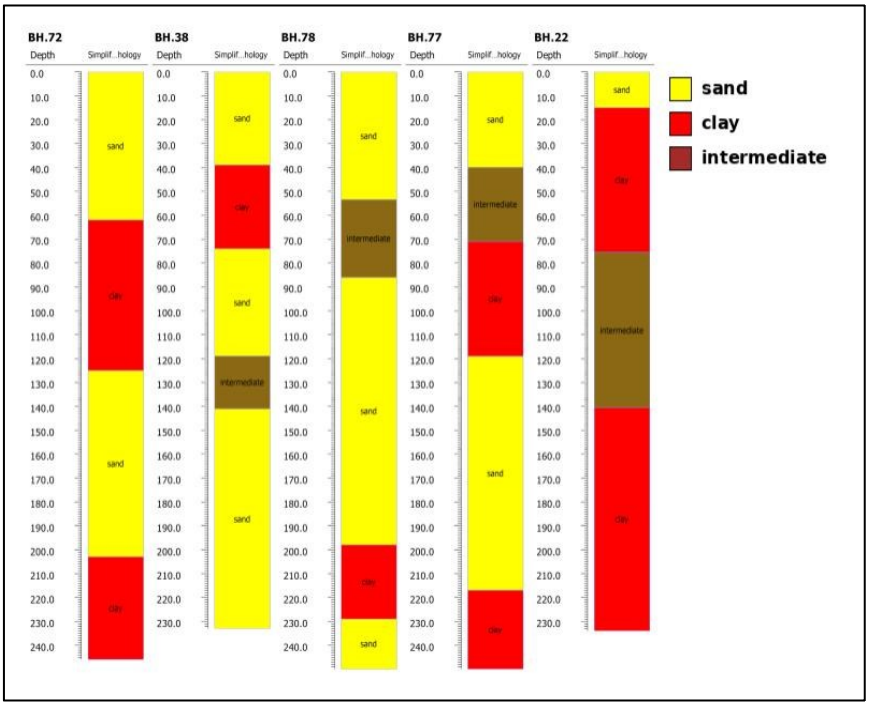
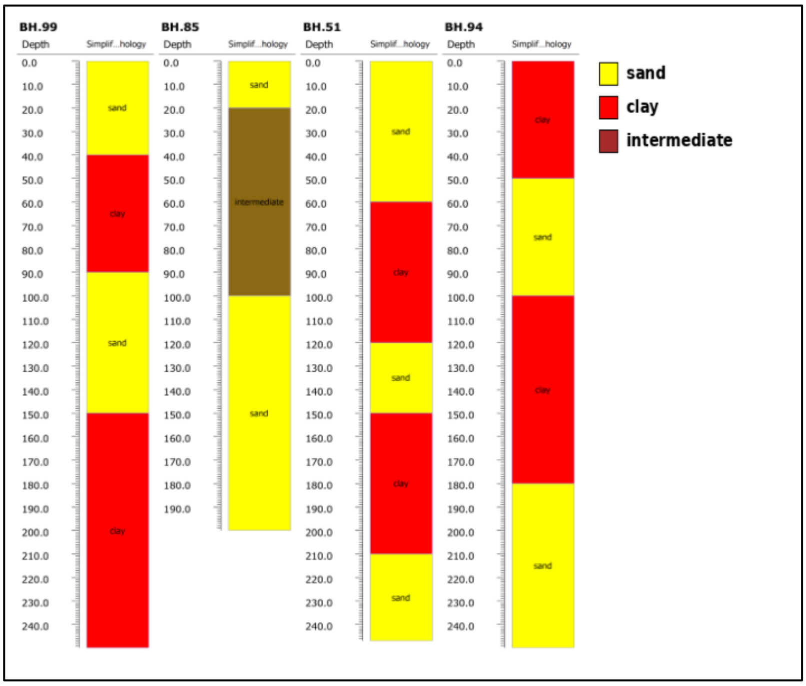


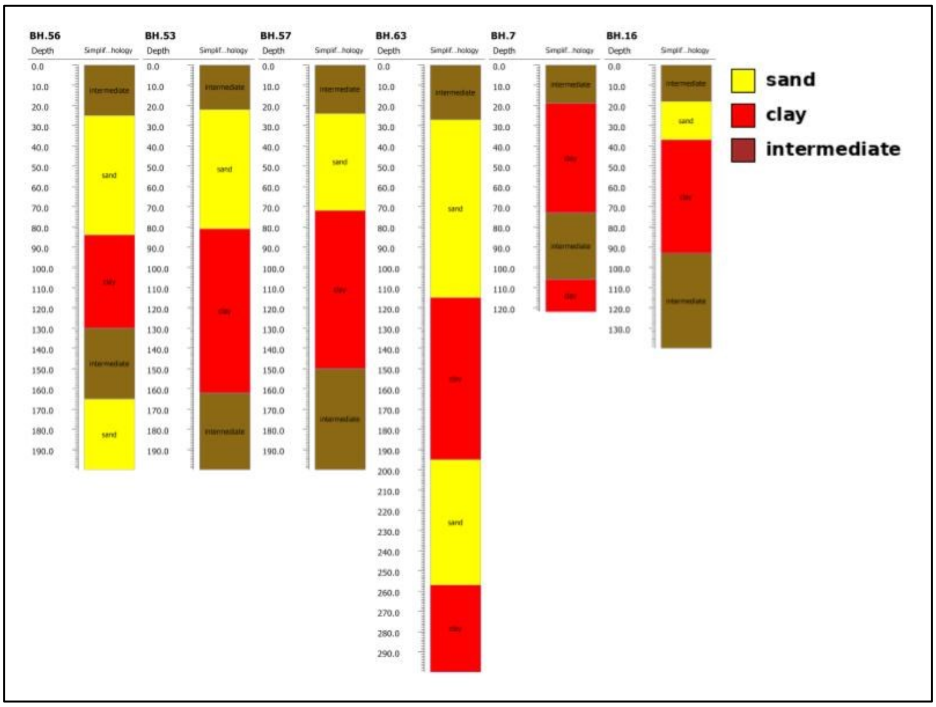
Figure 5.3. Created cross sections through study area



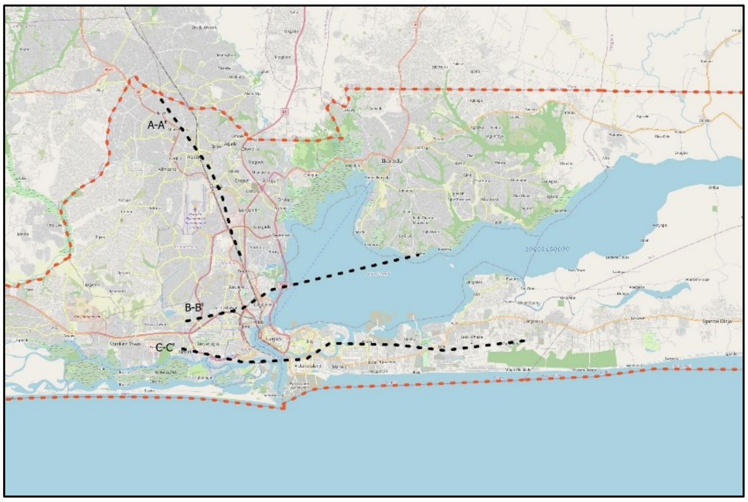
(a) North to south cross section lithology profile (AA')



(b) West to east cross section lithology profile (BB')



(c) Cross section along coastline (CC')



(d) Cross section showing in map

Figure 5.4. Lithology profiles whose traces are shown in the inset map

The model was built step by step by simulating the geological layers one at a time, starting from the youngest and moving downward through the stratigraphy. Each unit was created based on the interpreted lithological data from the selected boreholes. Figure 5.5 shows the first step in this process, representing the youngest sandy layer distributed across the study area. This layer, classified as D1, highlights the topmost permeable unit in the system.

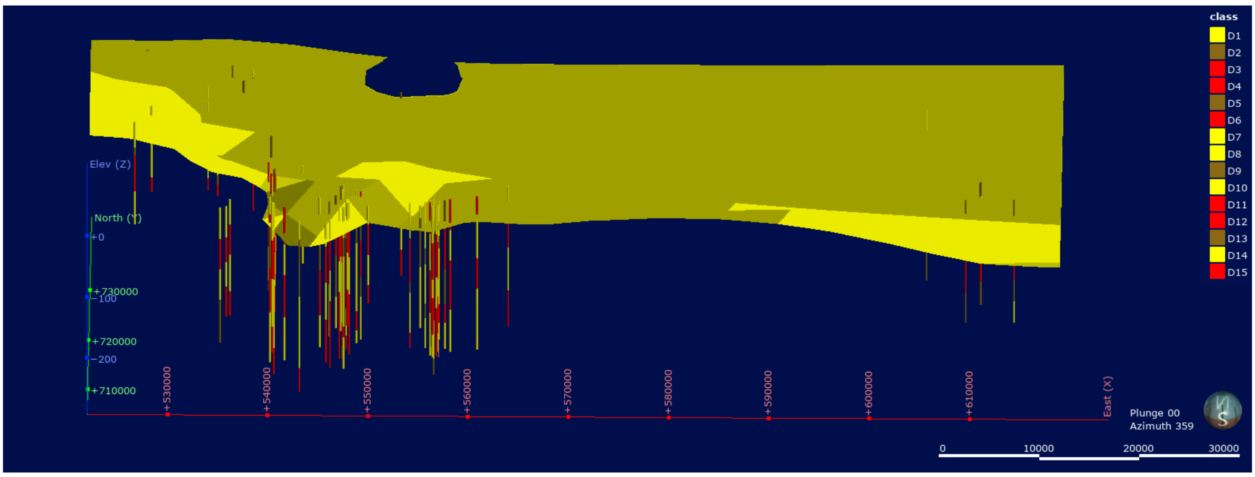


Figure 5.5. First step of 3D modeling, showing the youngest sandy layer

In the next stage, the first intermediate layer was introduced (Figure 5.6). Interestingly, in certain areas, this layer appeared above the sand, suggesting that in localized zones, the intermediate material is even younger than the upper sandy deposits. This behavior emphasizes the complex sedimentary processes across the region and reinforces the importance of a layer-by-layer modeling approach.

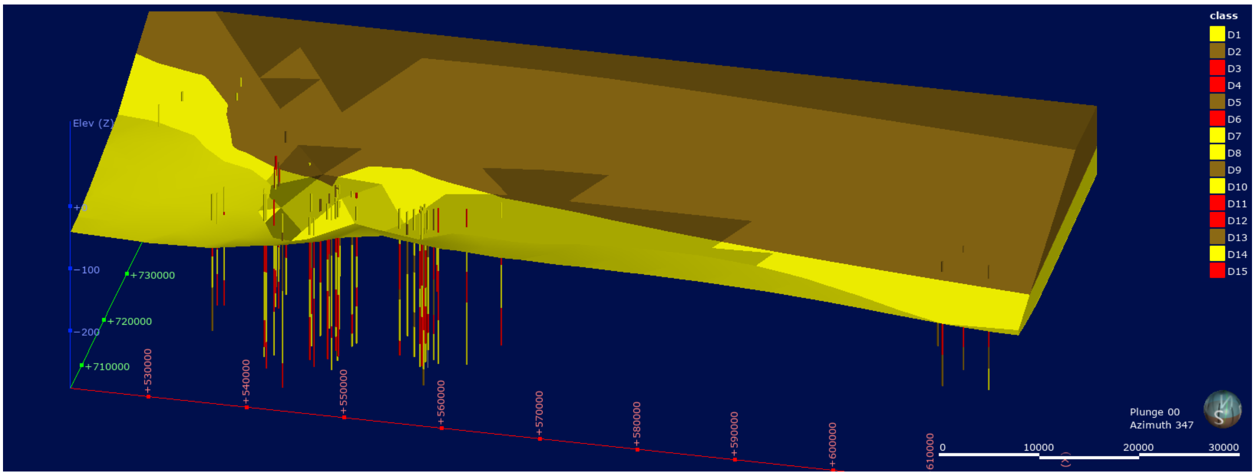


Figure 5.6. Second step of 3D modeling, showing the youngest intermediate layer

Following that, clay was added to the model (Figure 5.7). Overall, clay represents the youngest unit across the broader study area, often forming the topmost layer above both sand and intermediate materials.

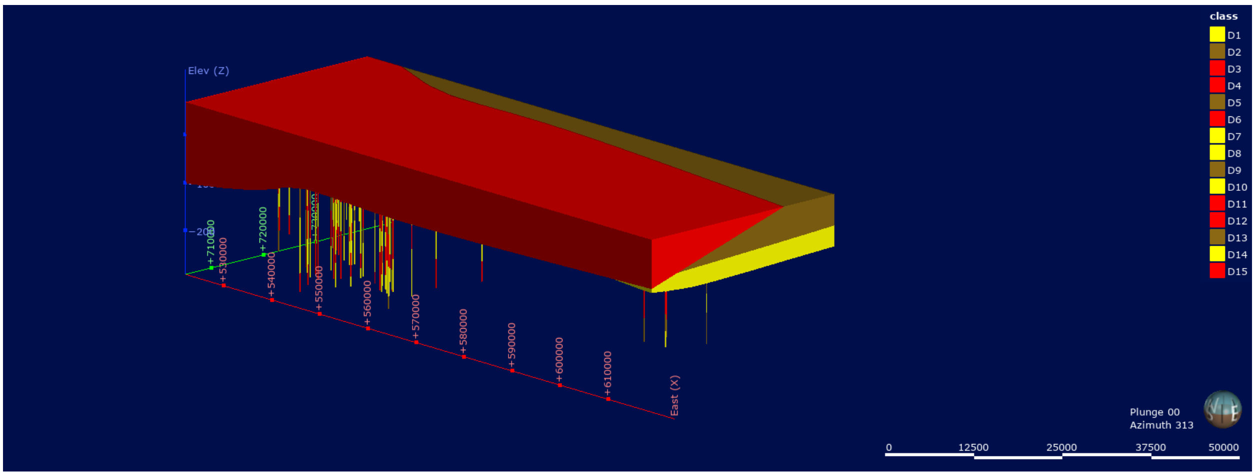


Figure 5.7. Youngest clayey layer

By adding each layer one by one and using the information from the boreholes, the model slowly took shape and became a clear 3D representation of the Lagos aquifer system. Figure 5.8 shows the final result of the 3D model.

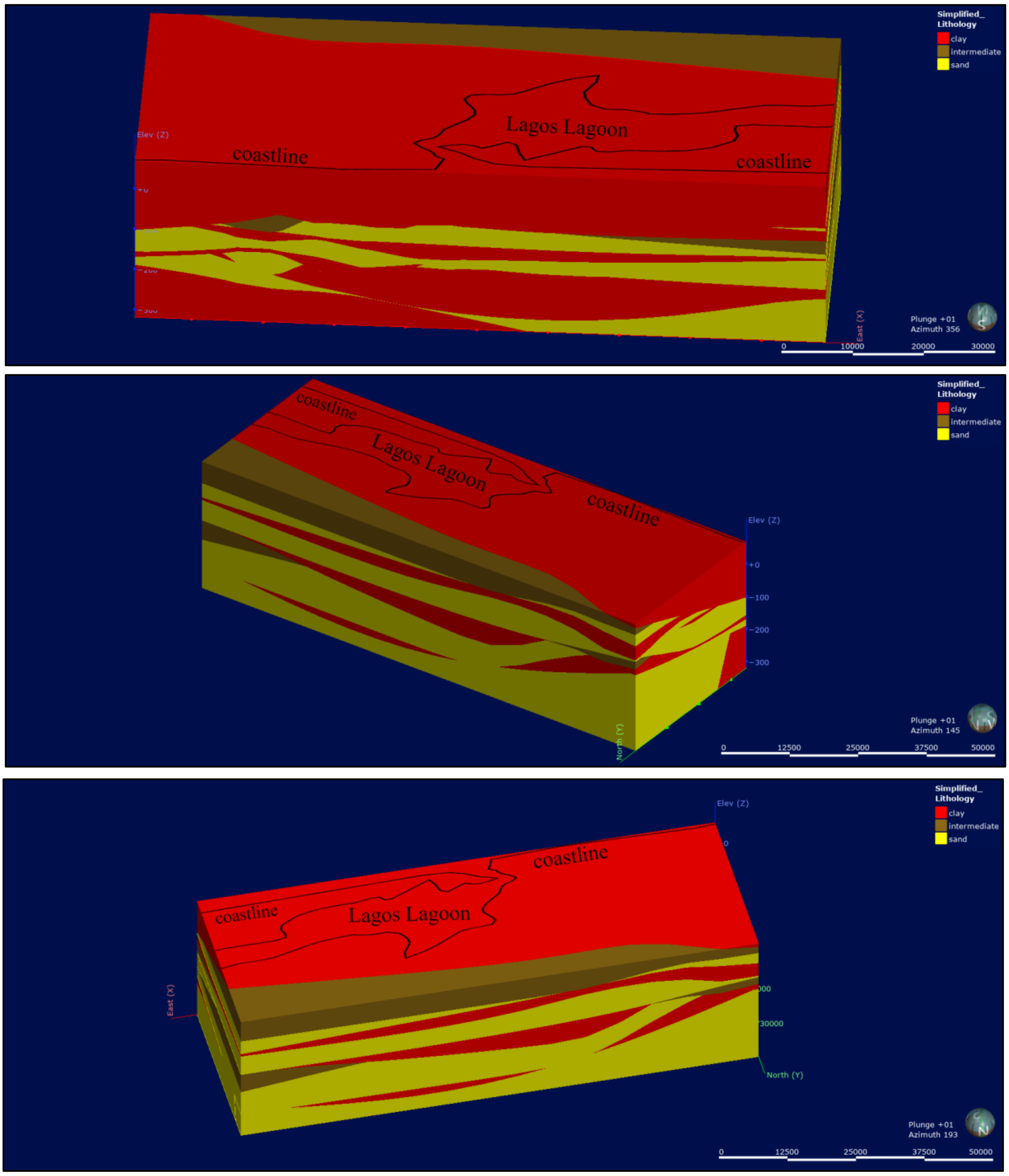


Figure 5.8. Final 3D geological model of the Lagos aquifer system

Chapter 6

Results and Discussion

Based on the final 3D geological model created with Leapfrog, the Lagos aquifer system is largely composed of sandy layers, which form the main groundwater-bearing units. Sandy units are extensive, continuous, and appear at multiple depths across the study area, indicating a complex but well-connected aquifer system.
To better understand the internal structure and layering of the subsurface, multiple vertical cross-sections were extracted from the 3D model. These cross-sections provide better and more clear insights into lithological variation, the continuity of aquifer layers, and the thickness of clay and intermediate units that separate or confine the aquifers.

Figures 6.1 to 6.4 show selected cross-sections at different parts of the study area. In each, yellow represents permeable sandy units, red represents impermeable clay layers, and brown represents intermediate lithologies like sandy clay or clayey sand.
Across all sections, we can observe:

- Dominance of Sand Layers: Most of the groundwater system is supported by thick, continuous sand bodies. These units represent the primary aquifers and suggest high storage and transmission potential.

- Discontinuous Clay Units: While clay layers are present and sometimes extensive near the surface, they are not always continuous at depth.

- Intermediate Layers: The intermediate layers appear as transitions between sand and clay and show more complex geometries.

The model also provides ideas about potential risks. In many areas—particularly in the central and coastal zones—thick clay units overlie sandy aquifers. These compressible clays may compact if underlying water is over-extracted and causing land subsidence. In addition, coastal sections show sandy aquifers beneath thin clay caps, making them potentially vulnerable to sea-level rise and saltwater intrusion, especially if groundwater levels fall below sea level.

Looking more closely at the four cross-sections:

- Figure 6.1, from the eastern part of the study area, shows a confined aquifer system. Thick sandy layers are trapped beneath a prominent clay layer, which helps retain pressure but poses a high risk of land subsidence if groundwater is excessively withdrawn.

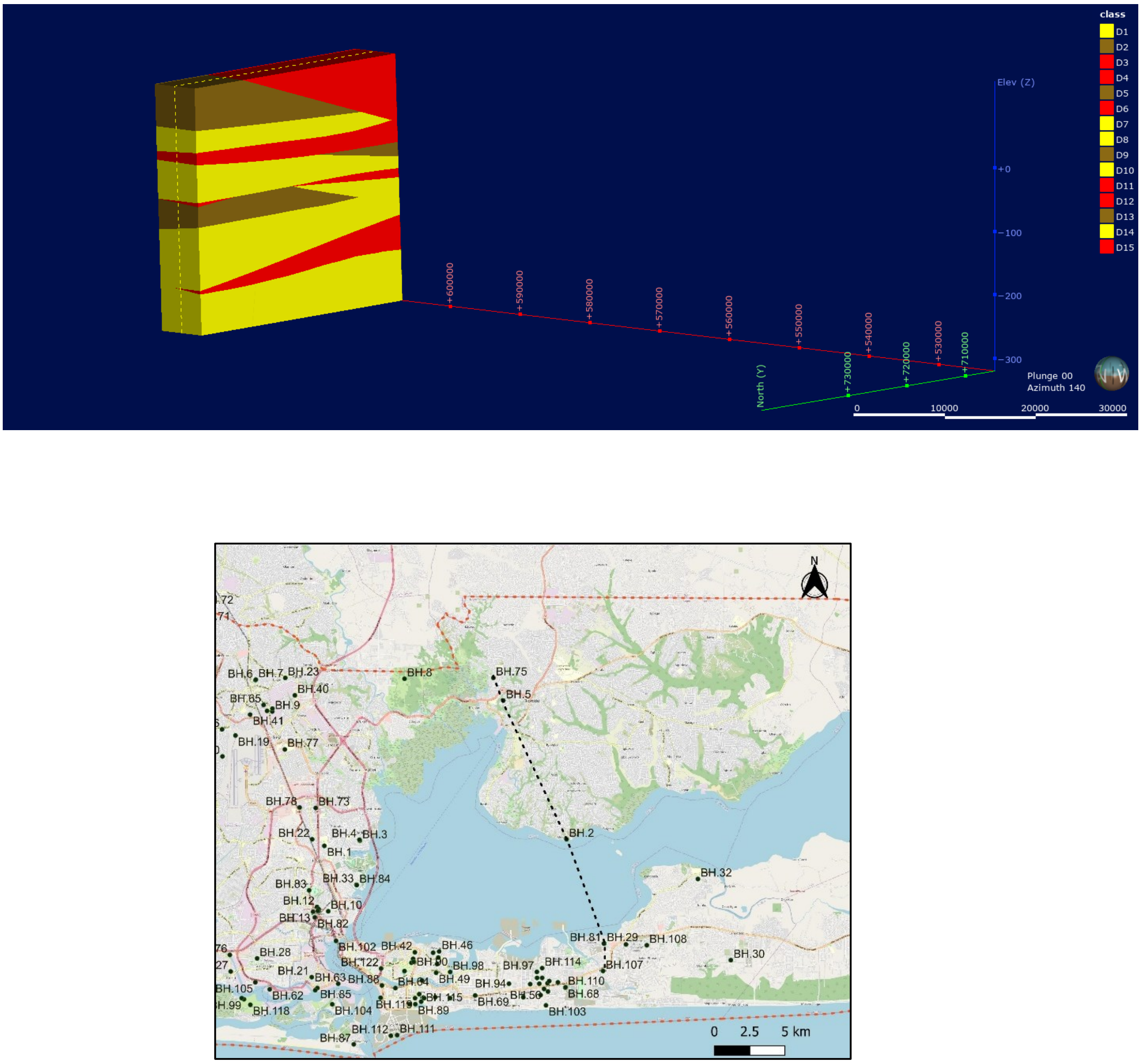


Figure 6.1. Vertical cross-section from north to south in the eastern part of the study area

- Figure 6.2, in the eastern region, has thinner clay cover and sand-dominated layers at both shallow and deep levels. This suggests unconfined or semi-confined conditions, with lower subsidence risk than in the previous section but greater exposure to surface contamination.

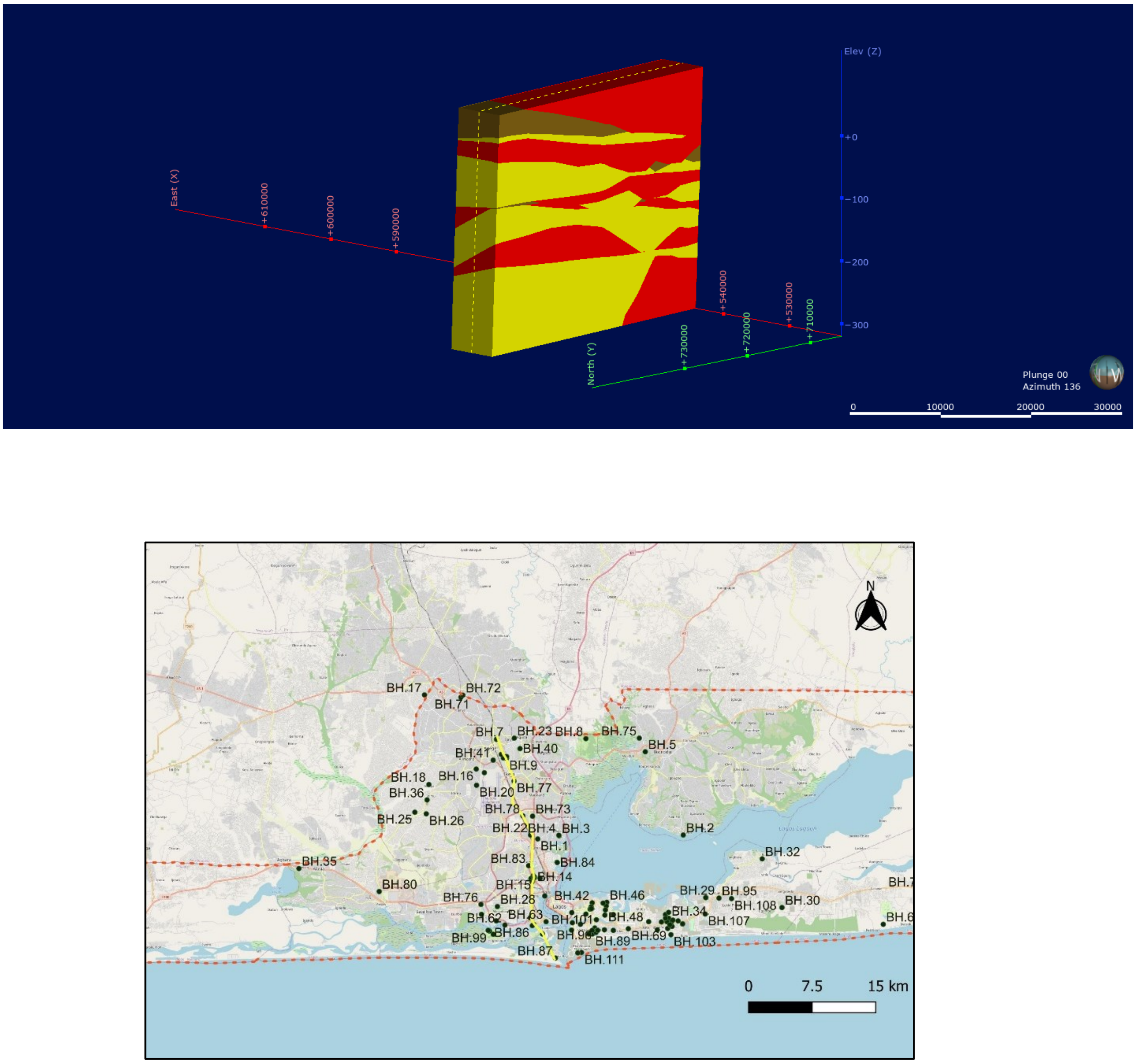


Figure 6.2. North to south cross-section of the model in the central part of the study area

- Figure 6.3, from the central zone, reveals a complex multi-aquifer structure with alternating sand, clay, and intermediate layers. Confined and semi-confined aquifers are present, and water extraction should be done carefully because of the risk of land subsidence.

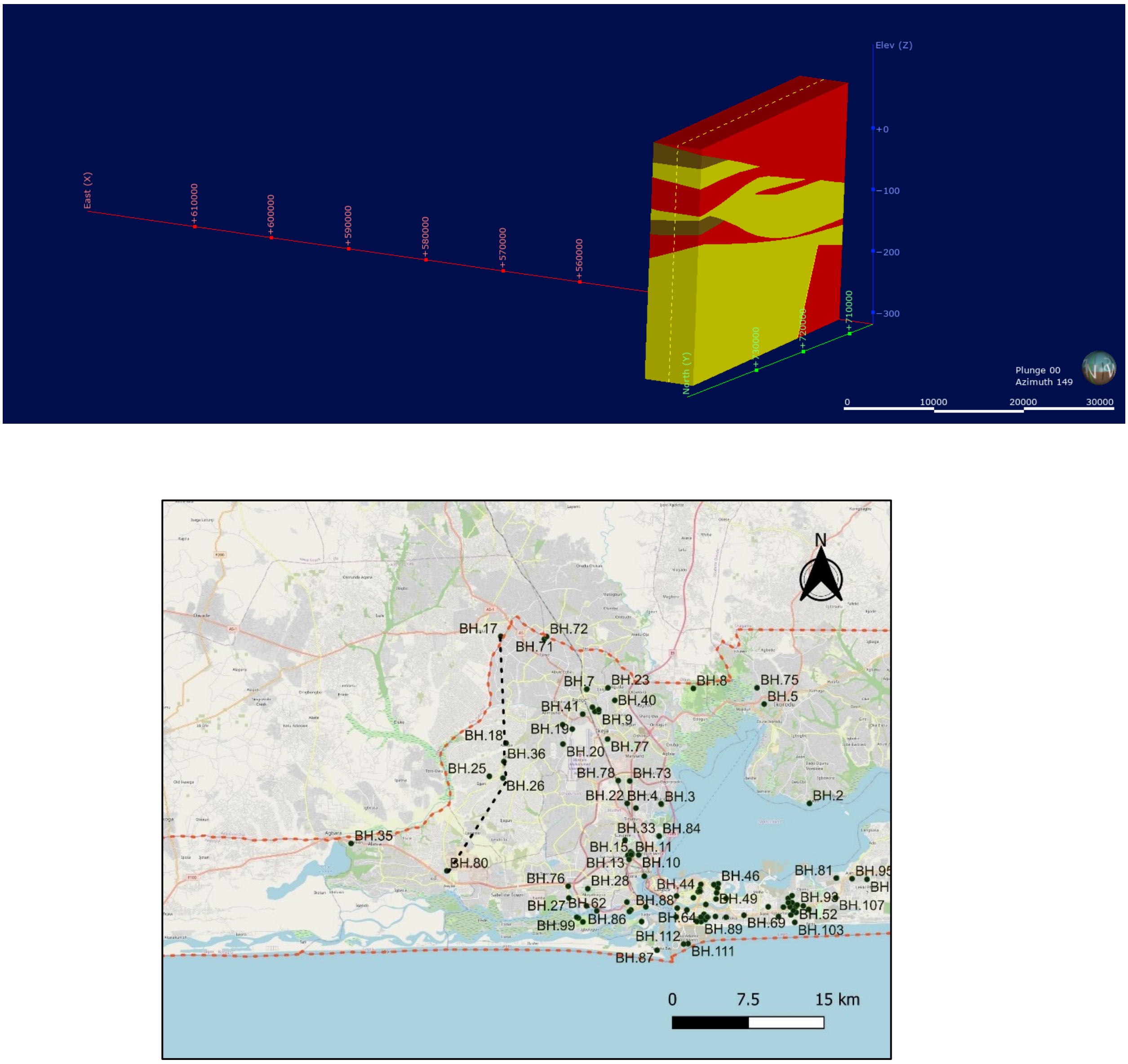


Figure 6.3. North to South cross-section of the 3D model in the western part of study area

- Figure 6.4 shows a west–east cross-section across the study area. The lithological arrangement is marked by multiple sandy layers, interbedded with intermediate and clay units. Sandy layers represent potential aquifers, particularly in the central part of the study area where they appear thick and continuous. However, the overlying clay layers are relatively thick and extensive, especially near the surface. This setup suggests the aquifers below are at least partially confined, and also at the risk of land subsidence if water is withdrawn too aggressively.

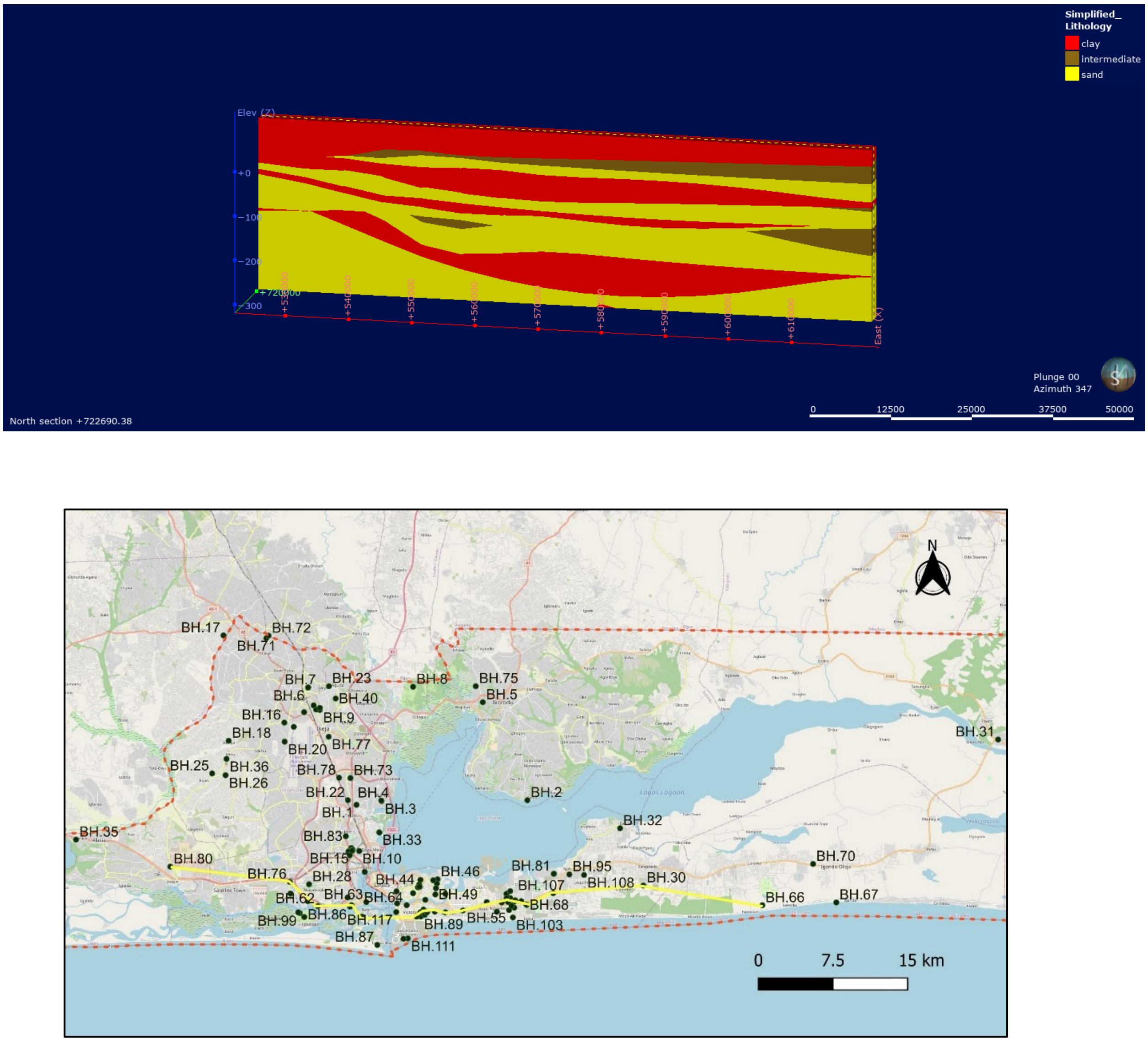


Figure 6.4. West - east cross section along the study area

Conclusion

The objective of the thesis was to develop a three-dimensional model of the Lagos aquifer system using available geology and hydrogeology information. The goal was to have a better understanding of the aquifer structure and its behavior and characterization.
The model was constructed using Leapfrog software and using the data collected from previous studies, institutional records, and the ENGULF project. After careful data filtering and simplifying lithologies into sand, clay, and intermediate, several cross sections were created through the study area. These cross sections have been used to classify the stratigraphy and analyze the geological trends.
The 3D model was built layer by layer from the youngest to the oldest layer integrating interpreted geological contacts from the borehole logs.
The model output indicates the Lagos aquifer system to be comprised primarily of extensive sandy layers, the main groundwater-aquifer units. The clay and intermediate material interleaves with these and form confined, semi-confined, and unconfined aquifer conditions in different parts of the region. Cross-section analysis revealed the possibilities and risks within the aquifer system including the risk of land subsidence in areas with thick compressible clay layers and contamination or risk of over-extraction in areas with shallow or unconfined sandy aquifers.

The 3D model developed in this study provides a solid framework for further hydrogeological analysis and decision-making. It allows for better spatial understanding of aquifer behavior and can serve as a reference for groundwater management, well planning, and risk assessment.

Bibliography

Gu, D., Li, J., Cao, Y., Zhang, W., & Wang, H. (2021). Global urbanization trends and water resource challenges. *Journal of Hydrology, 603*, 126845. https://doi.org/10.1016/j.jhydrol.2021.126845

Marlier, M. E., Jina, A. S., Kinney, P. L., & DeFries, R. S. (2016). Extreme air pollution in global megacities. *Current Climate Change Reports*, 2(1), 15–27. https://doi.org/10.1007/s40641-016-0032-z

Hoornweg, D., & Pope, K. (2017). Population predictions for the world's largest cities in the 21st century. *Environment and Urbanization, 29*(1), 195–216. https://doi.org/10.1177/0956247816663557

Desjardins, J. (2018, July 16). Animation: The world's largest megacities by 2100. *Visual Capitalist*. https://www.visualcapitalist.com/worlds-20-largest-megacities-2100/

Koko, A. F., Yue, W., Gana, A. A., Hamed, R., & Alabsi, N. (2021). Water scarcity in the fast-growing megacity of Lagos, Nigeria and opportunities for managed aquifer recharge. *Wiley Interdisciplinary Reviews: Water*, 8(2), e1733. https://doi.org/10.1002/wat2.1733

Healy, A., Upton, K., Capstick, S., Bristow, G., Tijani, M., Macdonald, A., Goni, I., Bukar, Y., Whitmarsh, L., Theis, S., Danert, K., & Allan, S. (2020). Domestic groundwater abstraction in Lagos, Nigeria: A disjuncture in the science-policy-practice interface. *Environmental Research Letters*, 15(4), 045006. https://doi.org/10.1088/1748-9326/ab7463

International Groundwater Resources Assessment Centre. (2021). *Groundwater in fast-growing cities in Western Africa*. https://www.un-igrac.org/resource/groundwater-fast-growing-cities-western-africa

Jimoh, R. A., Bankole, O. M., Ahmed, K., Christopher, O. A., Adeniji, M. A., Ebhodaghe, J., Sedara, S. O., Obende, P. W., Alebu, O., & Ezima, E. A. (2018). Use of geophysical logs in hydrogeological studies and borehole designs: Case study of Apapa coastal area, Lagos, Nigeria. *Applied Water Science, 8*(191). https://doi.org/10.1007/s13201-018-0804-9

Abiodun, B. J., Adegoke, J., Abatan, A. A., Ibe, C. A., Egbebiyi, T. S., Engelbrecht, F., & Pinto, I. (2017). Potential impacts of climate change on extreme precipitation over four African coastal cities. *Climatic Change, 143*(3), 399–413. https://doi.org/10.1007/s10584-017-2001-5

Balogun, I. I., Sojobi, A. O., & Galkaye, E. (2017). Public water supply in Lagos State, Nigeria: Review of importance and challenges, status and concerns and pragmatic solutions. *Cogent Engineering, 4*(1), 1329776. https://doi.org/10.1080/23311916.2017.1329776

Ikuemonisan, F. E., & Ozebo, V. C. (2020). Characterisation and mapping of land subsidence based on geodetic observations in Lagos, Nigeria. *Geodesy and Geodynamics, 11*(2), 151–162. https://doi.org/10.1016/j.geog.2019.12.006

World Population Review. (2024). *Lagos population 2024*. https://worldpopulationreview.com/cities/nigeria/lagos

Oteri, A. U., & Ayeni, R. A. (2003). *The Lagos megacity*. Akute Geo-Resource Ltd & Hanorado Global Solutions Nig Ltd.

Oyedele, K. F., Ayolabi, E. A., Adeoti, L., & Adegbola, R. B. (2009). Geophysical and hydrogeological evaluation of rising groundwater level in the coastal areas of Lagos, Nigeria. *Bulletin of Engineering Geology and the Environment, 68*(2), 137–143. https://doi.org/10.1007/s10064-008-0182-x

Weatherspark. (2025). *Average weather in Lagos, Nigeria*. https://weatherspark.com/y/55040/Average-Weather-in-Lagos-Nigeria-Year-Round

Cian, F., Delgado Blasco, J. M., & Carrera, L. (2019). Sentinel-1 for monitoring land subsidence of coastal cities in Africa using PSInSAR: A methodology based on the integration of SNAP and StaMPS. *Geosciences, 9*(3), 124. https://doi.org/10.3390/geosciences9030124

Oyedele, K. F., Oladele, S., & Okoh, C. (2015). Assessment of subsurface conditions in a coastal area of Lagos using geophysical methods. *Nigerian Journal of Technological Development, 12*(2), 36–41. https://doi.org/10.4314/njtd.v12i2.1

Akinlalu, A. A., & Afolabi, D. O. (2018). Borehole depth determination to freshwater and well design using geophysical logs in coastal regions of Lagos, southwestern Nigeria. *Applied Water Science, 8*, 152. https://doi.org/10.1007/s13201-018-0798-3

Adelana, S. M. A., Olasehinde, P. I., Bale, R. B., Vrbka, P., Edet, A. E., & Goni, I. B. (2008). An overview of the geology and hydrogeology of Nigeria. In S. M. A. Adelana & A. M. MacDonald (Eds.), *Applied groundwater studies in Africa* (pp. 171–202). CRC Press. https://doi.org/10.1201/9780203889497.ch11

Longe, E. O., Malomo, S., & Olorunniwo, M. A. (1987). Hydrogeology of Lagos metropolis. *Journal of African Earth Sciences, 6*(2), 163–174. https://doi.org/10.1016/0899-5362(87)90058-3

Akoteyon, I. S., Mbata, U. A., & Olalude, G. A. (2011). Investigation of heavy metal contamination in groundwater around landfill site in a typical sub-urban settlement in Alimosho, Lagos-Nigeria. *Journal of Applied Sciences in Environmental Sanitation, 6*(2), 155–163. https://www.researchgate.net/publication/283645038

Omosuyi, G. O., Ojo, J. S., & Olorunfemi, M. O. (1999). Borehole lithologic correlation and aquifer delineation in parts of the coastal basin of southwestern Nigeria: Implication for groundwater development. *Journal of Applied Science, 2*(2), 617–626.

Billman, H. G. (1976). Offshore stratigraphy and palaeontology of the Dahomey Embayment. In *Proceedings of the 7th Micropaleontology Colloquium*, Ile-Ife, Nigeria

Ako, B. D., Adegoke, O. S., & Petters, S. W. (1981). Stratigraphy of the Oshosun Formation in southwestern Nigeria. *Journal of Mining and Geology, 17*(1), 97–106.

Omatsola, M. E. (1981). Tectonic evolution and Cretaceous stratigraphy of the Dahomey Basin. *Journal of Mining and Geology, 18*, 130–137.

Nton, M. E. (2001). *Sedimentological and geochemical studies of rock units in the eastern Dahomey Basin, southwestern Nigeria* (Unpublished doctoral dissertation). University of Ibadan, Nigeria.

Olorode, D. O., Olatinsu, O. B., & Ugwoke, E. E. (2012). Site investigation using a combination of electrical resistivity technique and CPT: A case study of a coastal area of Lagos, Nigeria. *European Journal of Scientific Research, 81*(3), 344–356. https://www.researchgate.net/publication/286161349

Ogbe, F. G. A. (1970). Stratigraphy of strata exposed in the Ewekoro quarry, western Nigeria. In T. J. F. Dessauvagie & A. J. Whiteman (Eds.), *African geology* (pp. 305–322). Ibadan University Press.

Oke, S. A., Vermeulen, D., & Gomo, D. (2016). Aquifer vulnerability assessment of Dahomey Basin using the RTt method. *Environmental Earth Sciences, 75*, Article 1–9. https://doi.org/10.1007/s12665-015-5152-2

Okosun, E. A. (1998). Review of the early Tertiary stratigraphy of southwestern Nigeria. *Journal of Mining and Geology, 34*(1), 27–35.

Agagu, O. K. (1985). *A geological guide to bituminous sediments in southwestern Nigeria* (Unpublished M.Phil. dissertation). Department of Geology, University of Ibadan.

Olabode, O. F., & Comte, J.-C. (2024). Water scarcity in the fast-growing megacity of Lagos, Nigeria and opportunities for managed aquifer recharge. *WIREs Water*. https://doi.org/10.1002/wat2.1733

Bale, R., Adelana, S., & Wu, M. (2004). Water quality in a growing urban centre along the coast of southwestern Nigeria. In K. P. Seiler, C. Wu, & R. Xi (Eds.), *Research basins and hydrological planning* (pp. 83–91). Taylor & Francis. https://doi.org/10.1201/9781439833858.ch11

Kampsax, K., & Shwed, A. (1977). *Underground water resources of the Metropolitan Lagos* (Final report submitted to the Lagos State Ministry of Works).

Oloruntola, M. O., Bayewu, O. O., Mosuro, G. O., Folorunso, A. F., & Ibikunle, S. O. (2017). Groundwater occurrence and aquifer vulnerability assessment of Magodo Area, Lagos, Southwestern Nigeria. *Arabian Journal of Geosciences, 10*, Article 110. https://doi.org/10.1007/s12517-017-2914-3

Hockey, R. D. (1964). *The geology of part of South-Western Nigeria*. Federal Government of Nigeria.

Appendix A

Table A. 1 List of all collected boreholes, including their names, and coordinates.

SOURCE	Well ID	**Latitude**	**Longitude**
Lagos State Water Corporation	Shomolu-BH1	6.526666667	3.371138889
Lagos State Water Corporation	Shomolu-BH2	6.530833333	3.526333333
Lagos State Water Corporation	Shomolu-BH3	6.53	3.393888889
Lagos State Water Corporation	Shomolu-BH4	6.530555556	3.393611111
Lagos State Water Corporation	Shomolu-BH5	6.660555556	3.3935
Lagos State Water Corporation	Shomolu-BH6	6.619166667	3.485833333
Lagos State Water Corporation	Agege_BH1	6.632222222	3.326944444
Lagos State Water Corporation	Agege_BH2	6.6325	3.327222222
Lagos State Water Corporation	Agege_BH3	6.772777778	3.421388889
Lagos State Water Corporation	Agege_BH4	6.633055556	3.4225
Lagos State Water Corporation	Agege_BH5	6.612222222	3.337777778
Lagos State Water Corporation	Agege_BH6	6.774722222	3.423055556
Lagos State Water Corporation	Agege_BH7	6.770277778	3.420833333
Lagos State Water Corporation	Agege_BH8	6.770277778	3.420555556
Lagos State Water Corporation	Aguda _BH1	6.485	3.373611111
Lagos State Water Corporation	Aguda _BH2	6.485277778	3.3675
Lagos State Water Corporation	Aguda _BH3	6.487777778	3.366388889
Lagos State Water Corporation	Aguda _BH4	6.484722222	3.363888889
Lagos State Water Corporation	Aguda _BH5	6.486388889	3.3675
Lagos State Water Corporation	Aguda _BH6	6.485277778	3.366944444
Lagos State Water Corporation	Shasha_BH1	6.600833333	3.305555556
Lagos State Water Corporation	Shasha_BH2	6.679444444	3.250277778
Lagos State Water Corporation	Shasha_BH3	6.584444444	3.255
Lagos State Water Corporation	Shasha_BH4	6.596944444	3.314166667
Lagos State Water Corporation	Shasha_BH5	6.583611111	3.305833333
Lagos State Water Corporation	Apapa_BH1	6.532222222	3.4875

Lagos State Water Corporation	Apapa_BH2	6.443055556	3.363055556
Lagos State Water Corporation	Apapa_BH3	6.530833333	3.363333333
Lagos State Water Corporation	Apapa_BH4	6.533055556	3.479166667
Lagos State Water Corporation	Apapa_BH5	6.531388889	3.481388889
Lagos State Water Corporation	Apapa_BH6	6.633611111	3.346111111
Lagos State Water Corporation	Eko Hotel-BH 1	6.430277778	3.442222222
Lagos State Water Corporation	Egan Grammar School	6.555	3.24
Lagos State Water Corporation	Iron Market	6.553333333	3.252222222
Lagos State Water Corporation	Silica Industiries, Satellite Town	6.446666667	3.311111111
Lagos State Water Corporation	Cardoso Industrie, Kirikiri	6.455	3.328055556
Lagos State Water Corporation	VGC, Ajah	6.464444444	3.550555556
Lagos State Water Corporation	Sangotedo (BH2)	6.453888889	3.631666667
Lagos State Water Corporation	Akodo-BH	6.585555556	3.953888889
Lagos State Water Corporation	Lekki-BH1	6.505555556	3.610555556
Lagos State Water Corporation	Lakowe-BH	6.501944444	3.391666667
Lagos State Water Corporation	Badore-BH	6.51	3.444166667
Lagos State Water Corporation	Lekki-BH2	6.442583333	3.510722222
Lagos State Water Corporation	Ijanikin-BH	6.495277778	3.116388889
Lagos State Water Corporation	Igando	6.568055556	3.253055556
Lagos State Water Corporation	Eredo-BH	6.594166667	3.971111111
Lagos State Water Corporation	BH38	6.533611111	4.033333333
	Ilugbo_BH1	6.793611111	3.351388889
	Ilugbo_BH2	6.834444444	3.097777778
	Cadbury_BH3	6.6225	3.352222222
	Olugbo_BH4	6.770555556	3.570555556
Ilugbo et al.,2019	Guiness, Ikeja	6.729166667	3.466666667

	VIBH1	6.458888889	3.429166667
	VIBH2	6.454722222	3.428055556
	VIBH3	6.452222222	3.426944444
	VIBH4	6.446944444	3.4225
	VIBH5	6.459444444	3.444722222
	VIBH6	6.455555556	3.444166667
	VIBH7	6.451388889	3.443333333
	VIBH8	6.445833333	3.442777778
	LBH1	6.438611111	3.503055556
	LBH2	6.438888889	3.508888889
	LBH3	6.439166667	3.514166667
Akinlalu & Afolabi, 20218	LBH4	6.439722222	3.520833333
	Batching Plant A	6.469444444	4.003888889
	Batching Plant B	6.469166667	4.004444444
	22k Borehole	6.440277778	4.031111111
	2k Borehole	6.439722222	4.034166667
	E-Block Borehole	6.443055556	3.990555556
	Tin Can Island	6.435277778	3.336111111
	Wharf 2 Apapa	6.438888889	3.38
	Azare Crescent	6.436111111	3.416666667
	Takwa Bay Island, Apapa	6.616388889	3.332222222
	Ajayi Apata, Sangotedo	6.436111111	3.739722222
Yusuf, 2020	ITB Construction	6.438611111	3.806944444

	OMORIRE JOHNSON Lekki	6.436388889	3.525555556
	OZUMBA NBADIWE VI	6.406111111	3.417777778
	Eko Akete Awoyaya	6.4725	4.036111111
	Osborne Estate Ikoyi	6.416666667	3.523611111
Yusuf, 2020	Takwa Bay Island Apapa	6.431388889	3.467777778
	Badore	6.495833333	3.756944444
	HFP Cemetery Lakowe	6.473333333	3.785833333
	Ojokoro-BH1	6.676944444	3.289166667
	Ojokoro-BH2	6.679166667	3.291222222
	LASU-BH1	6.5508	3.3656
Lagos State Water Corporation	Eko Akete, Awoyaya	6.525833333	4.036111111
Lagos State Water Corporation	Royal Garden Estate, Ajah	6.633611111	3.479444444
Lagos State Water Corporation	Amuwo Odofin-BH1	6.457222222	3.310555556
Lagos State Water Corporation	Ikeja Waterworks	6.588055556	3.345833333
Lagos State Water Corporation	Nestle Nigeria Plc	6.551111111	3.355277778
Lagos State Water Corporation	Ijora_BH1	6.466166667	3.378611111
Lagos State Water Corporation	WNN	6.4709093	3.202003
Lagos State Water Corporation	VGC_ESTATE_AJAH	6.464444444	3.550277778
	Nigeria_Breweries_Iganmu	6.481111111	3.365
	Surulere_waterworks	6.498333333	3.361388889

	Bariga_waterworks	6.501666667	3.391944444
	Niger_Biscult	6.436111111	3.366666667
	Sugar_Industry	6.434722222	3.365277778
	Takwa_Bay	6.400277778	3.39
	IBTC	6.437777778	3.408055556
	Eko_Hotel	6.425833333	3.429444444
	Ikoyi_waterworks	6.452777778	3.428611111
	Dolphin_waterworks	6.452777778	3.428333333
	ParkView	6.458611111	3.440833333
	Femi_Okunu Est.	6.440555556	3.515277778
	Seed Education	6.438888889	3.489444444
	Royal _Garden	6.463888889	3.564444444
Oladipo et al., 2019	Akingbade_close	6.432222222	3.431944444
Adebowale, 2017	Victory_Park_Estate	6.4464094	3.5073253
	1st Avenue Ikoyi	6.44635	3.45177
	Ajayi Apa/Sangotedo	6.4335	3.73693
	Ajegunle water works	6.42898	3.31961
	Osborne Estate Ikoyi	6.41302	3.47008
	Badore	6.49635	3.70342
Yusuf, 2020	MRS Apapa	6.42498	3.33563

	Etim nyang CRT. VI	6.40006	3.43406
	APMTYARD, APAPA	6.44209	3.37999
	Azare cr.Apapa	6.43515	3.36607
	Oniru Estate	6.43025	3.49861
	Cappa VI	6.44097	3.43367
	Ijora Olopa	6.46617	3.37861
	Ijora CFAO	6.45375	3.36897
	Clover,Lekki	6.42509	3.51318
	Apapa Wharf	6.42578	3.37619
	Apapa DSTV	6.43977	3.3269
	Ajah/Eastline prject	6.44287	3.58593
	Victoria Island	6.42747	3.43317
Yusuf 2020	Lagos Island/FIRS.	6.4487	3.39625
	Ajah/ITB Construction	6.44698	3.54975
	Lekki/JP EST. PHSIII	6.46336	3.57781
	V/I Joseph N. Close.	6.42583	3.42567
	MTN Call Centre Lekki	6.4661	3.56867
	NNS Beecroft Naval Base, Apapa	6.45911	3.37131
	OMORIRE JOHNSON Street, Lekki	6.43664	3.52567
	OZUMBA NBADIWE, VI	6.40614	3.41779

	Tin-Can, APAPA	6.43548	3.33608
	PRODECO Guest House ,VI	6.40577	3.41378
	IKATE ELEGUSHI, Lekki	6.4435	3.49311
	Femi Okunnu, Lekki	6.44258	3.50747
	WILLOW GREENSEstate, Lekki	6.44881	3.51072
	Zenith Bank Head Office , VI	6.43006	3.43461
	Civil Centre Nigeria	6.42968	3.45177
	Oniru Royal Estate	6.42968	3.45177
	Eko Akete, Awoyaya	6.47022	3.78283
	Federal Palace Hotel	6.42993	3.40718
	Victoria Island	6.42418	3.42842
	HFP Cemetery, Lakowe	60.47068	30.79833
	NIGERDOCK, SNAKE ISLD	6.42547	3.3237
	LSWC, Ikoyi	6.42968	3.42923
	Niger Biscuit, Apapa	6.42968	3.31817
	Osborne Est, Ikoyi	6.42968	3.4351

	Police Headquarters, Obalende	6.44855	3.40747
	Takwa Bay Island, Apapa	6.42982	30.3884
	L/I, Apongbon wwks.	6.46057	3.38165

Table A. 2 Final selection of boreholes used for 3D modeling, including only those with known lithology

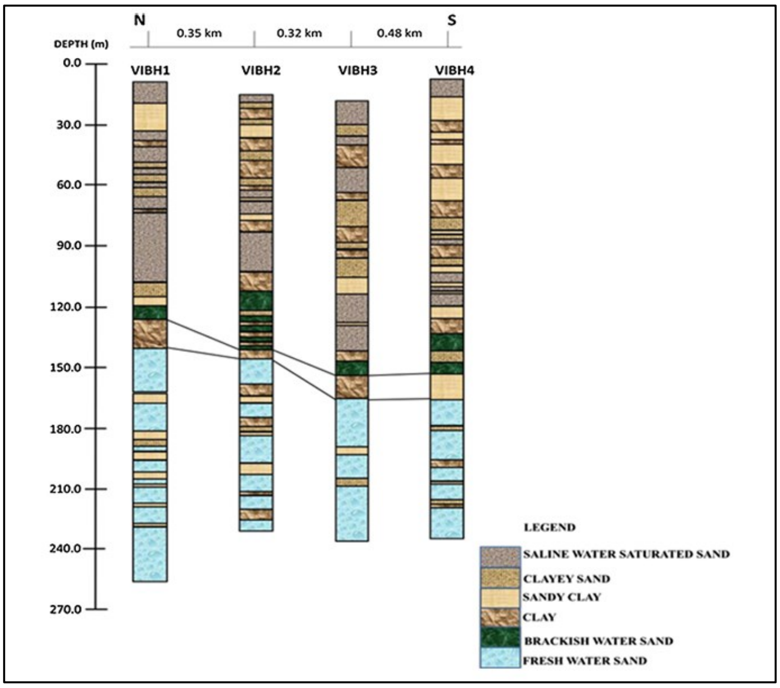
Well ID	Hole ID	**Latitude**	**Longitude**
Shomolu-BH1	BH.1	6.526666667	3.371138889
Shomolu-BH2	BH.2	6.530833333	3.526333333
Shomolu-BH3	BH.3	6.53	3.393888889
Shomolu-BH4	BH.4	6.530555556	3.393611111
Shomolu-BH6	BH.5	6.619166667	3.485833333
Agege_BH1	BH.6	6.632222222	3.326944444
Agege_BH2	BH.7	6.6325	3.327222222
Agege_BH5	BH.8	6.612222222	3.337777778
Aguda _BH1	BH.9	6.485	3.373611111
Aguda _BH2	BH.10	6.485277778	3.3675
Aguda _BH3	BH.11	6.487777778	3.366388889
Aguda _BH4	BH.12	6.484722222	3.363888889
Aguda _BH5	BH.13	6.486388889	3.3675
Aguda _BH6	BH.14	6.485277778	3.366944444
Shasha_BH1	BH.15	6.600833333	3.305555556
Shasha_BH2	BH.16	6.679444444	3.250277778
Shasha_BH3	BH.17	6.584444444	3.255
Shasha_BH4	BH.18	6.596944444	3.314166667
Shasha_BH5	BH.19	6.583611111	3.305833333
Apapa_BH2	BH.20	6.443055556	3.363055556

Apapa_BH3	BH.21	6.530833333	3.363333333
Apapa_BH6	BH.22	6.633611111	3.346111111
Egan Grammar School	BH.23	6.555	3.24
Iron Market	BH.24	6.553333333	3.252222222
Silica Industiries, Satellite Town	BH.25	6.446666667	3.311111111
Cardoso Industrie, Kirikiri	BH.26	6.455	3.328055556
VGC, Ajah	BH.27	6.464444444	3.550555556
Akodo-BH	BH.28	6.585555556	3.953888889
Lekki-BH1	BH.29	6.505555556	3.610555556
Lakowe-BH	BH.30	6.501944444	3.391666667
Lekki-BH2	BH.31	6.442583333	3.510722222
Ijanikin-BH	BH.32	6.495277778	3.116388889
Igando	BH.33	6.568055556	3.253055556
Ilugbo_BH1	BH.34	6.612616667	3.334416667
Ilugbo_BH2	BH.35	6.614066667	3.337866667
Cadbury_BH3	BH.36	6.6225	3.352222222
Olugbo_BH4	BH.37	6.610233333	3.323566667
VIBH1	BH.38	6.458888889	3.429166667
VIBH2	BH.39	6.454722222	3.428055556
VIBH3	BH.40	6.452222222	3.426944444
VIBH4	BH.41	6.446944444	3.4225
VIBH5	BH.42	6.459444444	3.444722222
VIBH6	BH.43	6.455555556	3.444166667
VIBH7	BH.44	6.451388889	3.443333333
VIBH8	BH.45	6.445833333	3.442777778
LBH1	BH.46	6.438611111	3.503055556
LBH2	BH.47	6.438888889	3.508888889
LBH3	BH.48	6.439166667	3.514166667
LBH4	BH.49	6.439722222	3.520833333

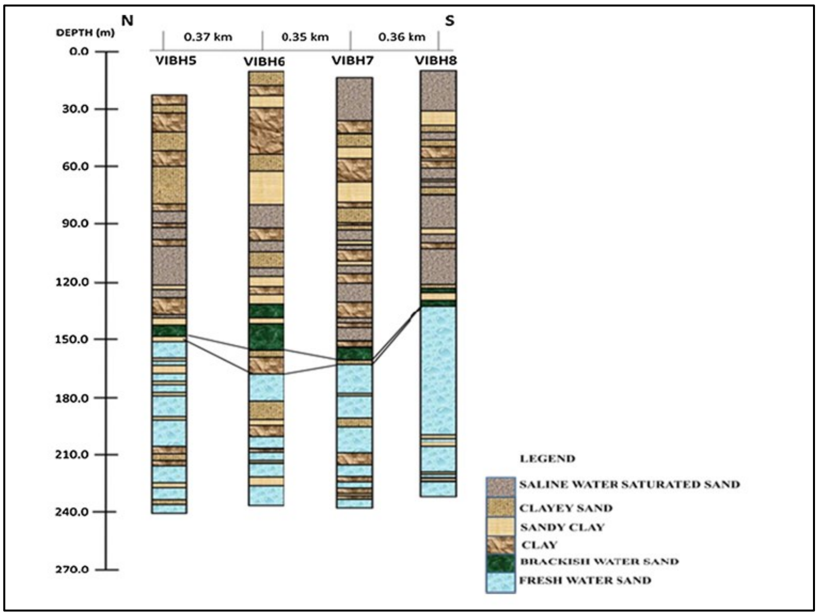
LBH8	BH.50	6.4338889	3.5144444
LBH9	BH.51	6.4316667	3.5097222
LBH12	BH.52	6.4355556	3.5119444
Batching Plant A	BH.53	6.469444444	4.003888889
Batching Plant B	BH.54	6.469166667	4.004444444
22k Borehole	BH.55	6.440277778	4.031111111
2k Borehole	BH.56	6.439722222	4.034166667
E-Block Borehole	BH.57	6.443055556	3.990555556
Tin Can Island / BH1	BH.58	6.435277778	3.336111111
Wharf 2 Apapa /BH4	BH.59	6.438888889	3.38
Azare Crescent/BH8	BH.60	6.436111111	3.416666667
HFP Cemetery Lakowe	BH.61	6.473333333	3.785833333
Eko Akete, Awoyaya	BH.62	6.525833333	4.036111111
Royal Garden Estate, Ajah	BH.63	6.633611111	3.479444444
Amuwo Odofin-BH1	BH.64	6.457222222	3.310555556
Nestle Nigeria Plc	BH.65	6.551111111	3.355277778
Ijora_BH1	BH.66	6.466166667	3.378611111
VGC_ESTATE_AJAH	BH.67	6.464444444	3.550277778
Nigeria_Breweries_Iganmu	BH.68	6.481111111	3.365
Surulere_waterworks	BH.69	6.498333333	3.361388889
Bariga_waterworks	BH.70	6.501666667	3.391944444
Niger_Biscult	BH.71	6.436111111	3.366666667
Sugar_Industry	BH.72	6.434722222	3.365277778
Takwa_Bay	BH.73	6.400277778	3.39

IBTC	BH.74	6.437777778	3.408055556
Eko_Hotel	BH.75	6.425833333	3.429444444
Ikoyi_waterworks	BH.76	6.452777778	3.428611111
Dolphin_waterworks	BH.77	6.452777778	3.428333333
ParkView	BH.78	6.458611111	3.440833333
Femi_Okunu Est.	BH.79	6.440555556	3.515277778
Seed Education	BH.80	6.438888889	3.489444444
Royal _Garden	BH.81	6.463888889	3.564444444
Akingbade_close	BH.82	6.432222222	3.431944444
Victory_Park_Estate	BH.83	6.4464094	3.5073253
bh 19/yusuf	BH.84	6.44635	3.451767
bh22/yusuf	BH.85	6.43025	3.49861
bh23/yusuf	BH.86	6.44097	3.43367
bh25/yusuf	BH.87	6.42509	3.51318
bh26/yusuf	BH.88	6.42578	3.37619
bh27	BH.89	6.43977	3.3269
bh28	BH.90	6.42747	3.43317
bh29	BH.91	6.44698	3.54975
bh30	BH.92	6.46336	3.57781
BH 31	BH.93	6.42583	3.42567
BH 32	BH.94	6.43664	3.52567
BH 33	BH.95	6.40614	3.41779
BH 34	BH.96	6.40577	3.41378
BH 35	BH.97	6.44258	3.50747
BH 36	BH.98	6.44881	3.51072
BH 37	BH.99	6.43006	3.43461
BH 38	BH.100	6.42968	3.45177
BH 39	BH.101	6.42993	3.40718
BH 41	BH.102	6.42547	3.3237
BH 42	BH.103	6.42968	3.42923
BH 43	BH.104	6.42968	3.31817
BH 44	BH.105	6.42968	3.4351
BH 45	BH.106	6.44855	3.40747

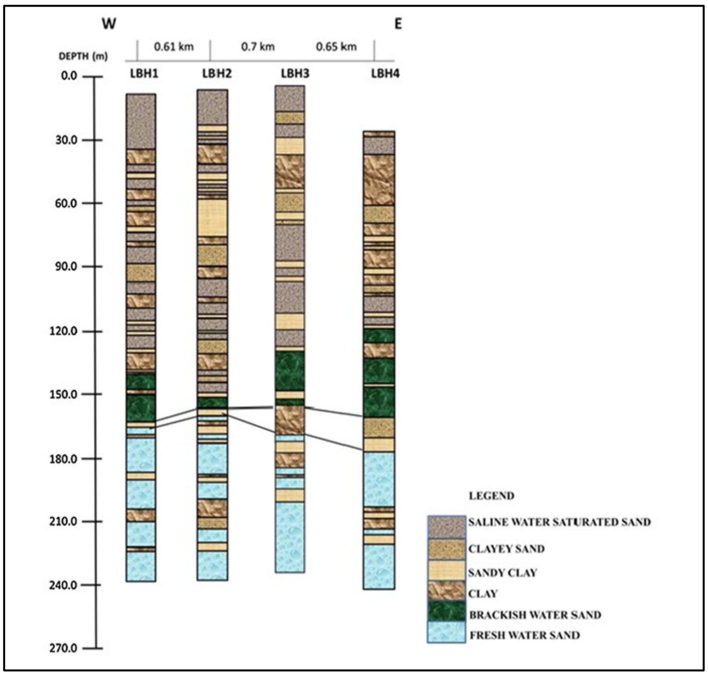
Appendix B



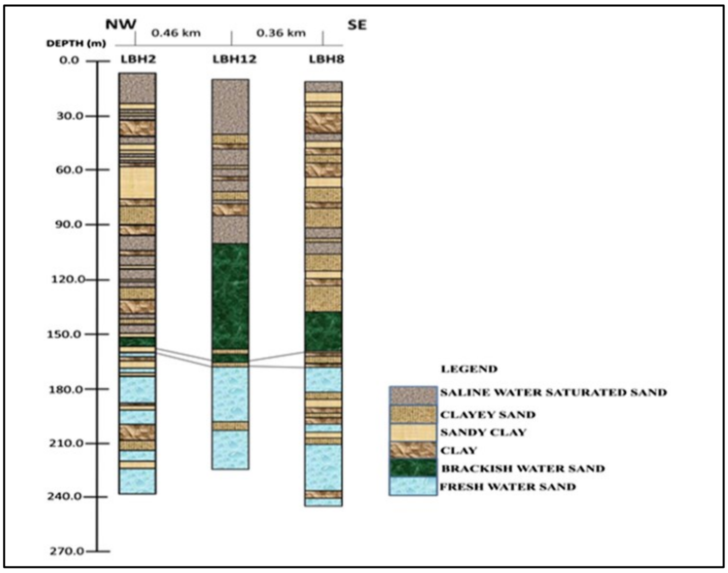
(a) Section A–A′ (Cameron–Mobolaji Johnson–Kingsway–Eboh)



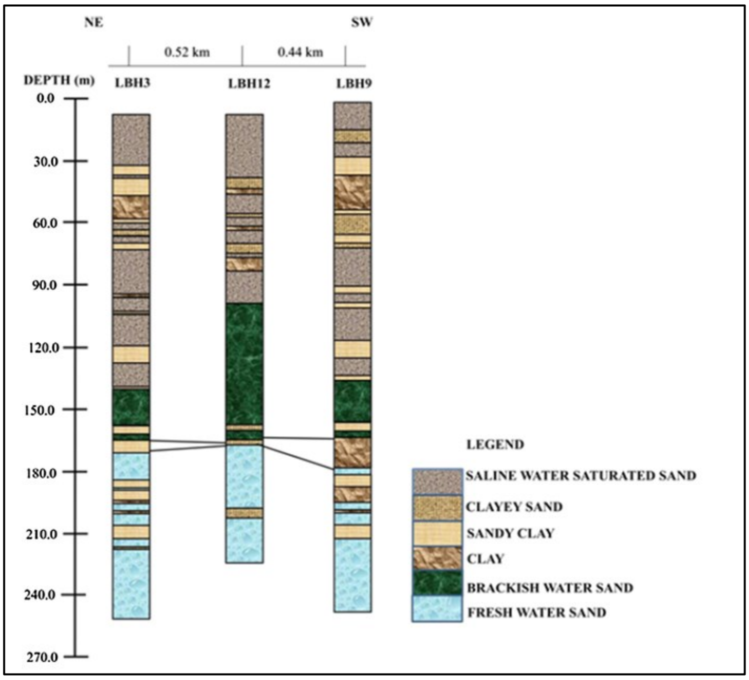
(b) Section B–B′ (Association–Onilegbale–MacDonald–Bourdillon)



(c) Section C–C′ (Igodu–Freedom Road–Akanni Ajiran–



(d) Section D–D′ (Unity–Lawal Silawal–Ologo)



(e) Section E–E′ (Akanni Ajiran–Lawal Silawal–Lekki Beach Road)

Figure B. 1. Correlation panels of lithological borehole profiles across selected coastal transects in Lagos, Nigeria. (From Akinlalu & Afolabi, 2018)

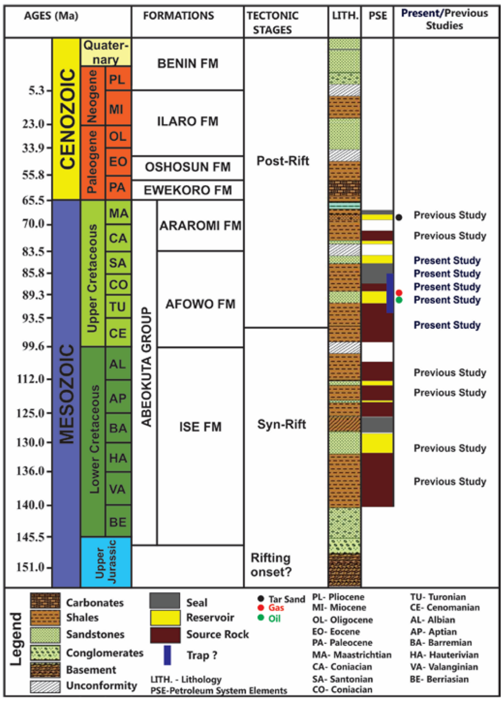


Figure B. 2. Chronostratigraphic chart of the Dahomey Basin showing key tectonic stages in relation to geological formation and lithologies (Modified after Adeoye et al., 2020).

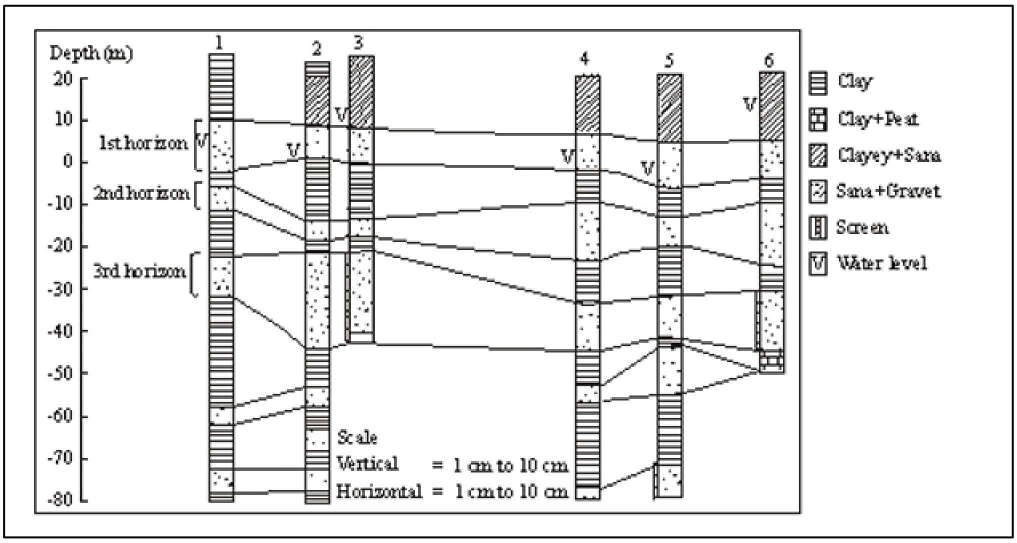
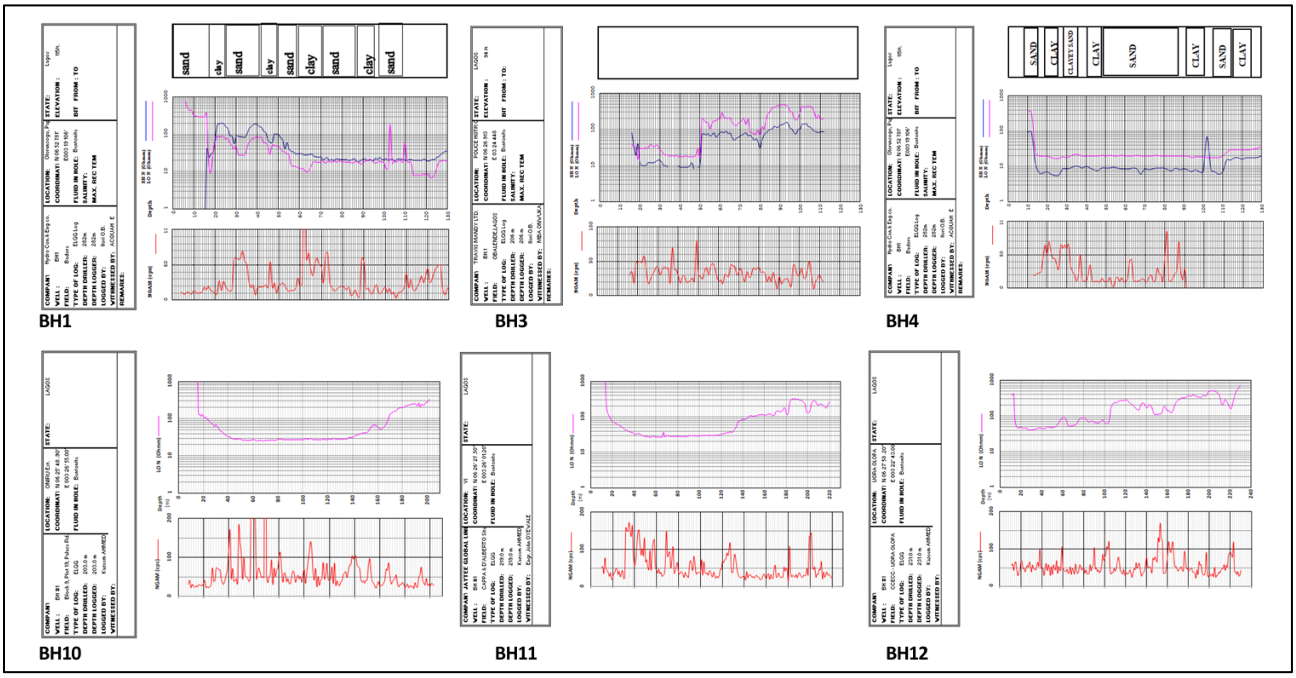
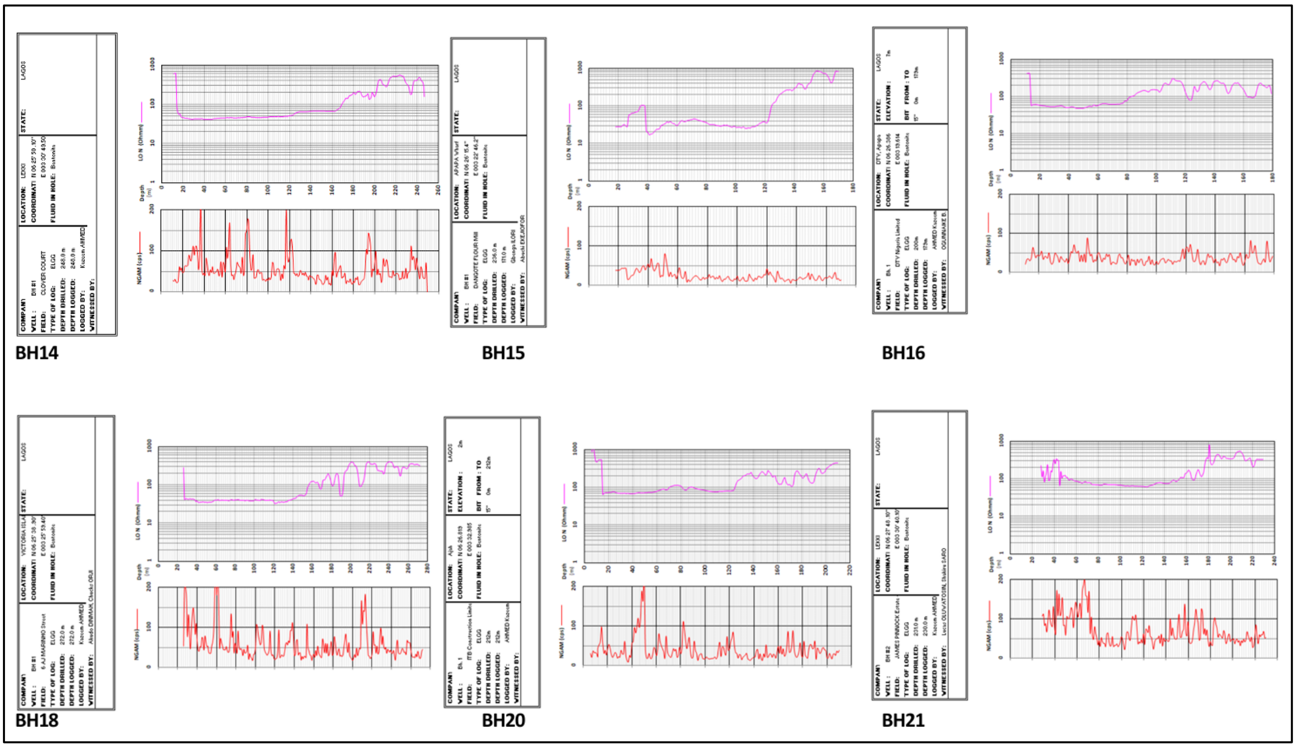
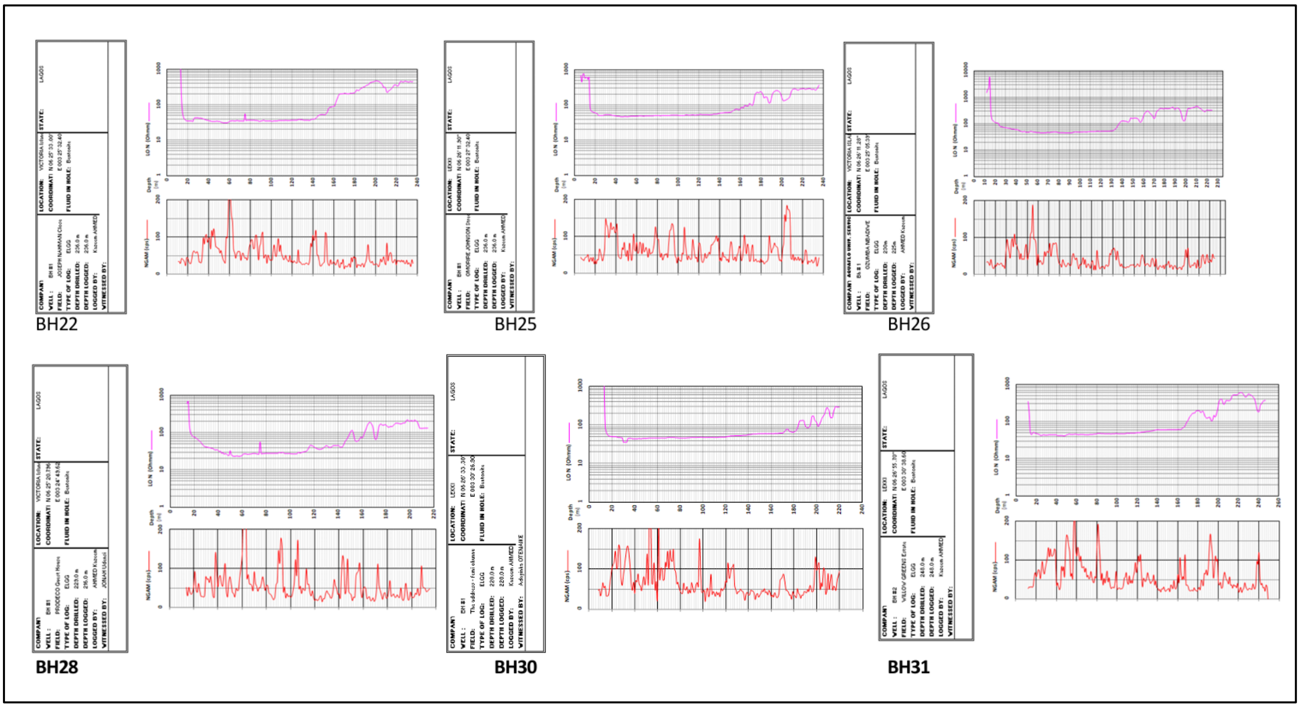


Figure B. 3. Lithologic correlation of sampled wells (From Longe, 2011)




BH14
BH15
BH16
BH18
BH20
BH21


BH22
BH25
BH26
BH28
BH30
BH31

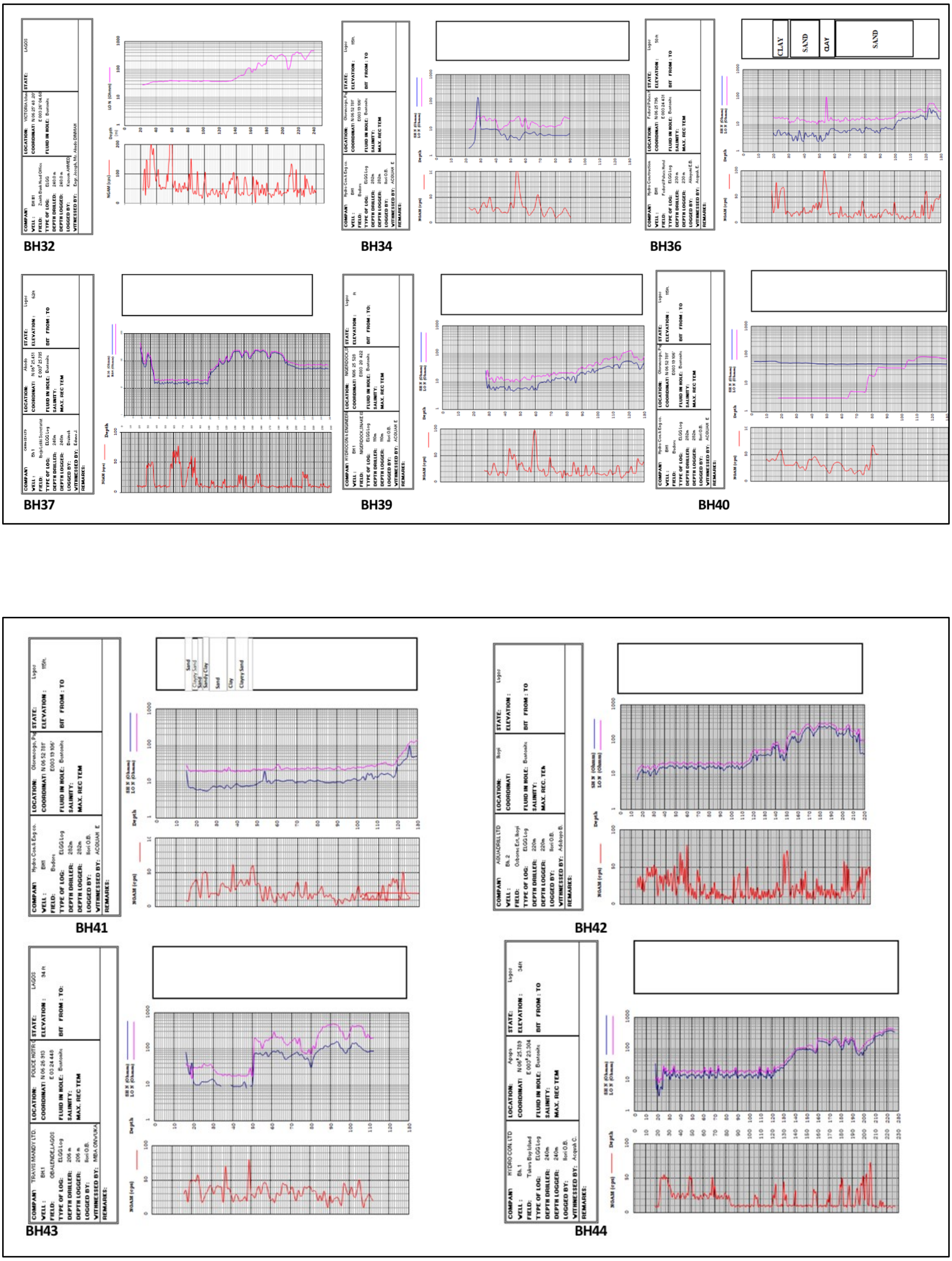


Figure B. 4. Borehole lithologies (From Yusuf, 2020)

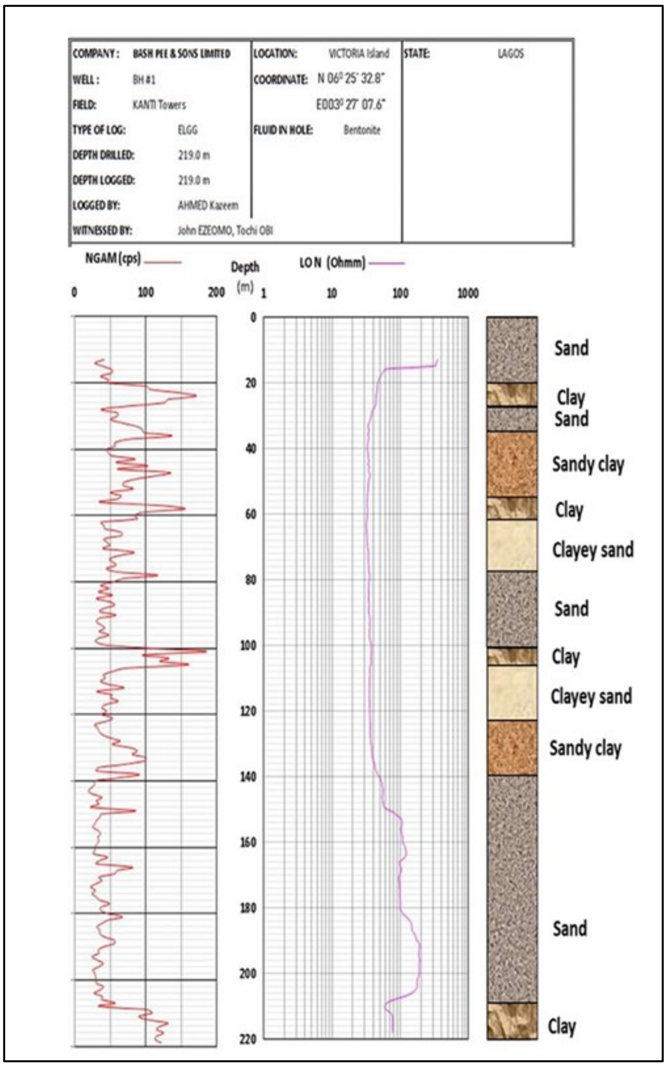
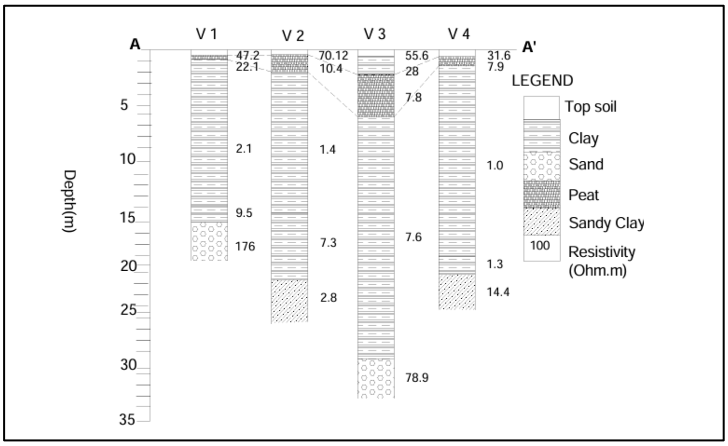
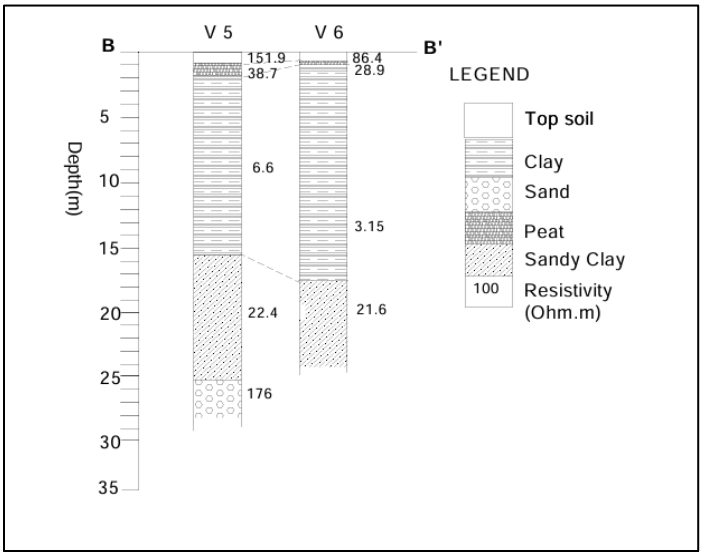


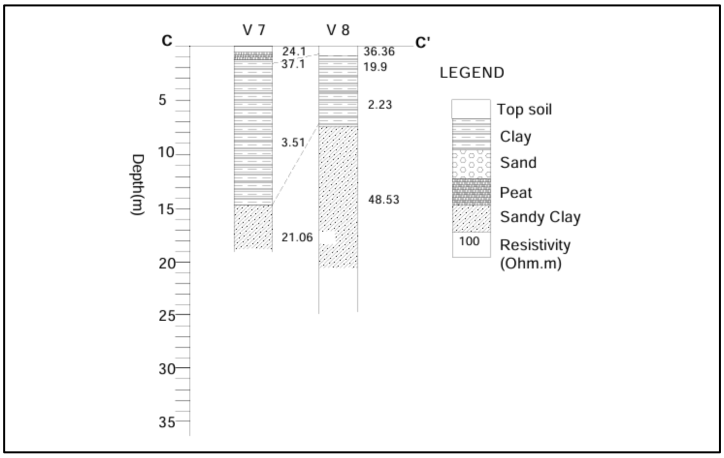
Figure B. 5. geophysical log for Borehole A at Kanti Towers, Victoria Island, Lagos (From Obakhume, 2022)



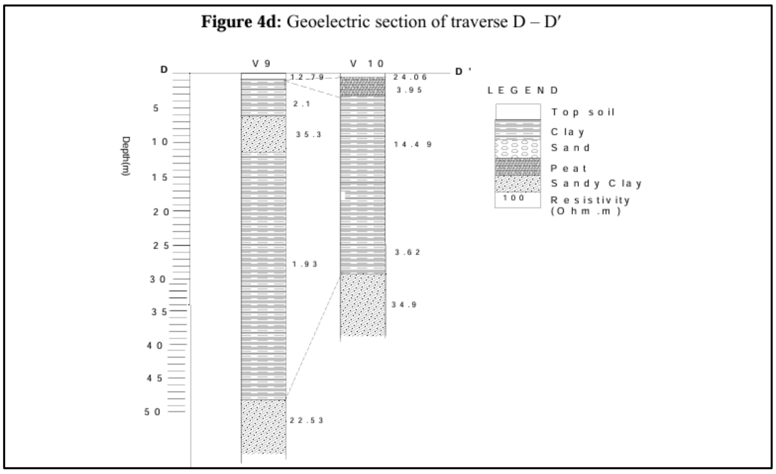
(a) Cross section A–A′ (VES 1 to VES 4)



(b) Traverse B–B′ (VES 5 and VES 6)



(c) Traverse C–C′ (VES 7 and VES 8)



(d) Traverse D–D′ (VES 9 and VES 10)

Figure B. 6. Geoelectric sections across selected traverses in Ilaje–Bariga/Akoka, Lagos State (From Olorode, 2012)

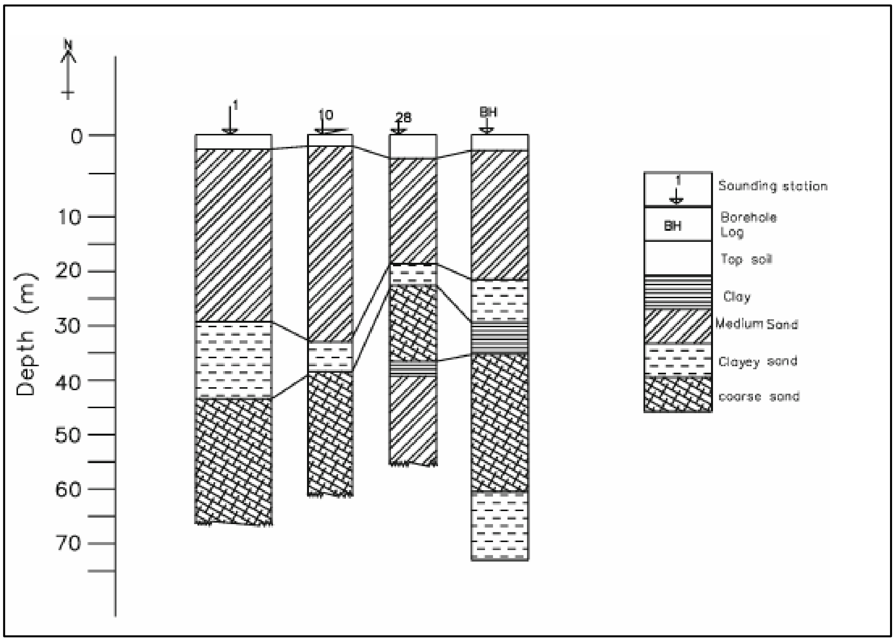


Figure B. 7. Inferred geoelectric section correlated with borehole log. (From Oyedele et al., 2009).

Table B. 1.Interpreted lithological profiles and their stratigraphy classification of selected boreholes used for Leapfrog 3D modeling.

name	***Hole ID***	***From***	***To***	***Simplified Lithology***	***class***
Agege_BH2	*BH.7*	*0*	*19*	*Intermediate*	*D2*
Agege_BH2	*BH.7*	*19*	*73*	*Clay*	*D4*
Agege_BH2	*BH.7*	*73*	*106*	*Intermediate*	*D9*
Agege_BH2	*BH.7*	*106*	*122*	*Clay*	*D6*
Agege_BH5	*BH.8*	*0*	*33*	*Intermediate*	*D2*
Agege_BH5	*BH.8*	*33*	*68*	*Clay*	*D4*
Agege_BH5	*BH.8*	*68*	*100*	*Intermediate*	*D9*
Agege_BH5	*BH.8*	*100*	*155*	*Clay*	*D6*
Aguda_BH3	*BH.11*	*0*	*51*	*clay*	*D3*
Aguda_BH3	*BH.11*	*51*	*129*	*Intermediate*	*D5*
Aguda_BH3	*BH.11*	*129*	*173*	*sand*	*D10*
Aguda_BH3	*BH.11*	*173*	*195*	*clay*	*D12*
Aguda_BH4	*BH.12*	*0*	*38*	*Clay*	*D3*
Aguda_BH4	*BH.12*	*38*	*62*	*Intermediate*	*D5*
Aguda_BH4	*BH.12*	*62*	*90.8*	*Clay*	*D4*
Aguda_BH4	*BH.12*	*90.8*	*170*	*Sand*	*D8*
Aguda_BH4	*BH.12*	*170*	*191*	*Clay*	*D12*
Aguda_BH5	*BH.13*	*0*	*21*	*Clay*	*D3*
Aguda_BH5	*BH.13*	*21*	*34.6*	*Intermediate*	*D2*
Aguda_BH5	*BH.13*	*34.6*	*99*	*Clay*	*D4*

Aguda_BH5	*BH.13*	*99*	*125*	*Sand*	*D8*
Aguda_BH5	*BH.13*	*125*	*162*	*Intermediate*	*D9*
Aguda_BH6	*BH.14*	*0*	*62*	*Intermediate*	*D2*
Aguda_BH6	*BH.14*	*62*	*136*	*Clay*	*D4*
Aguda_BH6	*BH.14*	*136*	*192*	*Sand*	*D10*
Aguda_BH6	*BH.14*	*192*	*235*	*Clay*	*D15*
Shasha_BH1	*BH.15*	*0*	*32*	*Sand*	*D1*
Shasha_BH1	*BH.15*	*32*	*84*	*Clay*	*D4*
Shasha_BH1	*BH.15*	*84*	*123*	*Sand*	*D8*
Shasha_BH1	*BH.15*	*123*	*135*	*Clay*	*D11*
Shasha_BH2	*BH.16*	*0*	*18*	*Intermediate*	*D2*
Shasha_BH2	*BH.16*	*18*	*37*	*Sand*	*D1*
Shasha_BH2	*BH.16*	*37*	*93*	*Clay*	*D4*
Shasha_BH2	*BH.16*	*93*	*140*	*Intermediate*	*D9*
Shasha_BH3	*BH.17*	*0*	*18*	*Sand*	*D1*
Shasha_BH3	*BH.17*	*18*	*44*	*Clay*	*D4*
Shasha_BH3	*BH.17*	*44*	*116*	*Sand*	*D8*
Shasha_BH3	*BH.17*	*116*	*140*	*Clay*	*D11*
Shasha_BH4	*BH.18*	*0*	*33*	*Sand*	*D1*
Shasha_BH4	*BH.18*	*33*	*92*	*Clay*	*D4*
Shasha_BH4	*BH.18*	*92*	*110*	*Sand*	*D8*
Shasha_BH4	*BH.18*	*110*	*126*	*Intermediate*	*D9*
Shasha_BH4	*BH.18*	*126*	*145*	*Clay*	*D11*
Shasha_BH5	*BH.19*	*0*	*21*	*Sand*	*D1*

Shasha_BH5	BH.19	21	83.5	Clay	D4
Shasha_BH5	BH.19	83.5	125	Sand	D8
Shasha_BH5	BH.19	125	145	Clay	D11
Apapa_BH2	BH.20	0	27	Sand	D1
Apapa_BH2	BH.20	27	48	Clay	D4
Apapa_BH2	BH.20	48	116	Intermediate	D5
Apapa_BH2	BH.20	116	188	Clay	D11
Apapa_BH2	BH.20	188	270	Sand	D14
Apapa_BH3	BH.21	0	37.5	Intermediate	D2
Apapa_BH3	BH.21	37.5	55	Clay	D4
Apapa_BH3	BH.21	55	140.2	Sand	D7
Apapa_BH3	BH.21	140.2	203	Clay	D12
Apapa_BH3	BH.21	203	263	Sand	D14
Apapa_BH6	BH.22	0	15	Sand	D1
Apapa_BH6	BH.22	15	75.5	Clay	D4
Apapa_BH6	BH.22	75.5	140.5	Intermediate	D9
Apapa_BH6	BH.22	140.5	234	Clay	D12
EGAN	BH.23	0	41	Sand	D1
EGAN	BH.23	41	55	Intermediate	D5
EGAN	BH.23	55	113	Clay	D6
EGAN	BH.23	113	167	Sand	D8
Akodo-BH	BH.28	0	43.5	Sand	D1
Akodo-BH	BH.28	43.5	100	Clay	D4
Akodo-BH	BH.28	100	174	Intermediate	D9

Akodo-BH	*BH.28*	*174*	*215*	*Sand*	*D10*
Akodo-BH	*BH.28*	*215*	*280*	*Intermediate*	*D13*
Lekki-BH2	*BH.31*	*0*	*55*	*Sand*	*D1*
Lekki-BH2	*BH.31*	*55*	*129.5*	*Intermediate*	*D5*
Lekki-BH2	*BH.31*	*129.5*	*197*	*Clay*	*D6*
Lekki-BH2	*BH.31*	*197*	*260*	*Sand*	*D10*
Lekki-BH2	*BH.31*	*260*	*286.5*	*Intermediate*	*D13*
VIBH1	*BH.38*	*0*	*39*	*Sand*	*D1*
VIBH1	*BH.38*	*39*	*74*	*Clay*	*D4*
VIBH1	*BH.38*	*74*	*119*	*Sand*	*D8*
VIBH1	*BH.38*	*119*	*141*	*Intermediate*	*D9*
VIBH1	*BH.38*	*141*	*233*	*Sand*	*D10*
VIBH2	*BH.39*	*0*	*31*	*Intermediate*	*D2*
VIBH2	*BH.39*	*31*	*112*	*Clay*	*D4*
VIBH2	*BH.39*	*112*	*142*	*Sand*	*D8*
VIBH2	*BH.39*	*142*	*179*	*Clay*	*D11*
VIBH2	*BH.39*	*179*	*231*	*Sand*	*D10*
VIBH3	*BH.40*	*0*	*42*	*Intermediate*	*D2*
VIBH3	*BH.40*	*42*	*115*	*Clay*	*D4*
VIBH3	*BH.40*	*115*	*236*	*Sand*	*D10*
VIBH4	*BH.41*	*0*	*28*	*Intermediate*	*D2*
VIBH4	*BH.41*	*28*	*97*	*Clay*	*D4*
VIBH4	*BH.41*	*97*	*165*	*Intermediate*	*D9*
VIBH4	*BH.41*	*165*	*217*	*Sand*	*D10*

VIBH5	BH.42	0	29	Clay	D3
VIBH5	BH.42	29	79	Intermediate	D5
VIBH5	BH.42	79	139	Clay	D6
VIBH5	BH.42	139	171	Intermediate	D9
VIBH5	BH.42	171	242	Sand	D10
VIBH7	BH.44	0	36	Sand	D1
VIBH7	BH.44	36	70	Clay	D2
VIBH7	BH.44	70	93	Intermediate	D5
VIBH7	BH.44	93	150.5	Sand	D8
VIBH7	BH.44	150.5	178	Clay	D11
VIBH7	BH.44	178	238	Sand	D10
VIBH8	BH.45	0	40	Sand	D1
VIBH8	BH.45	40	58	Clay	D2
VIBH8	BH.45	58	131	Intermediate	D5
VIBH8	BH.45	131	234	Sand	D10
LBH1	BH.46	0	74	Sand	D1
LBH1	BH.46	74	101	Intermediate	D5
LBH1	BH.46	101	165.5	Sand	D8
LBH1	BH.46	165.5	189	Intermediate	D9
LBH1	BH.46	189	238	Sand	D10
LBH2	BH.47	0	43	Sand	D1
LBH2	BH.47	43	97	Clay	D4
LBH2	BH.47	97	133	intermediate	D9
LBH2	BH.47	133	209	Clay	D11

LBH2	BH.47	209	238	intermediate	D13
LBH3	BH.48	0	54	Sand	D1
LBH3	BH.48	54	97	Clay	D4
LBH3	BH.48	97	149	Sand	D8
LBH3	BH.48	149	168	Clay	D6
LBH3	BH.48	168	235	Sand	D10
LBH4	BH.49	0	37.5	intermediate	D2
LBH4	BH.49	37.5	112	Clay	D4
LBH4	BH.49	112	169	intermediate	D9
LBH4	BH.49	169	200	Clay	D11
LBH4	BH.49	200	242	Sand	D10
LBH8	BH.50	0	60	Sand	D1
LBH8	BH.50	60	120	Clay	D4
LBH8	BH.50	120	150	Sand	D8
LBH8	BH.50	150	210	Clay	D11
LBH8	BH.50	210	240	Sand	D10
LBH9	BH.51	0	60	Sand	D1
LBH9	BH.51	60	120	Clay	D4
LBH9	BH.51	120	150	Sand	D8
LBH9	BH.51	150	210	Clay	D11
LBH9	BH.51	210	247	Sand	D10
LBH12	BH.52	0	60	Sand	D1
LBH12	BH.52	60	120	Clay	D4
LBH12	BH.52	120	150	Sand	D8

LBH12	BH.52	150	180	Clay	D6
LBH12	BH.52	180	225	Sand	D10
BH-1 Batching Plant A	BH.53	0	22	intermediate	D2
BH-1 Batching Plant A	BH.53	22	81	Sand	D1
BH-1 Batching Plant A	BH.53	81	162	Clay	D6
BH-1 Batching Plant A	BH.53	162	200	intermediate	D9
BH-4 2K Borehole	BH.56	0	25	intermediate	D2
BH-4 2K Borehole	BH.56	25	84	Sand	D1
BH-4 2K Borehole	BH.56	84	130	Clay	D6
BH-4 2K Borehole	BH.56	130	165	intermediate	D9
BH-4 2K Borehole	BH.56	165	200	Sand	D14
BH-5 E-Block Borehole	BH.57	0	24	intermediate	D2
BH-5 E-Block Borehole	BH.57	24	72	Sand	D1
BH-5 E-Block Borehole	BH.57	72	150	Clay	D6
BH-5 E-Block Borehole	BH.57	150	200	intermediate	D9
BH8_Azare Crescent	BH.60	0	32	intermediate	D2
BH8_Azare Crescent	BH.60	32	134	Clay	D4
BH8_Azare Crescent	BH.60	134	220	Sand	D10
ROYAL GARDEN ESTATE, AJAH	BH.63	0	27	intermediate	D2
ROYAL GARDEN ESTATE, AJAH	BH.63	27	115	Sand	D7
ROYAL GARDEN ESTATE, AJAH	BH.63	115	195	Clay	D6
ROYAL GARDEN ESTATE, AJAH	BH.63	195	257	Sand	D10
ROYAL GARDEN ESTATE, AJAH	BH.63	257	300	Clay	D15
Nigeria_Breweries_Iganmu	BH.68	0	38	Sand	D1

Nigeria_Breweries_Iganmu	*BH.68*	*38*	*95*	*Clay*	*D4*
Nigeria_Breweries_Iganmu	*BH.68*	*95*	*160.5*	*Sand*	*D8*
Nigeria_Breweries_Iganmu	*BH.68*	*160.5*	*197*	*Clay*	*D12*
Nigeria_Breweries_Iganmu	*BH.68*	*197*	*220*	*Sand*	*D14*
Surulere_Waterworks	*BH.69*	*0*	*31*	*Clay*	*D3*
Surulere_Waterworks	*BH.69*	*31*	*67*	*Sand*	*D7*
Surulere_Waterworks	*BH.69*	*67*	*137*	*Clay*	*D6*
Surulere_Waterworks	*BH.69*	*137*	*193*	*Sand*	*D10*
Surulere_Waterworks	*BH.69*	*193*	*210*	*intermediate*	*D13*
Bariga_Waterworks	*BH.70*	*0*	*41*	*Sand*	*D1*
Bariga_Waterworks	*BH.70*	*41*	*105*	*Clay*	*D4*
Bariga_Waterworks	*BH.70*	*105*	*160*	*Sand*	*D8*
Niger_Biscuit	*BH.71*	*0*	*56*	*Sand*	*D1*
Niger_Biscuit	*BH.71*	*56*	*125*	*Clay*	*D4*
Niger_Biscuit	*BH.71*	*125*	*237*	*Sand*	*D10*
Niger_Biscuit	*BH.71*	*237*	*280*	*Clay*	*D15*
Sugar_Industry	*BH.72*	*0*	*62*	*Sand*	*D1*
Sugar_Industry	*BH.72*	*62*	*125*	*Clay*	*D4*
Sugar_Industry	*BH.72*	*125*	*203*	*Sand*	*D10*
Sugar_Industry	*BH.72*	*203*	*246*	*Clay*	*D15*
Takwa_Bay	*BH.73*	*0*	*30*	*Sand*	*D1*
Takwa_Bay	*BH.73*	*30*	*124*	*intermediate*	*D5*
Takwa_Bay	*BH.73*	*124*	*240*	*Sand*	*D10*
Takwa_Bay	*BH.73*	*240*	*280*	*Clay*	*D15*

IBTC	BH.74	0	50	Sand	D1
IBTC	BH.74	50	119	intermediate	D5
IBTC	BH.74	119	193	Clay	D6
IBTC	BH.74	193	215	Sand	D10
IBTC	BH.74	215	245	Clay	D14
Eko_Hotel	BH.75	0	50	Sand	D1
Eko_Hotel	BH.75	50	81	intermediate	D5
Eko_Hotel	BH.75	81	195	Sand	D8
Eko_Hotel	BH.75	195	213	Clay	D12
Eko_Hotel	BH.75	213	265	Sand	D14
Ikoyi_Waterworks	BH.76	0	48	Sand	D1
Ikoyi_Waterworks	BH.76	48	80	intermediate	D5
Ikoyi_Waterworks	BH.76	80	204	Sand	D8
Ikoyi_Waterworks	BH.76	204	254	Clay	D12
Ikoyi_Waterworks	BH.76	254	275	Sand	D14
Dolphin_Waterworks	BH.77	0	40	Sand	D1
Dolphin_Waterworks	BH.77	40	71	intermediate	D5
Dolphin_Waterworks	BH.77	71	119	Clay	D4
Dolphin_Waterworks	BH.77	119	217	Sand	D10
Dolphin_Waterworks	BH.77	217	250	Clay	D12
ParkView	BH.78	0	53.5	Sand	D1
ParkView	BH.78	53.5	86	intermediate	D5
ParkView	BH.78	86	198	Sand	D8
ParkView	BH.78	198	229	Clay	D12

ParkView	BH.78	229	250	Sand	D14
Femi_Okunu Est.	BH.79	0	55	Sand	D1
Femi_Okunu Est.	BH.79	55	75	intermediate	D5
Femi_Okunu Est.	BH.79	75	167	Sand	D8
Femi_Okunu Est.	BH.79	167	197	Clay	D11
Femi_Okunu Est.	BH.79	197	225	Sand	D10
Seed Education	BH.80	0	56	Sand	D1
Seed Education	BH.80	56	130	Clay	D4
Seed Education	BH.80	130	146	intermediate	D9
Seed Education	BH.80	146	212	Sand	D10
Seed Education	BH.80	212	236	Clay	D12
Akingbade_Close	BH.82	0	63	Sand	D1
Akingbade_Close	BH.82	63	89	intermediate	D5
Akingbade_Close	BH.82	89	178	Clay	D6
Akingbade_Close	BH.82	178	223	Sand	D10
Akingbade_Close	BH.82	223	246	Clay	D15
Victory Estate BH2	BH.83	0	28	Sand	D1
Victory Estate BH2	BH.83	28	90	Clay	D4
Victory Estate BH2	BH.83	90	168	intermediate	D9
Victory Estate BH2	BH.83	168	214	Clay	D11
Victory Estate BH2	BH.83	214	240	Sand	D10
BH22 /yusuf	BH.85	0	20	sand	D1
BH22 /yusuf	BH.85	20	100	intermediate	D5
BH22 /yusuf	BH.85	100	200	sand	D8

BH23 / yusuf	*BH.86*	*0*	*30*	*sand*	*D1*
BH23 / yusuf	*BH.86*	*30*	*70*	*intermediate*	*D5*
BH23 / yusuf	*BH.86*	*70*	*120*	*sand*	*D8*
BH25 / yusuf	*BH.87*	*0*	*50*	*sand*	*D1*
BH25 / yusuf	*BH.87*	*50*	*120*	*clay*	*D4*
BH25 / yusuf	*BH.87*	*120*	*170*	*sand*	*D8*
BH25 / yusuf	*BH.87*	*170*	*250*	*clay*	*D12*
BH26	*BH.88*	*0*	*60*	*clay*	*D3*
BH26	*BH.88*	*60*	*110*	*sand*	*D7*
BH26	*BH.88*	*110*	*180*	*clay*	*D6*
BH26	*BH.88*	*180*	*250*	*sand*	*D10*
BH27	*BH.89*	*0*	*40*	*sand*	*D1*
BH27	*BH.89*	*40*	*90*	*clay*	*D4*
BH27	*BH.89*	*90*	*150*	*sand*	*D8*
BH27	*BH.89*	*150*	*190*	*clay*	*D12*
BH28	*BH.90*	*0*	*30*	*sand*	*D1*
BH28	*BH.90*	*30*	*80*	*clay*	*D4*
BH28	*BH.90*	*80*	*140*	*sand*	*D8*
BH28	*BH.90*	*140*	*200*	*clay*	*D11*
BH29	*BH.91*	*0*	*40*	*clay*	*D3*
BH29	*BH.91*	*40*	*100*	*sand*	*D7*
BH29	*BH.91*	*100*	*150*	*clay*	*D6*
BH29	*BH.91*	*150*	*250*	*sand*	*D10*
BH30	*BH.92*	*0*	*50*	*sand*	*D1*

BH30	*BH.92*	*50*	*100*	*clay*	*D4*
BH30	*BH.92*	*100*	*170*	*sand*	*D8*
BH30	*BH.92*	*170*	*230*	*clay*	*D12*
BH31	*BH.93*	*0*	*40*	*sand*	*D1*
BH31	*BH.93*	*40*	*90*	*clay*	*D4*
BH31	*BH.93*	*90*	*140*	*sand*	*D8*
BH31	*BH.93*	*140*	*250*	*clay*	*D12*
BH32	*BH.94*	*0*	*50*	*clay*	*D3*
BH32	*BH.94*	*50*	*100*	*sand*	*D7*
BH32	*BH.94*	*100*	*180*	*clay*	*D6*
BH32	*BH.94*	*180*	*250*	*sand*	*D10*
BH33	*BH.95*	*0*	*30*	*sand*	*D1*
BH33	*BH.95*	*30*	*80*	*clay*	*D4*
BH33	*BH.95*	*80*	*130*	*sand*	*D8*
BH33	*BH.95*	*130*	*240*	*clay*	*D12*
BH34	*BH.96*	*0*	*40*	*sand*	*D1*
BH34	*BH.96*	*40*	*100*	*clay*	*D4*
BH34	*BH.96*	*100*	*160*	*sand*	*D8*
BH34	*BH.96*	*160*	*230*	*clay*	*D12*
BH35	*BH.97*	*0*	*50*	*clay*	*D3*
BH35	*BH.97*	*50*	*110*	*sand*	*D7*
BH35	*BH.97*	*110*	*180*	*clay*	*D6*
BH35	*BH.97*	*180*	*250*	*sand*	*D10*
BH36	*BH.98*	*0*	*40*	*sand*	*D1*

BH36	*BH.98*	*40*	*100*	*clay*	*D4*
BH36	*BH.98*	*100*	*160*	*sand*	*D8*
BH36	*BH.98*	*160*	*250*	*clay*	*D12*
BH37	*BH.99*	*0*	*40*	*sand*	*D1*
BH37	*BH.99*	*40*	*90*	*clay*	*D4*
BH37	*BH.99*	*90*	*150*	*sand*	*D8*
BH37	*BH.99*	*150*	*250*	*clay*	*D11*
BH38	*BH.100*	*0*	*30*	*sand*	*D1*
BH38	*BH.100*	*30*	*80*	*clay*	*D4*
BH38	*BH.100*	*80*	*130*	*sand*	*D7*
BH38	*BH.100*	*130*	*160*	*clay*	*D6*
BH41	*BH.102*	*0*	*50*	*sand*	*D1*
BH41	*BH.102*	*50*	*90*	*clay*	*D4*
BH41	*BH.102*	*90*	*130*	*sand*	*D8*
BH41	*BH.102*	*130*	*180*	*clay*	*D12*
BH43	*BH.104*	*0*	*50*	*sand*	*D1*
BH43	*BH.104*	*50*	*100*	*clay*	*D4*
BH43	*BH.104*	*100*	*150*	*sand*	*D8*
BH43	*BH.104*	*150*	*220*	*intermediate*	*D13*