Hydrogeological Typologies of the Aquifer Systems underlying Lagos State, Nigeria

ECAR PROGRAMME

Open Report OR/25/039

BRITISH GEOLOGICAL SURVEY

ECAR PROGRAMME

OPEN REPORT OR/25/039

Keywords

Lagos, Nigeria, Groundwater, Water Supply.

Bibliographical reference

Holliday L, Upton K, MacDonald A, Healy A, Comte JC, Olabode OF, Olatunji A, Tijani M, Akanmu J, Longe E, Oshinlaja N, Cuthbert M, Aladejana J, Kolawole K, Alo O and Oteri A. 2025. Hydrogeological Typologies of the Aquifer systems underlying Lagos State, Nigeria. *British Geological Survey Open Report*, OR/25/039. 70pp.

Hydrogeological Typologies of the Aquifer Systems underlying Lagos State, Nigeria

L Holliday, K Upton, A MacDonald, A Healy, JC Comte, OF Olabode, A Olatunji, M Tijani, J Akanmu, E Longe, N Oshinlaja, M Cuthbert, J Aladejana, K Kolawole, O Alo and A Oteri.

Keyworth, Nottingham British Geological Survey 2025

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from the BGS shop at Nottingham and Cardiff (Welsh publications only). Shop online at https://shop.bgs.ac.uk/

The London Information Office also maintains a reference collection of BGS publications, including fossils, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from the BGS shop.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of UK Research and Innovation.

British Geological Survey offices

Nicker Hill, Keyworth,
Nottingham NG12 5GG

Tel 0115 936 3100

BGS Central Enquiries Desk

Tel 0115 936 3143
email enquiries@bgs.ac.uk

BGS Sales

Tel 0115 936 3241
email sales@bgs.ac.uk

The Lyell Centre, Research Avenue South,
Edinburgh EH14 4AP

Tel 0131 667 1000
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road,
London SW7 5BD

Tel 020 7589 4090
Tel 020 7942 5344/45
email bgslondonstaff@bgs.ac.uk

Cardiff University, Main Building, Park Place,
Cardiff CF10 3AT

Tel 029 2167 4280

Geological Survey of Northern Ireland, 7th Floor,
Adelaide House, 39-49 Adelaide Street, Belfast, BT2 8FD

Tel 0289 038 8462
www2.bgs.ac.uk/gsni/

Natural Environment Research Council, Polaris House,
North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501
www.nerc.ac.uk

UK Research and Innovation, Polaris House,
Swindon SN2 1FL

Tel 01793 444000
www.ukri.org

Website: https://www.bgs.ac.uk
Shop online: https://shop.bgs.ac.uk/

Foreword

This report is the published product of a study by the British Geological Survey (BGS) in partnership with Cardiff University, Aberdeen University, the University of Lagos and the University of Ibadan to develop a Groundwater Demonstrator for Lagos. The report aims to present the current conceptual understanding of groundwater systems underlying the state by compiling all pre-existing and openly accessible groundwater data and research, which was then supplemented by groundwater level data and key water quality parameters collected by the University of Ibadan and the University of Lagos at 44 sites across Lagos State since 2021. Results from this study can be used to inform future hydrogeological investigations across the state, allowing for stakeholders to better understand, monitor and manage the state's groundwater resources.

Acknowledgements

We would like to thank Lagos State Water Corporation, Lagos State Ministry of Environment and Water Resources and other individual private well-owners for helping to provide access to the monitoring boreholes within the University of Lagos and the University of Ibadan datasets.

The work of BGS was funded by the BGS International NC Programme 'Geoscience to tackle global environmental challenges', NERC reference NE/X006255/1.

The work of Oluwaseun Olabode and Jean-Christophe Comte (University of Aberdeen) was funded by the Nigerian Tertiary Education Trust (grant no. TETF/ES/UNIV/ONDO/TSAS/2018), as well as the Scottish Funding Council (SFC) and Overseas Development Assistance (ODA) through the International Science Partnerships Fund (ISPF).

The work of Cardiff University, University of Ibadan and University of Lagos was funded by UKRI, through a Future Leaders Fellowship held by Dr. Adrian Healy (UKRI grant numbers MR/SO31863/1 and MR/X022943/1).

The British Geological Survey, Cardiff University and the University of Ibadan also acknowledge previous support from the UK's Global Challenges Research Fund through the project: Resilience in Groundwater Supply Systems (RIGSS), grant number NE/P01545X/1.

The authors would like to thank Donald John MacAllister (BGS) for his thorough review of this report.

Contents

FIGURES

TABLES

Summary

WATER SECURITY CHALLENGES

With a population of 15 million in 2020 and an annual population growth rate of 3.5%, Lagos mega-city is predicted to be the world's most populous city by 2100 (Desjardins, 2018). The city is grappling with a critical water-supply challenge (Lagos Water Corporation, 2010; UN News, 2016), exacerbated by inadequate infrastructure and a growing population (Jideonwo, 2014; Balogun et al., 2017; Olabode and Comte, 2024). Lagos' piped water supply system originally dates to 1910, with the first official commissioning in 1915 (World Bank, 1988). This was followed by numerous expansion and modernization projects up to 1991. In 2004 within the framework of the National Urban Water Sector Reform Programme (NUWSRP), Lagos State Water Supply Project was initiated to increase access to public water supplies as part of a 15-year expansion program (FMWR-NUWSRP, 2004). Despite those interventions it is estimated that less than one tenth of the population of Lagos City have access to a municipal water supply.

In the absence of piped water, the majority of residents are reported to rely upon groundwater as their primary source of drinking water, largely through privately installed wells and boreholes. Groundwater also supports abstraction for industry across the State. Despite the reliance of Lagos on groundwater, information on the characteristics of the underlying groundwater resource is sparse and fragmented. In 2024, the Resilient Water Accelerator (RWA) – a global initiative bringing together decision makers, technical experts, and investors to address water insecurity and risk – launched the Lagos Water Partnership (LWP). This initiative aims to address the issue of water security in Lagos by driving investment in climate-resilient water projects, striving to maximise the potential of groundwater in playing an increasingly strategic role in the provision of climate-resilient water supply through this partnership (Healy, 2024).

LAGOS GROUNDWATER SYSTEM

Whilst groundwater has the potential to offer climate-resilient water supplies, the current lack of in-depth understanding of the groundwater resources across Lagos State hinders its effective development and management. Previous efforts to understand and model the State's underlying aquifers are inadequate and built upon limited data.

This report synthesizes available groundwater data and information to assess the groundwater system underlying Lagos State, providing an updated understanding of the region's aquifers, identifying key knowledge gaps and uncertainties, and offering recommendations to address these concerns to ensure the future sustainability of Lagos' groundwater resources.

Across Lagos, the key regional aquifer systems, all of which contain multiple water-bearing horizons, are summarized below.

1. The shallow aquifer system comprises the hydraulically connected and generally unconfined ***Alluvium and Upper Coastal Plain Sands (UCPS)***. Lithology consists of highly heterogeneous, unconsolidated and poorly to moderately sorted sands, gravels, clays, silts and muds, which are intercalated, with facies rapidly changing. The aquifer thickens southward, from up to ~ 30 mbgl in the north, to ~ 160 mbgl in the south; with thickness of individual water-bearing sand and gravel horizons typically ranging from 5 to 30 m. Information on aquifer properties are limited, but transmissivity locally heterogenous and varies significantly over large scales, with estimates ranging from 13 to 2333 m^2/day. Yields of up to 100 m^3/hour have been recorded in Shomolu. This aquifer is highly vulnerable to degradation and depletion, although issues appear to be localised, confined to specific areas of anthropogenic contamination and over-abstraction. Within the central coastal belt, from Apapa to Lekki, saline intrusion is evident, and significant abstraction from limited freshwater lenses is likely to cause upconing or further saline intrusion. Outside of this belt, where contamination risks can be managed, the aquifer can support small-scale domestic supply but is unsuitable for large-scale public supply.

2. The ***Lower Coastal Plain Sands (LCPS)*** appears to be a moderately to highly productive aquifer system, comprising of intercalated and unconsolidated sands, gravels, clays and lignites, and sand content is typically higher within the LCPS than the UCPS. A near-continuous clay layer (semi-)confines the LCPS, minimising hydraulic connectivity with the shallow UCPS aquifer or surface water and largely protecting the LCPS from anthropogenic contamination and saline intrusion. The LCPS generally ranges from 30 to 50 m thickness in the north but can be over 80 m thick in the south, reaching depths of at least 290 mbgl in some locations. Thickness of individual aquifer horizons typically range from 2.5 to 45 m. Aquifer properties are highly variable due to rapidly changing facies and spatial heterogeneity. Transmissivity ranges from 95 to 3700 m^2/day, with higher transmissivity generally reported in the south of the state. Productivity is not widely reported, although transmissivity values suggest the aquifer has the potential to support larger-scale public and industrial water supply if adequately planned and managed. Further investigation is required for full characterisation and to fully understand contamination risks. Despite concerns of over-abstraction and declining water levels, recent monitoring data suggests that water levels might be slowly rebounding in some parts of Lagos City. Continuing long-term monitoring is essential.

3. The ***Abeokuta Formation*** is the deepest and potentially the most productive aquifer system underlying Lagos State. The aquifer comprises of sandstones, gritstones and basal conglomerates, intercalated with claystone, siltstone and shale aquicludes, and is believed to be hydraulically separated from the UCPS and LCPS aquifers by the Ilaro and Ewekoro Formations. The aquifer is encountered at depths below 450 mbgl in the north, and due to the southerly dipping nature of the sediments underlying Lagos State, will be even deeper in the south (depth unknown). Total aquifer thickness is expected to range from 250 to 300 m. Limited information on aquifer properties is available, with reported transmissivity ranging from 2189 to 3200 m^2/day. The aquifer is expected to be high yielding (reported yields of up to 200 m^3/hour in Ogun and Osun states) and of general good quality, but further investigation is needed to characterise this system within Lagos State. The Abeokuta Formation may present an economically viable resource for larger-scale abstraction, including public or industrial supply, more likely where the system is shallower in the north of the state. Presence of some ferruginous sandstone horizons suggests a potential risk of elevated iron concentrations, although this can be treated and poses minimal risk to human health.

Whilst a simplified overview of these aquifer systems can be made across the state, due to geological complexity, the UCPS and LCPS aquifers are heterogeneous and display a high level of hydrogeological variability, even at a local scale. Therefore, within this more regional overview, six initial typologies have been identified, reflecting variations between the three main aquifer systems, with each typology presenting differing opportunities and risks. These typologies can be broadly summarized as:

- ***Typology A: Inland Northwest*** describes the aquifer systems in the north-west of Lagos State, from Agege to Ikorodu. It comprises of heavily urbanised and industrialised zones. Groundwater in this region is used for both domestic and industrial water supplies, sourced from shallow wells and a mixture of low-volume motorised boreholes operated by households and high-volume motorised boreholes operated commercially. Both the CPS aquifers and the Abeokuta Formation are utilised in this area, although only industrial boreholes tend to tap from the Abeokuta Formation due to its depth (> 460 mbgl). The alluvium is generally absent, other than in river floodplains. The UCPS here comprises of up to 30 m of sand with intercalated clays and is occasionally semi-confined. Whilst saline intrusion is not evident, localised anthropogenic contamination is apparent within the shallow aquifer. The confined and more sand-dominated LCPS, bearing fresh groundwater, is separated from the UCPS by an up to 60 m thick clay aquitard, and is encountered typically at depths from ~ 70 to ~ 120 mbgl. The Abeokuta Formation is encountered at depths below ~ 450 mbgl, with 10 to 30 m thick sand horizons providing deeper groundwater resources, expected to be fresh and of good quality.

- ***Typology B: Lagos Mainland Urban Centre*** describes the aquifer systems around Lagos mainland's urban centre, from Gbagada to Aguda. It comprises of high population density, heavy urbanisation and industrialization. Groundwater in this region is used for both domestic and industrial water supplies, sourced from shallow wells and a mixture of low-volume motorised boreholes operated by households and high-volume motorised boreholes operated commercially. Interbedded sands, gravels and clays of the UCPS are found up to depths of 70 mbgl, thinning southward, with evidence of anthropogenic contamination within much of the shallow aquifer across this typology and evidence of saline intrusion towards the lagoon. Here, the LCPS is much better suited for potable water supply systems and is separated from the UCPS by a 10 to 45 m thick clay aquitard, with groundwater generally being fresh and expected to be largely protected from anthropogenic contamination. Found at depths typically below 90 mbgl, water-bearing sand and gravel horizons are typically 6 to 34 m thick and appear to have good potential for abstraction, although localised over-abstraction is evident. The thickness, sand content and productivity of aquifer horizons increases southwards. Information surrounding the Abeokuta Aquifer in this area is unavailable

- ***Typology C: Urbanised Coastal Centre*** covers the aquifer systems along the central coastal belt from Apapa to Lekki, characterized by high population density, urbanization, and industrialization. Groundwater in this region is used for both domestic and industrial water supplies, sourced from shallow wells and a mixture of low-volume motorised boreholes operated by households and high-volume motorised boreholes operated commercially. Overlain by alluvium, the UCPS reaches depths of up to 190 mbgl and consists of 10 to 60 m thick beds of medium to coarse grained sands and gravels, intercalated with clayey sand and clay layers of up to 75 m thickness. Here, the UCPS faces localized anthropogenic contamination and saline intrusion, resulting in borehole abandonment. Small-scale domestic supply relies on a shallow freshwater lens within the UCPS, which risks upconing of saline water if over-exploited, although there is also risk of degraded water quality from anthropogenic sources within this shallow lens. Generally found at depths of below 160 mbgl, the medium to coarse grained sand and gravel aquifer horizons of the LCPS are hydraulically disconnected by the UCPS by a 5 to 15 m thick clay aquitard. Better protected from saline intrusion and anthropogenic contamination, the LCPS is reported to produce fresh water, hence is more suitable for potable water supply and large-scale abstraction. Data from the Abeokuta Formation is lacking, but it is likely too deep for abstraction to be economically viable.

- ***Typology D – Coastal Southwest at Badagry*** describes the aquifer systems across Badagry LGA, a coastal area situated between Lagos City and the Benin border. It comprises an urban centre and surrounding rural communities. Groundwater in this region is predominantly used for domestic supply, sourced from hand-dug wells and motorized boreholes, mainly drawing from the shallow aquifer system (sandy clay alluvium and UCPS), which extends to ~ 100 mbsl. Localised anthropogenic contamination, attributed to the shallow water table is evident, although there appears to be limited evidence of saline intrusion. Found at depths from 300 to 400 mbsl and separated from the UCPS by a ~ 200 m aquitard, the sand-dominated LCPS aquifer system appears more suitable for water supply due to the presence of more extensive sands and is expected to be highly productive with good water quality. The Abeokuta Formation aquifer is found beyond 958 mbgl, making it unsuitable as an economically viable aquifer system in the area, therefore is disregarded within this typology.

- ***Typology E: Lithological Anomaly at Lakowe*** describes the lithological anomaly observed within the aquifer systems between Awoyaya and Lakowe in Ibeju-Lekki, situated between Lagos Lagoon and the coastline, east of Lagos. The area, less developed than the Lagos mainland, Victoria Island, and Lekki, has experienced rapid urbanization in recent years, transitioning into a growing commercial and residential zone. Within this typology, aquifer systems do not appear to be suitable for any significant water supply, due to the UCPS and LCPS being clay dominated. Shallow UCPS sand horizons suffer anthropogenic contamination, whilst deeper sand horizons bear brackish water.

- ***Typology F: Inland Northeast at Epe*** is located in northeastern Lagos, extending from Epe town and Itoikin northward to the border. This area includes both urban and rural zones, with urbanization concentrated around Epe town and near the lagoons. Protected wetlands are increasingly threatened by development, sand-mining and uncontrolled land reclamation. Water usage is for domestic, industrial and agricultural purposes, including irrigation (cassava, pineapple, rice). Here, the undifferentiated CPS aquifer is clay-dominated, with only thin (~ 5 m) and non-laterally extensive sand horizons, hence only appears suitable for small-scale domestic supply. Found at relatively shallower depths (from 211 mbgl) than the rest of the state, the sandstone horizons of the Abeokuta Formation may be more appropriate for larger-scale abstraction or public water supply and is expected to be highly productive and of good quality. However, further hydrogeological investigation is required, as current data for the area is limited.

Further refinement of these typologies, and their transition zones, are still required for more robust conceptualization of the groundwater system at the state-scale.

Based on the limited data available, within the UCPS and LCPS the overarching trends across Lagos State appear to reflect:

- Increased thickness of aquifer from north to south;
- Increased sand content from north to south;
- Increased productivity (yields and transmissivities) from north to south.

Until recently, a lack of observational data on groundwater quality and quantity has resulted in a speculative narrative of state-wide groundwater depletion and contamination based on limited evidence. However, monitoring data collected by the University of Lagos (UNILAG) and the University of Ibadan (UNI-IBADAN), analysed as part of this report, suggest that depletion and contamination is localised, rather than widespread.

Significant uncertainty remains in our conceptualisation of Lagos State's groundwater resources, as the updated conceptual understanding proposed within this report has been developed from pre-existing literature of varying quality, quantity and reliability and a relatively short period of monitoring. These uncertainties include development of a geological framework from minimal direct borehole logs, with increased reliance on pre-interpreted geophysical data; uncertainties in pre-existing data interpretation; and limited spatial coverage. Additionally, the *Lagos Groundwater Demonstrator* monitoring networks are not yet strategically widespread, and it is possible that observed localised depletion and quality concerns may be less localised than currently understood, and that further zones of concern are not yet identified. Furthermore, a lack of supplementary information, such as abstraction regime and borehole information, limit the potential for monitoring data analysis.

RECOMMENDATIONS

Given the dependence of Lagos on its groundwater systems, we recommend the implementation of a comprehensive programme of activities designed to safeguard this essential resource into the future:

1. ***Stakeholder Engagement and Data Collation*****:** We recommend that Lagos State initiate a 'Big Conversation on Groundwater', engaging professionals, practitioners, policy officials and the public. We propose that Lagos State develop a groundwater database that collates available data on groundwater and provides a means to display this data in the future to inform groundwater governance and decision-making.

2. ***Development of a Robust Groundwater Monitoring Network*****:** We recommend that a robust, strategic and co-ordinated monitoring network is established and maintained across all aquifer systems, ensuring good spatial coverage. We propose that this should incorporate the exiting UNI-IBADAN and UNILAG network; engage a cadre of committed and knowledgeable borehole owners and extend future data collection at sites with historic monitoring records. These efforts should include addressing existing data gaps, ensuring

proper management and maintenance of monitoring points, and collecting long-term water level and quality data to support evidence-based decision-making.

3. ***Further Hydrogeological Investigation*:** We recommend that further hydrogeological investigation be undertaken to more fully understand the groundwater typologies occurring in Lagos State and the connectivity of the aquifers. We propose that the data collated and collected through the first two phases described above should be used to verify, further refine and expand the conceptual model of the Lagos groundwater system, supporting the planning of further investigation. This will involve refining the geological framework (e.g. geophysical surveys); groundwater level, flow and depletion mapping; water quality assessments; pumping tests to define hydraulic properties and evaluate sustainable yields; closing the water balance (understanding recharge and discharge); and socioeconomic surveys to understand groundwater use across different sectors. This information could be fed into a numerical groundwater model which, following capacity building and training, could be handed over to relevant authorities and decision-makers supporting water supply efforts across the state. This model would be crucial for enabling evidence-informed decision-making to ensure long-term sustainability and resilience of groundwater resources for water supply in Lagos State.

4. ***Improvement of Groundwater Practice, Policy and Management*:** We recommend that the critical role played by small-scale abstractors (households, institutions and small businesses) in maintaining functional water supply infrastructure is formally acknowledged and planned for. We propose that Lagos State adopt a policy of conjunctive water supplies, maintaining the long-term inclusion of groundwater-fed supply in areas where quality and quantity is sufficient. In areas where groundwater supplies are suitable for larger scale abstraction, support should be provided to small-scale private users of groundwater in the medium term, with the long-term aim to transition from small-scale private supplies to strategic (centralized or decentralized) public water supplies, which may also be dependent upon groundwater. Key activities could include the establishment of a dedicated monitoring division; groundwater productivity and vulnerability mapping; abstraction regulation (e.g. licenses, permits); the development of source protection strategies to ensure long-term water security; explore household engagement toward groundwater management; launch a public awareness campaign on the theme of “Love Lagos, Love Groundwater”.

By addressing these steps, Lagos can begin to develop a sustainable groundwater management framework, which will improve access to clean drinking water, protect the aquifers from over-exploitation, and ensure resilience in the face of future population growth and climate change.

1 Introduction

With a population of 15 million in 2020 and an annual population growth rate of 3.5%, Lagos mega-city is predicted to be the world's most populous city by 2100 (Desjardins, 2018). Over a decade ago, Lagos was reported to be struggling with a growing water-supply gap (Lagos Water Corporation, 2010), and in 2016, the UN's Special Rapporteur identified Lagos City to be suffering from a water crisis (UN News, 2016). In 2024, the Resilient Water Accelerator (RWA) – a global initiative bringing together decision makers, technical experts, and investors to address water insecurity and risk – launched the Lagos Water Partnership (LWP). This initiative aims to address the issue of water security in Lagos by driving investment in climate-resilient water projects.

Groundwater, which is inherently more resilient to climate shocks than surface water, currently plays a significant role in the provision of water in Lagos. It is estimated that less than one tenth of the population of Lagos City have access to a municipal water supply (ARUP, n.d), an issue that continues to be exacerbated by the growing population and inadequate management and regulation of water resources (Jideonwo, 2014; Balogun et al., 2017; Olabode and Comte, 2024).

Therefore, in the absence of piped water, many residents are reported to rely upon groundwater as their primary source of drinking water, largely through privately installed wells and boreholes (Healy et al., 2020). This proliferation of groundwater use has resulted in localised instances of groundwater depletion, anthropogenic contamination and saltwater intrusion, which could potentially reduce the quality and quantity of resource availability into the future (Adiat, 2019; Ajani et al., 2021; Akoteyon et al., 2018; Balogun et al., 2017; Oloruntola et al., 2017; Ola et al., 2019; Oladapo et al., 2014; Tijani et al., 2018; Olabode, 2025).

There is significant potential for groundwater to continue to play a strategic role in the provision of climate-resilient water supply through the LWP (Akanmu et al, 2024). However, this requires an in-depth understanding of the groundwater resource across Lagos State to inform sustainable development and management. Previous efforts to regionally understand and model the state's underlying aquifers rely on limited data and do not adequately capture the complexity of the groundwater system. Furthermore, until recently, a lack of observational data on groundwater quality and quantity has resulted in a narrative of state-wide groundwater depletion and contamination, based on limited evidence and historic studies.

This report provides a summary of the groundwater system of Lagos State, based on evaluation and analysis of available groundwater data (including recently acquired groundwater level monitoring data) and literature. It also highlights the major knowledge gaps and uncertainties in our understanding. Finally, we make recommendations to address these knowledge gaps to support the future development of groundwater resources, and the necessary associated policy frameworks, as part of a wider strategy for resilient water supply in Lagos.

2 Regional Overview

2.1 GEOLOGY

Lagos State is located along the eastern margin of the fault-bound Dahomey (Benin) Basin, which extends from Accra, Ghana through Togo, Benin and into Nigeria. The transboundary basin formed during Late Jurassic to Early Cretaceous rifting, linked to the opening of the Gulf of Guinea (Burke et al., 1971; Whiteman, 1982). It is bound to the west by the Okitipup Ridge at the Benin Hinge line, separating it from the Niger Delta Basin, and to the east by the Ghana Ridge (Jones & Hockey, 1964; Coode-Blizard, 1996).

Geology within this portion of the basin consists of a sedimentary sequence (Figure 1;Table 1), overlying the Pre-Cambrian Crystalline Basement Complex. This sequence, which resulted from basin subsidence during the Middle to Upper Cretaceous and Tertiary periods, and influenced by sea transgression and regressions, includes fluvial, lacustrine and marine deposits associated with the African Plate's drift phase (Storey, 1995; Mpanda, 1997). The gently (~ 1°) southerly-dipping sedimentary sequence exceeds 1400 m thickness along Nigeria's coastline (Hockey & Jones, 1964; Billman, 1976; Omatsola & Adegoke, 1981). Lateral extent and thickness of sediments across the basin varies significantly, though there is a general thickening across Lagos from north to south and east to west (Jones and Hockey, 1964; Longe et al., 1987; Coode-Blizard, 1996). Both the Alluvium and Coastal Plain Sands (CPS) formations are exposed at the surface in Lagos State (Figure 1).

Stratigraphic nomenclature for the basin's key formations varies across studies (Jones & Hockey, 1964; Ogbe, 1972; Omatsola & Adegoke, 1981; Agagu, 1985; Billman, 1992). For consistency, the original nomenclature of Jones and Hockey (1964) is adopted in this framework, outlined in Table 1.

Although the basin is structurally bound, there is no direct evidence of smaller-scale geological structure within Lagos State. Coode-Blizard (1996) proposed potential faulting in the eastern part of the state, based on the identification of a thick clay layer deemed to reflect absence of part of the Coastal Plain Sands in one borehole at Lakowe. However, this may reflect inconsistency within borehole logging interpretations and/or large and rapid lateral variations in clay content within the Coastal Plain Sands, rather than large-scale faulting; further investigation is required to ascertain this.

Table 1: Stratigraphic sequence of the geology underlying Lagos State, as delineated by Jones & Hockey (1964). Aka = also known as; Fmtn = Formation.

Age		Formation	Description
Quaternary	Recent	Alluvium	Coastal sands, clays, silts and muds, and alluvial deposits of coarse sands with clay lenses and pebble (gravel) beds, deposited along coastal belt and surrounding major rivers (Coode-Blizard, 1996).
Tertiary	Oligocene – Pleistocene	Coastal Plains Sands, CPS (*aka Benin Fm/ Continental Terminal*)	Non-marine onshore sequence of unconsolidated, poorly sorted variations of clays, sands, gravels & rare thin lignite. Depositional environments across the Dahomey basin include fluvial (meandering and braided) and debris flow (Olabode & Mohammed, 2016).
Tertiary	Eocene	Ilaro Formation	Marked colour change from CPS due to period of oxidising conditions. Predominantly clay, silt and pyritic shale. Occasionally fine-grained argillaceous sand or bearing bands of phosphatic minerals. Depositional environment transitioning south to north from marine to continental, reflecting changes between sandy estuarine and deltaic continual beds (Olabode & Mohammed, 2016).
Tertiary	Palaeocene	Ewekoro Formation (*subdivided into Ewekoro, Oshosun & Akinbo Fm)*	Lens-shaped fossiliferous limestone with marl and minor sand (arenaceous towards base), deposited in a shallow marine environment (Jan de Chine, 1980).

Upper Cretaceous	Late Senonian	Abeokuta Formation (*subdivided into Araromi, Afowo & Ise Fm)*	Dominated by sandstone. Conglomerate in a sandstone matrix at base, overlain by coarse-grained, clayey and poorly sorted sandstones (Omosanya et al., 2012), with interbeds of marine shales, siltstones and limestones in some areas. Depositional environment changing from fluvial/continental to marine.
		Unconformity	
Pre-Cambrian		Crystalline Basement	Metamorphic crystalline basement (granites and migmatites).

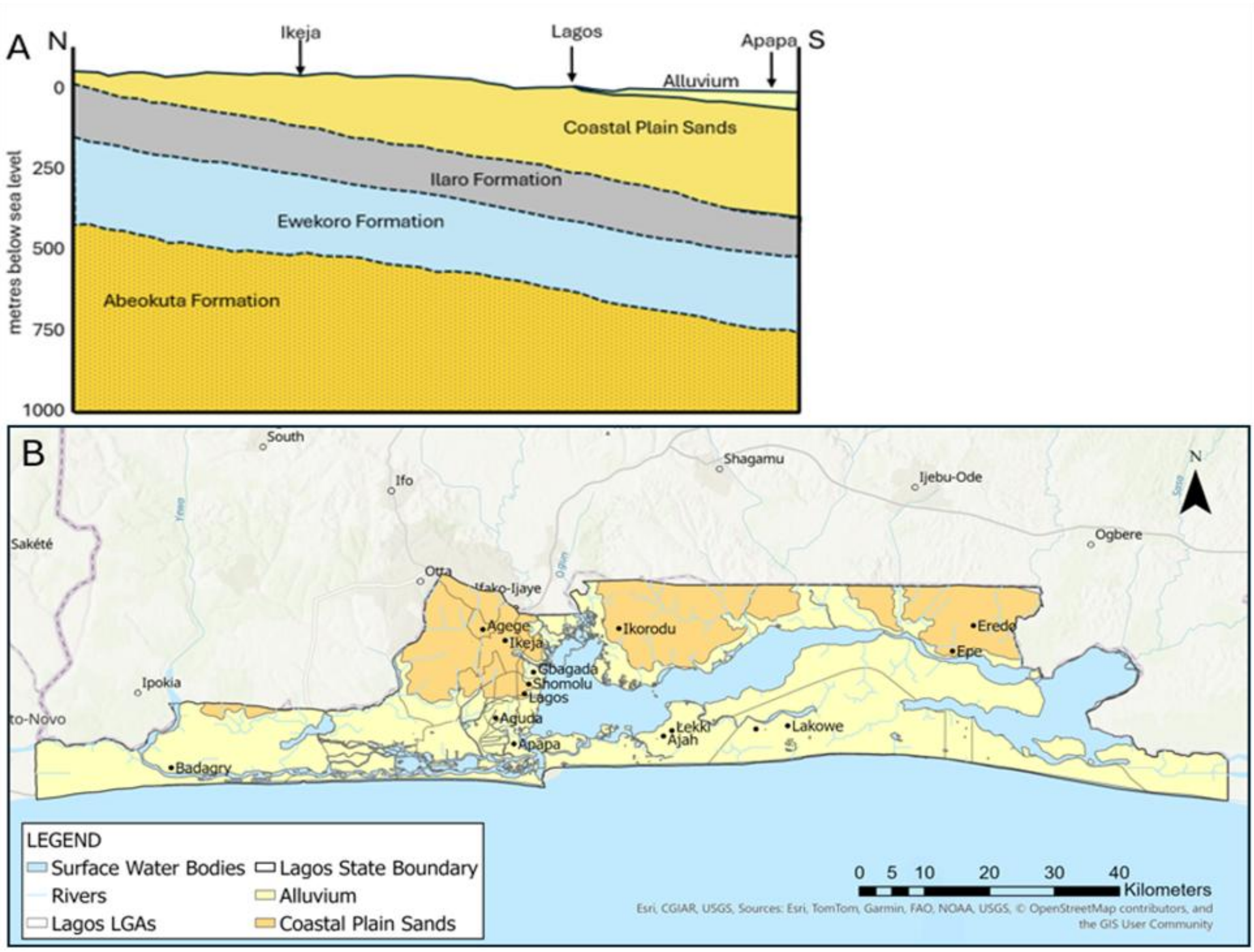

Figure 1: (a) generalised schematic geological cross-section for Lagos State. Vertical exaggeration applied, accentuating the apparent dip of the formations. (b) surface geology of Lagos State (geological shapefile modified after Olabode & Comte, 2024). LGA = Local Government Areas. Basemap: Esri, CGIAR, USGS, TomTom, Garmin, FAO, NOAA, USGS © OpenStreetMap contributors and the GIS User Community. BGS © UKRI 2025.

2.2 HYDROGEOLOGICAL OVERVIEW

In Lagos State, four primary aquifer units are identified for potential water supply (shallow to deep): Recent Alluvium (RA), Upper Coastal Plain Sands (UCPS), Lower Coastal Plain Sands (LCPS), and the Abeokuta Formation (AF).

The Ilaro and Ewekoro Formations are not considered viable aquifers in Lagos due to their poor groundwater potential (Offodile, 2002). The Ilaro Formation is predominantly impermeable shale or clay, and whilst the Ewekoro Formation may theoretically possess aquifer capacity (Longe et al., 1987), difficulties in distinguishing these limestone layers have been reported, and in Eredo, fissured limestone caused issues with loss of circulation during drilling (Coode-Blizard, 1996).

Aquifers within the Dahomey Basin exhibit significant lateral and vertical variability (Kampsax-Kruger, 1977; Longe et al., 1987; Onwuka, 1990; Coode-Blizard, 1996), and this is reflected within Lagos. Six general variations in aquifer typology have been identified across Lagos State from pre-existing information; these are outlined in detail in Section 4.

2.2.1 Recent Alluvium

The RA aquifer is a shallow, unconfined, unconsolidated system (Longe, 2011), extending in a 15-20 km belt along the coastline and river drainage networks (Oyegoke, 1986; Oteri & Ayeni, 2016). The aquifer typically has a thickness of 8 to 12 m, reaching up to 30 m near the coast, and is hydraulically connected to the surface water system and UCPS below. The aquifer is heavily exploited for private domestic and agricultural use via hand-dug wells or shallow boreholes (Longe et al., 1987; Balogun et al., 2017). Information on the hydrogeological properties of the RA are unavailable.

Groundwater recharge in the RA is predominantly precipitation-driven, with rapid infiltration and short residence times, consistent with the region's high annual rainfall (> 2000 mm) (Aladejana et al., 2020a; Longe, 2011). Due to its shallow water level, unconfined nature and proximity to the coast, the RA aquifer is susceptible to anthropogenic contamination and saline intrusion (Longe et al., 1987; Adiat, 2019; Oke et al., 2016; Oladeji, 2020), as discussed in Section 3.3.1.

2.2.2 Upper and Lower Coastal Plain Sands

Together, the Upper and Lower Coastal Plain Sands serve as the state’s primary water source for domestic, public, and industrial use (Oteri & Ayeni, 2016), with over 95% of boreholes abstracting from these horizons (Coode-Blizard, 1996; Longe, 2011). The CPS consists predominantly of intercalated clays, sands and gravels, forming a multi-layer aquifer system with groundwater flow and storage concentrated in the higher permeability sand and gravel layers. Due to significant geological heterogeneity, the thickness and extent of aquifer layers is highly variable, both within and between the main upper and lower horizons. A semi-continuous clay aquitard separating the upper and lower systems has been identified across the state (Coode-Blizard, 1996), although the extent of this is not well defined, and locally can be absent. Often, the upper and lower systems are not well-delineated in the literature.

From north to south, sand content and overall aquifer thickness increase, as do transmissivity and yield (Longe et al., 1987; Coode-Blizard, 1996). However, hydraulic properties and yields are highly variable due to geological heterogeneity, and local clay lenses can significantly affect the lateral continuity and productivity of aquifer layers (Longe, 2011), as discussed in Sections 2.2.2.1 and 2.2.2.2 below.

Groundwater recharge is primarily precipitation-dominated with rapid infiltration and short residence times, especially in the shallow, unconfined UCPS sediments (Yusuf et al., 2018). Spatially distributed modelling by Olabode & Comte (2022) suggests an average of 30% of precipitation recharges the shallow unconfined aquifer units within Lagos (average annual rainfall expected to be 2000 to 2500 mm/year (Tijani et al., 2018)). Recharge is expected to be lower within the heavily urbanised centre of the state, where there are more impermeable surfaces and drainage infrastructure, than toward the well-vegetated rural parts of east and west Lagos. Recharge is further influenced by flood-flow and surface water interactions, particularly during the wet season, in proximity to lagoons and, near the coast, by seawater intrusion (Longe et al., 1987; Ayolabi et al., 2013; Akinbinu, 2015; Aladejana et al., 2020a). The LCPS receives less direct recharge due to its semi-confined nature and depth, although in northern areas where the LCPS is unconfined it receives direct recharge from precipitation. Modelling indicates that infiltration and recharge into the aquifer system have decreased between 2000 and 2020, which has been attributed to a change in land use and urbanisation (Olabode & Comte, 2022).

Groundwater facies across the CPS are predominantly Na-SO_4 and Ca-HCO_3, with minor variations including mixed facies (Na-HCO_3, Ca-(Na)-HCO_3, Ca-SO_4), Na-Cl, Ca-Cl, and K-Cl (Olatunji et al., 2005; Tijani et al., 2005; Aladejana et al., 2020a). Typically, the lower horizons and northern parts of the state are more Na-HCO_3 dominated, whilst the upper horizons, particularly towards the coast and in proximity to lagoons are more Na-Cl dominated. These facies reflect endmembers influenced by both rock-weathering processes (Ca/Mg-HCO_3) and saline influences such as seawater and lagoons (Na-Cl). Cation exchange between these new members results in the Na-HCO_3 facies observed in the lower horizons and to the north of the state.

An up-to-date and comprehensive understanding of groundwater levels and flow across the entire state is limited due to the absence of a spatially targeted groundwater monitoring network. However, historic studies suggest a significant decline in groundwater levels over time, primarily attributed to over-abstraction driven by industrial activity and high water demand from a growing population. Comparisons between groundwater level data from Kampsax Kruger (1977) and Coode-Blizard (1996) reveal a decline in groundwater levels within the CPS between 1977 and 1996 (Olabode, 2025). The aquifer's upper and lower systems were not clearly differentiated in these studies. At abstraction centres such as Apapa (south) and Ikeja (north), large regional cones of depression developed, with the inferred 0 metre above sea level (masl) piezometric contour shifting 15 km northward between 1977 and 1996 (Coode-Blizard, 1996). Groundwater flow reversals leading to saline intrusion were also reported. Groundwater modelling by Coode-Blizard (1996) and Asiwaju-Bello & Oladeji (2001) supported these findings, modelling significant drawdown in western Lagos, attributed to unregulated abstraction, with less drawdown in the more rural eastern parts of the state. More recent monitoring data suggest that despite remaining issues of localised depletion; the water table is rebounding across many parts of the state (see Section 3.2).

The prevailing groundwater flow direction is generally from north to south across the state (Kampsax-Kruger, 1977; Coode-Blizard, 1996; Asiwaju-Bello, 2001; Olabode, 2025). However, localised flow patterns, particularly near cones of depression, have been identified in areas of intense abstraction. Yusuf & Abiye (2019) suggest a more complex, multi-directional flow at a local scale, influenced by borehole extraction, clay layer distribution, and groundwater-surface water interactions.

Where current available literature and information allows, the behaviour of the Upper and Lower Coastal Plain Sands has been differentiated in Section 2.2.2.1 and 2.2.2.2

Water-bearing horizons in the LCPS typically consist of poorly to well sorted, fine to coarse grained sands and gravels, and are intercalated with clay lenses. They typically have a higher sand content than the overlying UCPS system.

2.2.2.1 Upper Coastal Plain Sands

The UCPS is mostly unconfined, with water-bearing horizons, typically intercalated with clay, consisting of poorly to moderately sorted, fine to medium grained sands and medium to coarse grained sand and gravel. This aquifer is typically hydraulically connected to the RA where overlain. The Upper CPS is rarely differentiated from the overlying alluvium, creating difficulty when delineating total aquifer thickness. However, thickness of individual aquifer horizons typically ranges from 5 to 30 m, with significant local variations (Longe et al., 1987; Coode-Blizard, 1996; Oladepo et al., 2014; Aladejana et al., 2020).

Due to the shallow unconfined nature, transmissivity varies significantly across the state (Adelana et al., 2004). Electrical resistivity investigations provide transmissivity estimations of between 13 and 310 m^2/day (Fatoba et al., 2014), while values reported from pumping tests range from 100 to 2333 m^2/day (Coode-Blizard, 1996; Longe, 2011). Significant variations are observed even at local scales, as seen at Shomolu, where transmissivity ranges from 224 to 2333 m^2/day and yield from 62 to 100 m^3/h (Longe, 2011). Specific capacity ranges from 1 to 32.2 m^3/h/m (Oyegoke, 1986; Longe, 2011) and storage coefficients range from 2×10^{-4} to 5×10^{-4} (Oyegoke, 1986).

The shallow water table and unconfined nature of the UCPS, coupled with its proximity to the coast and heavily urbanised and industrialised zones, render it vulnerable to anthropogenic contamination and saline intrusion, as discussed in Section 3.3.1.

2.2.2.2 Lower Coastal Plain Sands

The LCPS is typically confined by a thin, near-continuous clay aquitard, which limits hydraulic connection with the UCPS (Coode-Blizard, 1996) and leads to artesian or sub-artesian conditions

(Akinbinu, 2015). There is not a wide-enough spread of publicly available geological logs across the state to confirm a state-wide extent of the confining layer, although it appears to be mostly absent or significantly thinned in some localities, particularly north of the lagoons (Olabode and Comte, 2024). It is likely that the identified confining clays reflect multiple semi- continuous clay layers, rather than one singular continuous aquitard.

The thickness of individual LCPS aquifer horizons ranges from 2.5 to 45 m (Longe et al., 1987; Coode-Blizard, 1996; Oladepo et al., 2014; Aladejana et al., 2020). Water-bearing horizons in the LCPS typically consist of poorly to well sorted, fine to coarse grained sands and gravels, and are intercalated with clay lenses. They typically have a higher sand context than the overlying UCPS system.

Hydraulic properties within the LCPS are highly variable, due to rapidly changing facies and spatial heterogeneity (Coode-Blizard, 1996; Longe, 2011), with reported transmissivity ranging from 95 to 3700 m²/day (Coode-Blizard, 1996), and with higher transmissivity generally observed in southern Lagos (Table 2; Longe et al., 1987). The LCPS has potential to yield volumes of significant regional importance, if boreholes are properly sited, designed and managed.

Although data is limited, due to its deeper, semi- or variably confined nature, the LCPS is less susceptible to anthropogenic contamination and saline intrusion compared to the shallow aquifer systems of Lagos State, as further discussed in Section 3.3.2.

Table 2: Average values of aquifer characteristics reported for aquifer horizon 3 (assumed to be LCPS) by Longe et al. (1987) from a) step-drawdown tests and b) **long-term constant rate tests using Theis (highlighted in bold)**.

Location	Yield (m^3/hour)	Specific Capacity (m^3/h/m)	Transmissivity (m^2/day)	Permeability (m/s x10^{-5})	Storage Coefficient (x10^{-4})
Agege	54.4	2.96	129.6	7.5	
Shasha	70.8	3.71	241.9 **337.0**	10	**2.5**
Shomolu	80.1	14.9	2315.5 **1900.8**	37	**4.9**
Aguda	97.2	28.6	5123.5 **2574.7**	245.8	**3.8**
Apapa	99.3	17	3024 **1952.6**	121.9	**1.9**

2.2.3 Abeokuta Formation

The Abeokuta Formation (AF) is confined and geothermal in places (43 to 80°C), acting as a multi-layered aquifer system, with water-bearing horizons composed of ferruginous or friable sandstones, gritstones, and basal conglomerates, separated by intercalated claystone, siltstone and shale aquicludes (Jones & Hockey, 1964; Coode-Blizard, 1996; Bankole et al.,2022). It is the deepest and most productive aquifer in Lagos State (Coode-Blizard, 1996; Oladapo et al., 2014; Oteri & Ayeni, 2016; Yusuf et al., 2018; Aladejana et al., 2020a), with total aquifer thickness ranging from 250 to 300 metres (Wali et al., 2021). The aquifer is believed to be hydraulically separated from the CPS by the shale dominated Ilaro Formation and Ewekoro Formation (Oyegoke, 1986).

The AF is highly productive (Kampsax-Kruger, 1977), with transmissivity values ranging from 2189 to 3200 m²/day (Coode-Blizard, 1996) and specific capacity from 8 to 17.55 m^3/h/m (Adelana et al., 2004; Carter, undated report, in Offodile, 2002). Reported yields range from 29 to 200 m³/hour in Ogun and Osun States (Idowu et al., 1999; Offodile, 2002; Oyegoke et al., 2012), and it is considered more productive than the CPS in northern Lagos (Coode-Blizard, 1996). While this aquifer is extensively developed in Ogun State, where it is encountered at depths of 300 to 550 m (Oteri & Ayeni, 2016), in Lagos, its depth (over 450 m below sea level in the northwest) limits its use to commercial and industrial purposes due to high drilling costs (Longe et al., 1987;

Coode-Blizard, 1996; Oteri & Ayeni, 2016). Industrial boreholes in Igbonia and Ikeja have successfully tapped water from depths exceeding 600 m (Adelana et al., 2004).

3 Groundwater Quality and Quantity

3.1 GROUNDWATER MONITORING

Three datasets across Lagos State, monitoring groundwater of varying depths, have been compared as part of this study (Table 3; Figure 2). The UNI-IBADAN and UNILAG monitoring networks, funded by UKRI Future Leaders Fellowship, reflect a collaborative effort between Cardiff University, the University of Lagos, the University of Ibadan and the British Geological survey to improve the understanding of groundwater systems within Lagos. These networks were installed to address a critical data gap, as part of "*The Lagos Groundwater Demonstrator*". The RIGSS dataset, funded by the UK Global Challenges Research Fund, reflects a collaboration between the British Geological Survey, Cardiff University, the University of Ibadan and the University of Maiduguri.

Table 3: Description of analysed datasets. EC = electrical conductivity; TDS = Total Dissolved Solids; WL = water level.

Dataset	Collection Method	Time Period	Interval	Data	Aquifer System
RIGSS, 42 points	Manual	April and May 2017	Singular measurement	EC, TDS, Temp, pH, major and minor cations, E. Coli	Borehole depths for 28/42 sites (range: 2.07 to 60 m depth; median: 3.5 m; mean: 15.7 m) and are inferred to be monitoring the water level of the shallower Alluvium/UCPS aquifer system. Collected as part of Healy et al. (2020) research efforts.
UNI-IBADAN, 24 points	Manual	April 2022 to April 2024	Monthly to June 2023, then bi-monthly	WL, EC, TDS, pH	Whilst borehole depths are not available, partners involved in network installation believe these to be 'shallow' and therefore an assumption has been made that this dataset is monitoring water level within the shallow, unconfined Alluvium and UCPS aquifer systems which are believed to be hydraulically connected.
UNILAG, 16 points	Automated and manual	35 months from May 2021 to March 2024	10 minutes to 10 hours by data logger (with significant gaps). Monthly manual.	WL, EC	Borehole depths for 13/16 sites (range: 91.95 to 240 m depth; median: 120 m; mean: 146.6 m) and are inferred to be monitoring the water level of the deeper LCPS aquifer system.

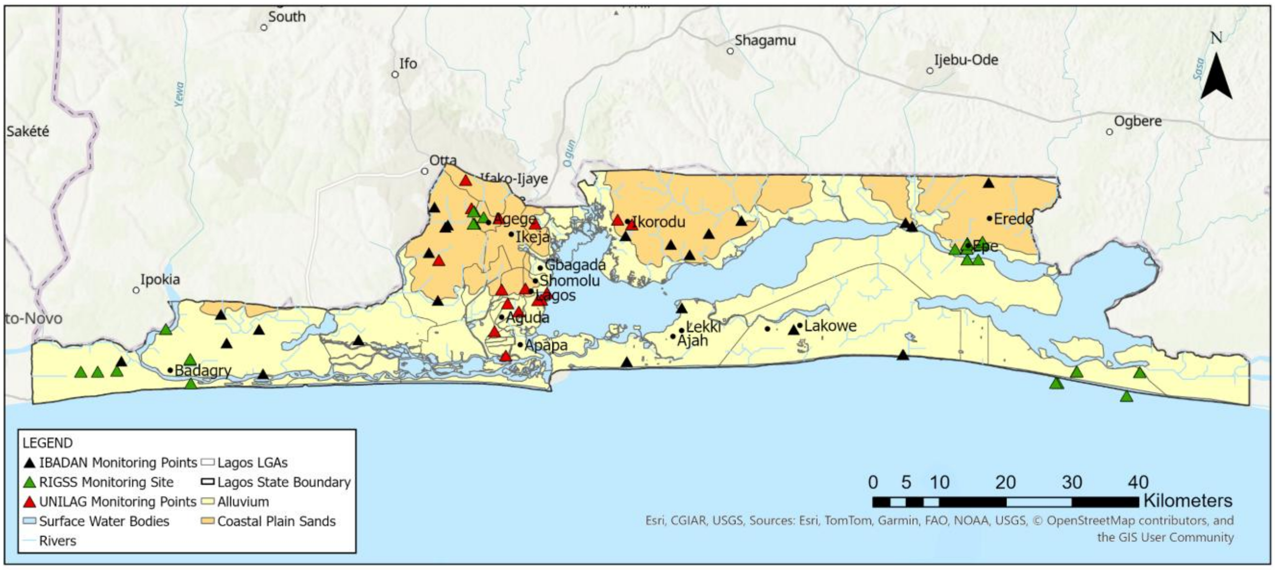

Figure 2: Location of RIGSS, UNI-IBADAN and UNILAG datasets (geological shapefile modified after Olabode & Comte, 2024). Basemap: Esri, CGIAR, USGS, TomTom, Garmin, FAO, NOAA, USGS © OpenStreetMap contributors and the GIS User Community. BGS © UKRI 2025.

3.2 GROUNDWATER LEVEL AND FLOW

Analysis of the UNI-IBADAN and UNILAG datasets allow a preliminary understanding of groundwater level and flow to be developed for Lagos State. Assuming that UNI-IBADAN data represents the Alluvium/UCPS and UNILAG data represents the LCPS, these findings highlight variations in behaviour of the aquifer systems, as outlined in Sections 3.2.1 and 3.2.2.

Both datasets indicate a general north-to-south groundwater flow direction across Lagos State (Figure 4; Figure 7). Localised deviations from this flow pattern are observed, particularly near areas of intense abstraction or near surface water bodies such as the Lagos Lagoon. These findings align with previous studies (Kampsax-Kruger, 1977; Coode-Blizard, 1996; Asiwaju-Bello & Oladeji, 2001; Olabode, 2025) and suggest that while the general flow remains consistent, localised variations are primarily driven by human activity, geological heterogeneity and surface water interactions.

Whilst these monitoring networks represent a good first step towards monitoring the UCPS and LCPS aquifers, both spatial and temporal coverage is currently too limited to identify any long-term trends in groundwater level or quality. To understand if any currently identified trends are seasonal (from rainfall), related to groundwater abstraction, or a combination, long-term analysis of rainfall and water level data would be required.

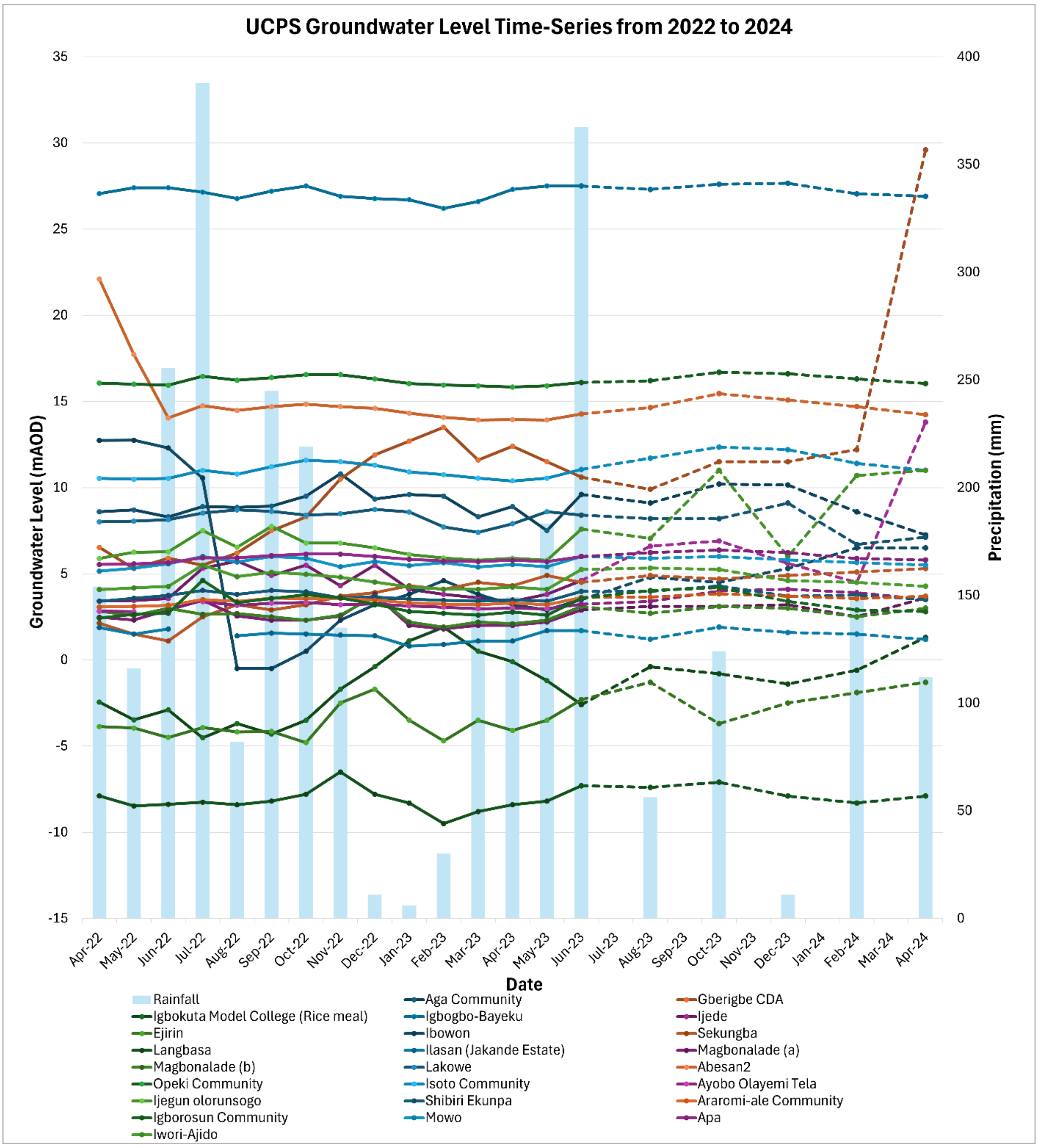

Figure 3: Hydrograph of UNI-IBADAN monitoring data for the UCPS, providing a time-series comparison of water level with monthly precipitation. Solid line indicates monthly data; dashed line indicates bi-monthly data. BGS © UKRI 2025.

3.2.1 UCPS

Average groundwater level within the UCPS is generally close to sea level, with some localised instances of the water table being below sea level (Figure 4). Seasonal water level fluctuations are more pronounced within the shallow, unconfined UCPS aquifer system (Figure 3) than the deeper LCPS aquifer (Figure 6). Typically, the water table is shallower during wetter months, associated with increased recharge from rainfall, and deeper during the drier months due to reduced recharge and increased evapotranspiration. However, at Ibowon, Gberigbe and Igbokuta Model College, north of Lagos Lagoon, groundwater levels continue to rise following the end of the wet season, even during months of no rainfall. Whilst there is insufficient data to ascertain the cause, it likely reflects delayed recharge or downflow from further north where recharge volumes are greater.

Over a 2-year comparison period from April 2022 to April 2024 (end of dry season), the UNI-IBADAN dataset for the UCPS shows significant variability in water table fluctuation (Figure 3). Of the 24 monitoring sites, 16 sites reported a rise in water table elevation (range: 0.1 m to 23.1 m), while 8 sites experienced an overall decline in water table elevation (range: 0.02 m to -7.9 m). A decline greater than 1 m was only recorded at three sites: Aga Community, Abesan and Ibowon. With Aga and Abesan located in highly urbanised areas, it is likely that this reflects localised over-abstraction and drawdown. A rise greater than 1 m was recorded at seven sites, with the greatest rises at Gberigbe, Igbokuta, Ijede, Sekungba, Ejirin and Ijegun. Whilst information surrounding recharge and abstraction is lacking, this general water level rebound across most sites indicates that active recharge within the UCPS is compensating overall groundwater withdrawal. Whilst aquifer depletion appears localised, the mixed pattern of groundwater level decline and rebound in the shallow aquifer highlights the importance of robust long-term monitoring and adequate management of Lagos groundwater to ensure future sustainability and resilience.

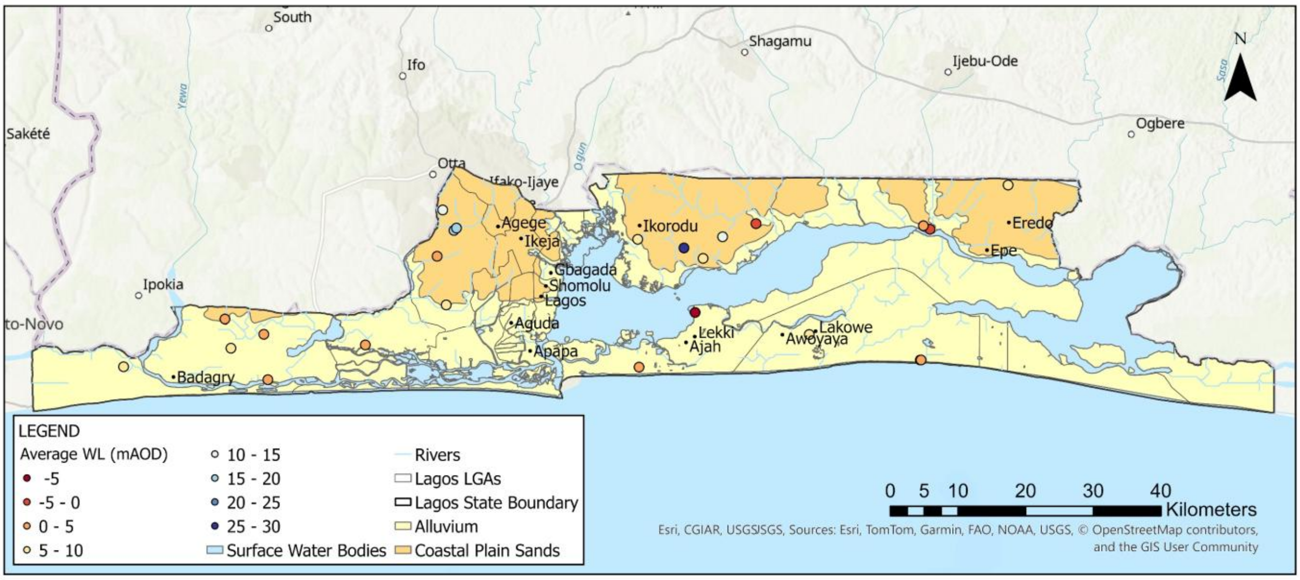

Figure 4: Groundwater level (mAOD) across the shallow aquifer (Alluvium and UCPS) within Lagos State. Data from UNI-IBADAN dataset. Basemap: Esri, NASA, NGA, USGS, TomTom, Garmin, FAO, NOAA, USGS © OpenStreetMap contributors and the GIS User Community. BGS © UKRI 2025.

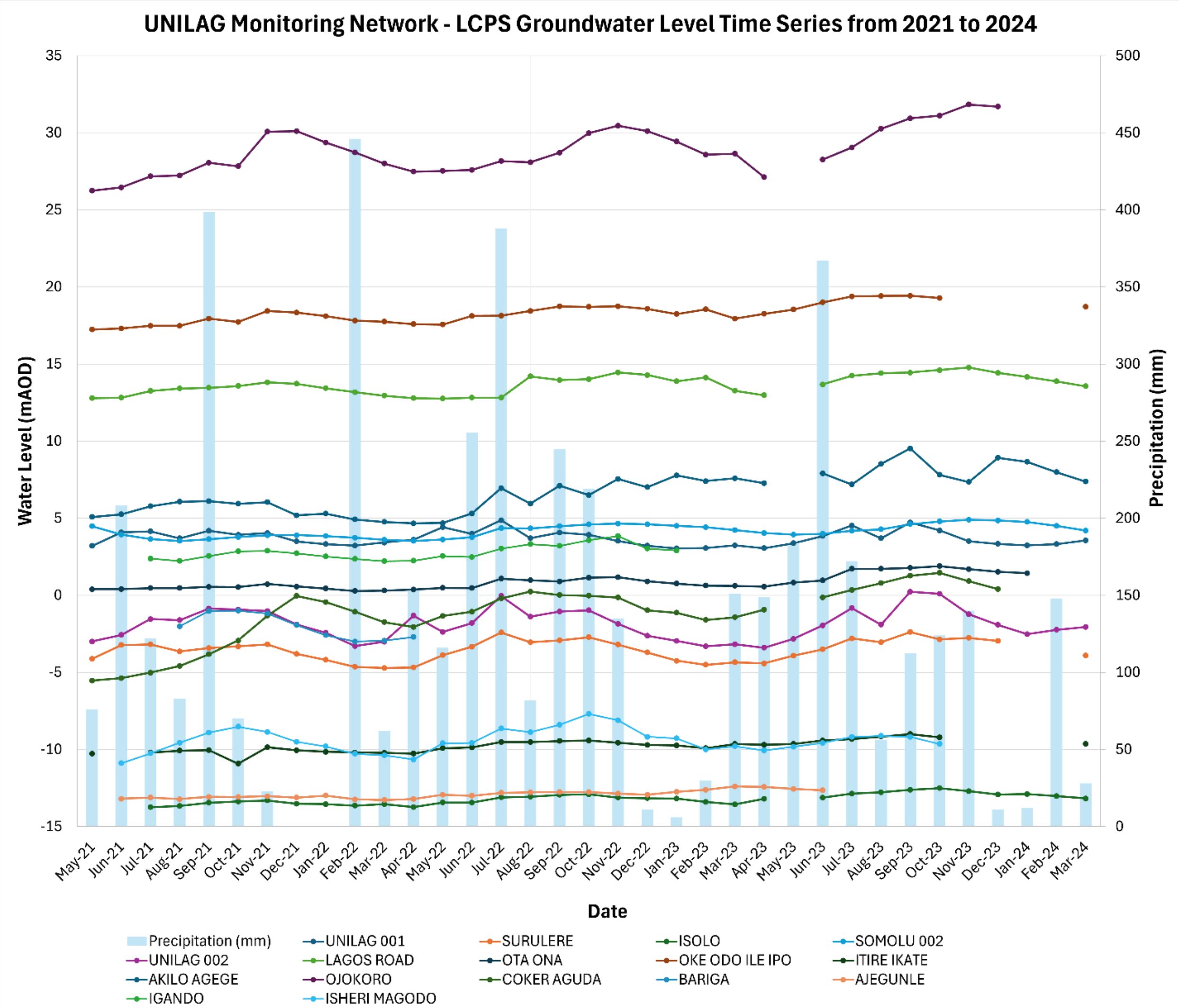

Figure 5: Hydrograph of UNILAG monitoring data, providing a time-series comparison of LCPS water level with monthly precipitation. BGS © UKRI 2025.

3.2.2 LCPS

The UNILAG dataset for the deeper, semi-confined aquifer system (LCPS) indicates that groundwater levels are typically less sensitive to seasonal variation than the UCPS. This reduced seasonal response is likely associated with the confined nature of the aquifer and greater storativity. Locations that display more seasonal variation (e.g. Unilag 002 and Bariga) are generally located near to Lagos lagoon, and therefore may be hydraulically connected, further recharged by rising lagoon levels during the rainy season.

Boreholes within the LCPS show a more consistent trend in terms of overall water level change over the 2-year comparison period from October 2021 to October 2023 (end of wet season), with all sites recording a uniform rise in water levels. The increase ranged from 0.3 m to 4.4 m, indicating that current abstraction rates from the LCPS are broadly sustainable. This could be attributed to the aquifer's extensive recharge area further north where the LCPS outcrops at surface, despite a large proportion of urban land cover which maybe also be associated with some urban return flow (i.e. re-infiltration of water abstracted elsewhere).

The more consistent behaviour within the deeper LCPS, compared to the UCPS, can likely be attributed to either a) the (semi-) confined nature of the LCPS or b) fewer pumping effects within the LCPS. The presence of the clay aquitard separating the LCPS from the UCPS and confining the LCPS, means hydraulic connectivity with the surface is, potentially, more limited. This reduces the influence of climatic or anthropogenic pressures when compared to the UCPS, which is more vulnerable due to its shallow, unconfined nature. Alternatively, as the UCPS is more accessible, it is widely used for small-scale supplies across the state. This could result in abstraction sites being densely located, and therefore increased interference and pumping effects being observed within the shallower aquifer.

Whilst a direct comparison with Kampsax-Kruger (1977) and Coode-Blizard (1996) water level datasets for the LCPS cannot be made due to data collection from different sites, with no overlapping borehole records, a broader comparison of spatially interpolated groundwater levels by Olabode (2025) suggested that water levels may be rebounding across parts of the state (although are still lower than in 1977), and in localised areas where they may be continuing to decline, it does not appear to be at the rate of decline observed between 1977 and 1996. Lack of data, such as long-term continuous groundwater level records, abstraction regimes and recharge volumes, means that it is not possible to determine if this is linked to increased recharge (e.g. higher rainfall and/or urban return flow), decreased discharge (e.g. lower abstraction), or a combination of these factors. Despite a rebound of the water table being observed, it remains close to (within 5 m) or below sea level at all UNILAG sites from Isolo and Shomolu southward (Figure 7).

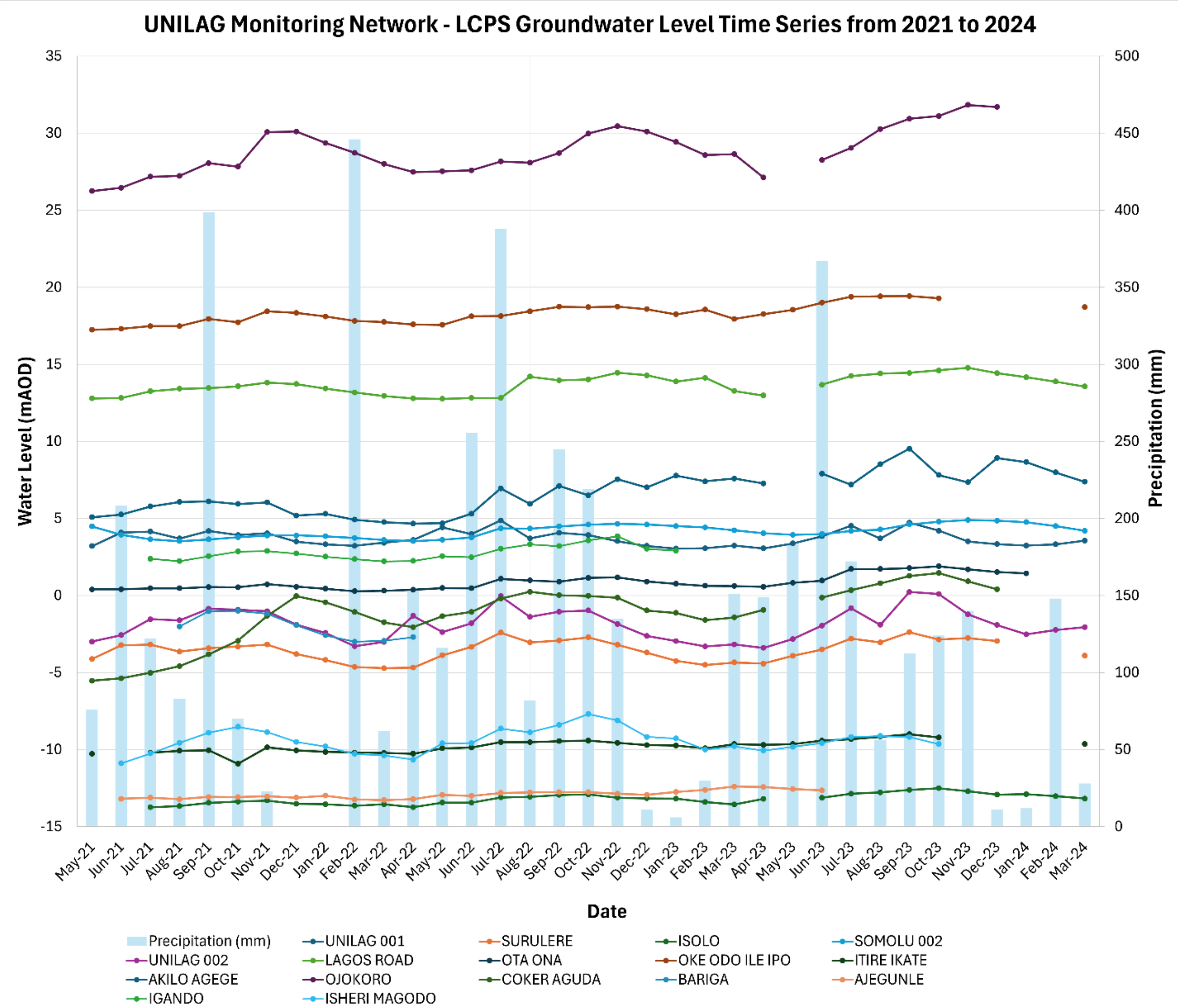

Figure 6: Hydrograph of UNILAG monitoring data, providing a time-series comparison of LCPS water level with monthly precipitation. BGS © UKRI 2025.

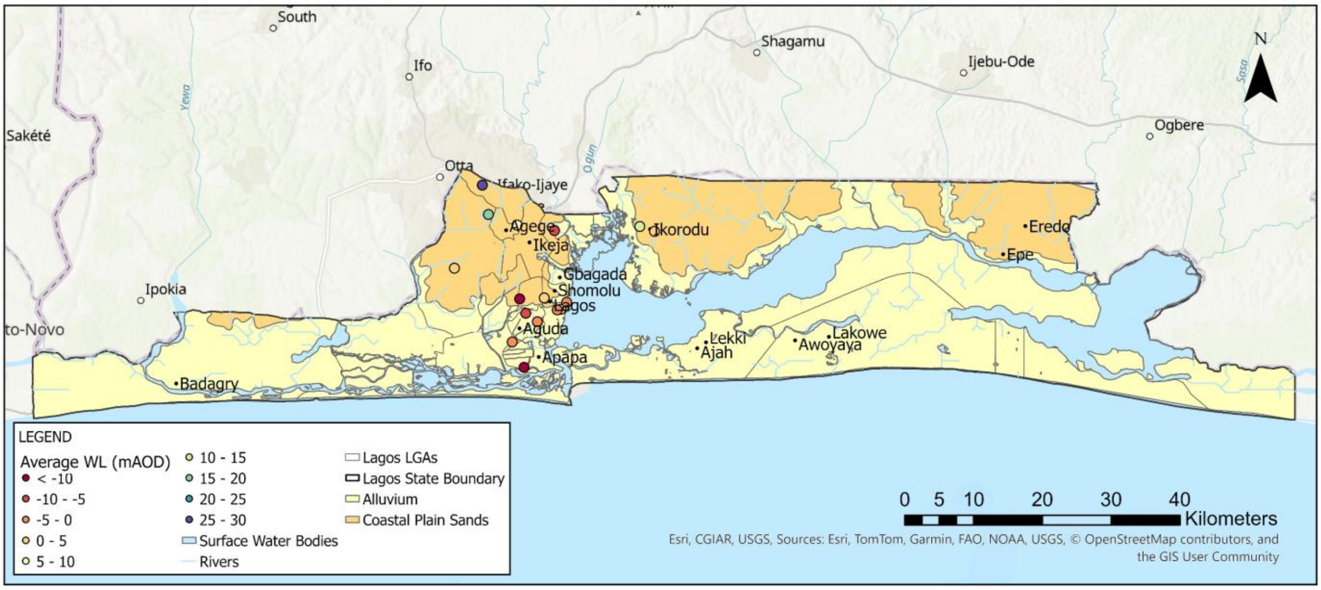

Figure 7: Groundwater level (mAOD) across the LCPS aquifer within Lagos State. Data from UNILAG dataset. Basemap: Esri, NASA, NGA, USGS, TomTom, Garmin, FAO, NOAA, USGS © OpenStreetMap contributors and the GIS User Community. BGS © UKRI 2025.

3.2.3 Abeokuta Formation

No datasets monitored the Abeokuta Formation.

Water level information of the Abeokuta Formation within the state was not available as part of this study. Regionally, within the Ogun Basin, the depth to water level within the formation is reported to vary between 19.8 and 52.8 mbgl (Wali et al., 2021). The aquifer also has artesian conditions, yielding head pressures of +15 m at Eredo and Itoikin (Coode-Bizard, 1996). Reports of artesian boreholes along with the confined nature of the Abeokuta Formation suggests that water level is likely relatively shallow but may be highly variable dependent upon site-specific conditions. Water level is expected to be shallower at lower elevations.

3.3 GROUNDWATER QUALITY

3.3.1 Shallow Aquifers

The RA and UCPS aquifers are hydraulically connected and share similar lithological properties, with groundwater in these shallow unconfined systems particularly vulnerable to anthropogenic contamination (Abekoteyon et al., 2018). There is no evidence of a state-wide groundwater salinity issue, although saline intrusion is evident along the central coastal belt between Lekki and Ajah.

Water quality studies indicate that whilst many wells and boreholes across the state produce good quality drinking water, others yield groundwater quality parameters that exceed WHO (2022) permissible limits or Nigerian Standards for Drinking Water Quality (NSDWQ), including electrical conductivity (EC), total dissolved solids (TDS) calcium, total hardness, pH, chloride, nitrate, sulphate, chromium, cadmium, lead, copper, zinc, nickel, arsenic, manganese, iron, faecal coliforms and E. Coli (Longe et al., 1987; Coode-Blizard, 1996; Adelana et al., 2004; Bale et al., 2004; Babatunde, 2012; Soladoye & Yinusa, 2012; Akoteyun, 2015; Oyeyemi et al., 2015; Ameloko & Ayelabi, 2018; Healy et al., 2018; Aladejana et al., 2020b; Popoola et al., 2020; Sogbanmu, 2020; Ajani et al., 2021; Olaruntoba et al., 2021; Majolagbe et al., 2023; Tunde et al., 2023). However, it is important to note that contamination is localised, and that contamination is not reported at all sample sites. For example, within the RIGGS dataset, generally nitrate concentrations remain below the WHO (2022) permissible limit of 50 mg/l (Figure 8).

Sources of contamination are varied, including municipal waste, industrial effluents (particularly chemical and pharmaceutical), landfill leachate, ports, agriculture, lack of wastewater management and septic tank or pit latrine seepage (Adelane et al., 2004; Bale et al., 2004; Babatunde, 2012; Soladoye & Yinusa, 2012; Oyeyemi et al., 2015; Popoola et al., 2020; Shiru et al., 2020; Ajani, et al., 2021; Tunde et al., 2023).

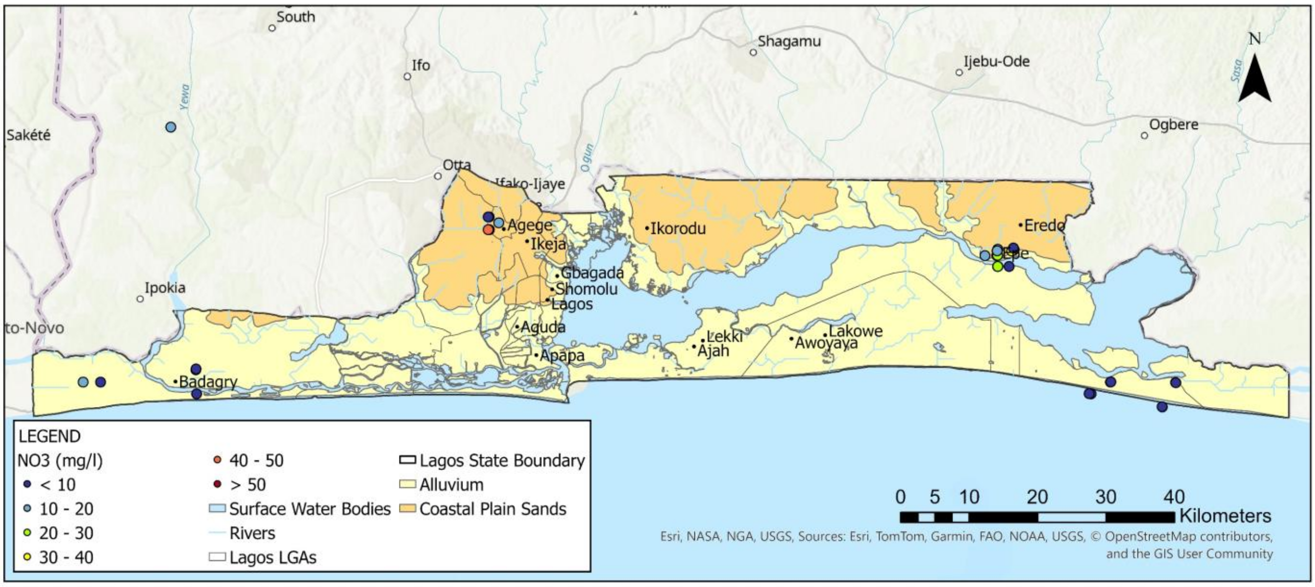

Figure 8: Distribution of RIGGS dataset nitrate concentration (mg/l) across the shallow aquifer (Alluvium/UCPS) of Lagos State. Basemap: Esri, NASA, NGA, USGS, TomTom, Garmin, FAO, NOAA, USGS © OpenStreetMap contributors and the GIS User Community. BGS © UKRI 2025.

Contamination is generally more prevalent in shallow hand-dug wells than boreholes, highlighting the vulnerability of the shallow aquifer system. This is evident in the RIGGS dataset, where E. coli concentrations exceed the WHO (2022) permissible limit of 0 MPN (Most Probably Number)/100 ml at 19 out of 40 sites, with 12 of these sites exceeding 100 MPN/100 ml. Where temporal groundwater quality data is available, this indicates that in some locations, contamination is more pronounced in the dry season, when reduced rainfall limits the dilution of contaminants. However, there is localised evidence of certain parameters (e.g. Cl, SO_4, PO_4, NO_3, Fe, Mn, Cu, Pb) being elevated within some wells and boreholes during the wet season (Ameloko & Ayolabi, 2018), likely due to increased mobilisation of contaminants.

A zone of saline intrusion is evident from Apapa to Lekki, where excessive groundwater abstraction exacerbates the problem (Oteri, 1985; Kampsax & Kruger, 1980; Onwuka & Amadi, 1986; Kennard & Lapworth, 1987; Ola et al., 2008). Here, a thin freshwater lens (20 to 40 m thick) can often be found overlying the brackish groundwater. When this freshwater lens is pumped, saline upconing occurs, drawing saline water into the overlying aquifer layers (Oteri & Atolagbe, 2003). The base of the brackish groundwater lens is highly variable, even locally, and influenced by the complex geological structure and heterogeneity of the aquifer system (Coode-Blizard, 1996; Oydele & Meshida, 2004; Ola et al., 2008; Akinlalu & Afolabi, 2018; Jimoh et al., 2018). Away from the main zone of salinity, geophysical surveys around the University of Lagos have identified saline water influx from Lagos Lagoon and nearby creeks (Ayolabi et al., 2013). Research indicates a mixing of Ca-HCO_3 and Na-Cl groundwater facies, with the shallower reaches of the UCPS hosting higher ratios of Cl/HCO_3 ratios, further corroborating with the RA/UCPS being influenced by saltwater intrusion (Oyedele et al., 2009; Akoteyon, 2015 ; Akoteyon et al., 2018; Nlend et al., 2018; Aladejana et al. 2020; Popoola et al., 2020; Tijani et al., 2020; Asiwaju-Bello et al., 2021).

Whilst saline intrusion is evident around the coastal urban centre, based on UNI-IBADAN and RIGSS datasets, the shallow aquifer (Alluvium and UCPS) appears fairly fresh across the remainder of the state (Figure 9). The UNI-IBADAN dataset predominantly reports fresh groundwater with EC values ranging from 11 to 920 µS/cm during the wet season (April to October) and from 20 to 930 µS/cm during the dry season (November to March). The mean EC is 224 µS/cm and 238 µS/cm, respectively. Whilst EC ranges and averages during both wet and dry season are similar; there is a pattern of higher EC during drier months. This is attributed to dilution effects from increased recharge during the wet season. 37 out of 40 RIGGS monitoring sites in Epe, Badagry, Lekki, and Orile Agege Local Government Areas (LGAs), produce fresh groundwater, with EC values ranging from 83 to 717 µS/cm. The remaining three sites in Badagry and Ogile Agege are classified as "slightly saline" according to FAO (1992), with EC values ranging from 1002 to 1257 µS/cm and TDS between 631 and 835 mg/L. EC values are strongly correlated with nitrate concentrations (correlation coefficient 0.88) suggesting that elevated EC is more likely to result from local contamination (e.g. from municipal, domestic waste, or agricultural inputs) than from saline intrusion, even near to the coastline. At Epe and Agege, EC is typically higher in shallow hand-dug wells compared to boreholes, likely due to contamination from surface runoff or wastewater. In contrast, at Lekki, EC tends to be higher in boreholes than in hand-dug wells, which aligns with the hypothesis of a shallow freshwater lens overlying a brackish water body within the RA and UCPS here.

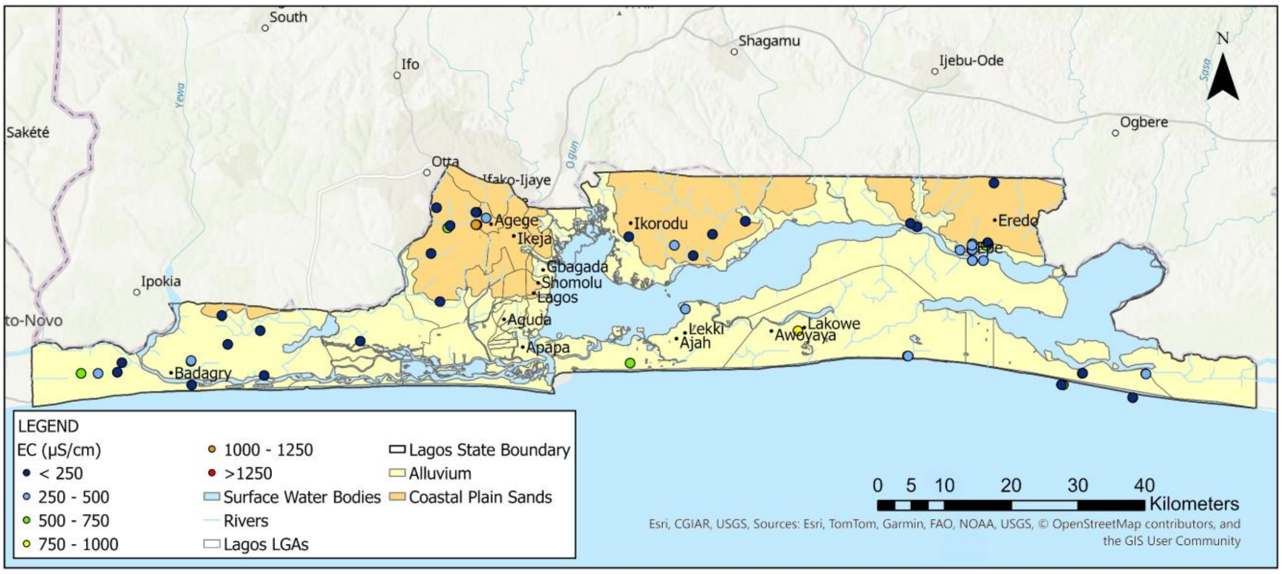

Figure 9: Distribution of average electrical conductivity (µS/cm) across the shallow aquifer (Alluvium and UCPS) within Lagos State. Data from RIGGS and UNI-IBADAN datasets. Basemap: Esri, NASA, NGA, USGS, TomTom, Garmin, FAO, NOAA, USGS © OpenStreetMap contributors and the GIS User Community. BGS © UKRI 2025.

Whilst groundwater quality within the shallow aquifer can be of good quality, it remains at high risk to water quality degradation where in proximity to contamination sources. Whilst there is no significant evidence of saline intrusion across most of the monitoring sites, localized anomalies, and presence of other contaminants (e.g. nitrate) alongside salinity suggest that both saline intrusion and anthropogenic contamination may contribute to variations in groundwater quality. Further investigation is required to better understand the specific sources of contamination and to assess the long-term sustainability of groundwater resources in these regions.

3.3.2 LCPS

The LCPS is generally considered less vulnerable to both saline intrusion and anthropogenic contamination compared to the shallower systems (Balogun et al., 2019). Akoteyon (2013) compared water quality between the UCPS and LCPS at similar locations, finding that while the UCPS had common water quality issues, these were not observed in the LCPS, with all parameters meeting WHO (2022) acceptable limits. This is largely attributed to the presence of a semi-continuous clay aquitard separating the Upper and Lower CPS (Coode-Blizard, 1996; Adelana et al., 2004), typically found at the base of the UCPS brackish water lens, separating it from the LCPS freshwater zone (Akinlalu & Afolabi, 2018).

Although the LCPS appears to be well-protected from anthropogenic contamination, Adelana et al. (2004) found that TDS, sulphate, chloride, fluoride, and ammonia exceeded WHO limits in ‘deep’ boreholes, though concerns were less common and more spatially variable than in shallow boreholes. It is unclear if these deep boreholes are in the UCPS or LCPS, but if in the LCPS, this suggests potential water quality risks in this system. Further investigation is required.

Additionally, elevated concentrations of geogenic iron have been exhibited. Coode-Blizard (1996) found that 23 out of 27 tested sites had Total Fe concentrations exceeding the NSDWQ limit of 0.3 mg/l. While iron contamination does not pose a health risk (WHO, 2022), it can affect the aesthetic qualities of water, including taste and colour. Iron concentrations can generally be mitigated through standard treatments such as oxidation and filtration.

Where salinity data is available from literature, groundwater in the LCPS is reported to be of good quality and predominantly fresh (< 241 µS/cm) up to depths of 300 m, even near the coast where the shallow aquifers are more prone to higher salinity (Coode-Blizard, 1996; Akoteyon, 2013; Oladepo et al., 2014). EC data collected by UNILAG from 15 of the 16 monitoring sites in the LCPS indicate the aquifer is predominantly fresh, with EC values below 443 µS/cm (Figure 10). This supports the assertion that the LCPS is generally at low risk of saline intrusion or contamination. Seasonal variations in EC are observed at almost half of the monitoring locations, with EC slightly lower during the wet season, whilst no clear seasonal trends are observed within the other monitoring locations.

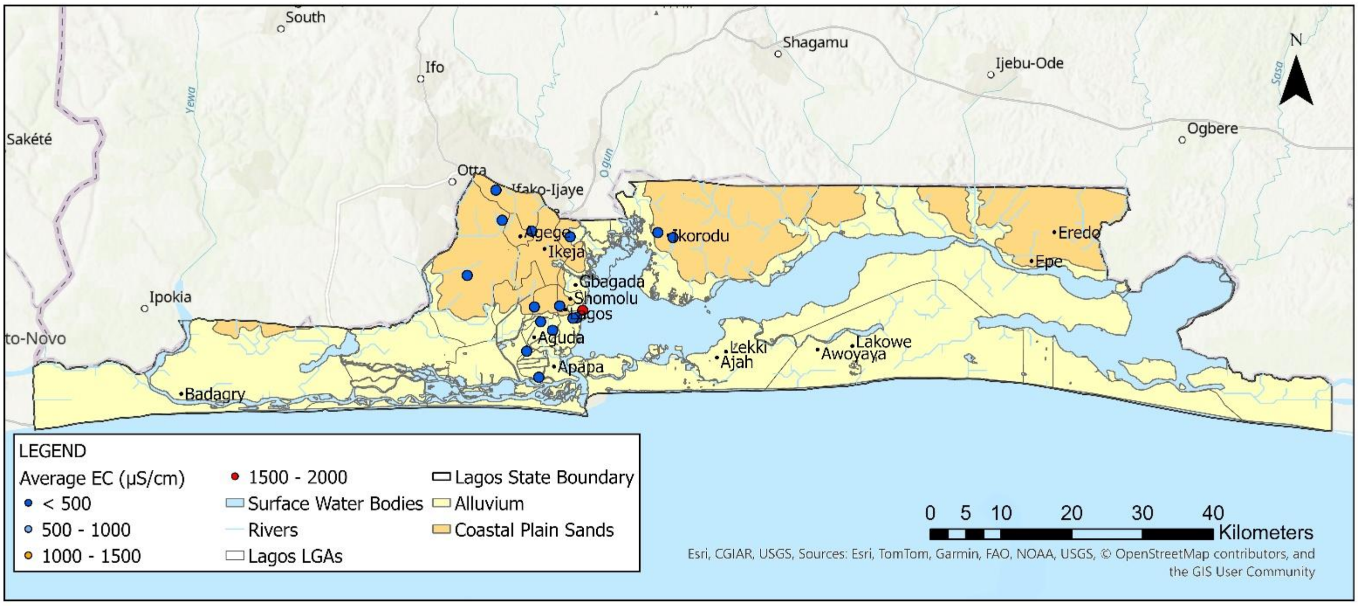

Figure 10: Distribution of average electrical conductivity (µS/cm) across the LCPS aquifer within Lagos State. Data from UNILAG dataset. Basemap: Esri, NASA, NGA, USGS, TomTom, Garmin, FAO, NOAA, USGS © OpenStreetMap contributors and the GIS User Community. BGS © UKRI 2025.

Anomalous to other UNILAG monitoring locations, limited data at the Bariga site records EC values ranging from 1246 to 2446 µS/cm. Located on the shoreline of the brackish Lagos Lagoon, and with water levels consistently below sea level, the elevated EC at Bariga is likely due to reversed pressure gradients, allowing brackish lagoon water to intrude into the aquifer. This raises queries regarding the confining clay layer, which is thought to protect the LCPS from saline intrusion (Coode-Blizard, 1996), as lithological logging (Oladepo et al., 2014) suggest there is an approximately 45 m thick layer of clay and sandy clay confining the LCPS at Bariga. Alternatively, the observed salinity could result from contamination between the UCPS and LCPS due to poor borehole construction. Notably, UNILAG were unable to provide records of borehole depth for the site at Bariga, raising the possibility that it may monitor the UCPS rather than the LCPS. Further investigation is required.

3.3.3 Abeokuta Formation

No datasets were available for the Abeokuta Formation; therefore, the conceptualisation of this aquifer system is solely developed from a review of pre-existing literature.

Dominant hydro-chemical facies are identified as Na-Cl and Ca-HCO_3, with intermediates of Ca-Cl and Na-HCO3, which suggests mixing of fresh groundwater with saline influences, possibly due to marine intrusion or long residence times (Aladejana et al., 2020a). However, the aquifer is reported to typically yield fresh groundwater with Electrical Conductivity (EC) values ranging from 102.63 to 580.8 µS/cm across Lagos State (Coode-Blizard, 1996) and from 23 to 151 µS/cm in Ogun State (Kareem et al., 2016; Odjegba et al., 2021; Bankole et al., 2022). However, at Eredo (in Lagos State) brackish groundwater has been reported from below 342 m (Coode-Blizard, 1996). pH across Lagos State is acidic to neutral, ranging from 5.45 to 7 (Coode-Blizard, 1996).

High residence times could result in geogenic water quality degradation, particularly in areas with longer groundwater flow paths, or where bituminous minerals (Offodile, 2022) are reported, although the water-bearing aquifer may be at a shallower depth than tar sands and bituminous minerals (Adeyemi et al., 2013). As the formation is ferruginous (Okosun, 1990), there is also risk of iron concentrations exceeding WHO drinking water standards, which may impact taste and colour and require treatment. In Lagos State, concentrations of up to 4.4 mg/l have been reported (Coode-Blizard, 1996).

Water quality data for the Abeokuta Formation in Lagos State are limited, but available reports indicate no significant quality concerns (Coode-Blizard, 1996). Given the thick overlying aquitards and confined nature of the system, it is unlikely to be impacted by saline intrusion or anthropogenic contamination. However, where the AF is near or at the surface further north in Ogun State, whilst studies typically indicate water quality falls within drinking water standards (Aladejana & Talabi, 2013; Kareem et al., 2016; Odjegba et al., 2021), localised exceedance of WHO drinking water standards have been reported, attributed to anthropogenic contamination. These exceedances include elevated concentrations of alkalinity, calcium, aluminium, chloride, bicarbonate, magnesium, iron, zinc, cadmium, lead, nickel and faecal coliforms (Aladejana & Talabi, 2013; Bankole et al., 2022; Odjegba et al., 2021). There is a low risk of these contaminants affecting groundwater within the Abeokuta Formation at Lagos State, due to the depth the aquifer is encountered providing increased protection, and the distance from where the formation outcrops allowing for increased attenuation, it is expected the water will be of better quality.

4 Hydrogeological Typologies

There is currently a limited volume of openly available data regarding the aquifer system underlying Lagos State, with accessible data providing poor spatial and temporal coverage. From the data available, it is evident that lithological composition, aquifer properties and groundwater quality of the aquifer systems varies significantly across Lagos. Particularly, each of the aquifers form multi-horizon systems, with the number, thickness and extent of horizons within the CPS appearing to change significantly both laterally and vertically.

Based on the limited available data, six generalised groundwater typologies have been developed to describe the hydrogeological complexity and variation across the state (Figure 11): (A) the north-west zone spanning from Agege to Ikorodu, north of Lagos lagoon; (B) the heavily urbanised, central Lagos mainland; (C) the central coastal belt from Apapa to Ajah; (D) the rural southwestern coastal belt of Badagry; (E) the lithological anomaly at Lakowe; and (F) the northeastern inland area at Epe. These typologies should be used in tandem with the four aquifers, to improve the understanding of how aquifer behaviour varies across the state and any local considerations that may need to be considered.

It is important to note that given the lack of available data, along with the highly heterogenous nature of the basin's sediments, there may be significant local deviations within groundwater typologies, and there remains a significant level of uncertainty both within typologies and when defining their boundaries. Typology A, B and C have been developed from more available data and literature than Typology D, E and F. Therefore, there is greater confidence in the definitions of typology A, B and C; whereas, typology D, E and F are, allocated as 'minor' typologies, capture unique features of groundwater systems in these areas, but could also reflect very localised variations in hydrogeology. Due to lack of available data, any additional typologies outside of the areas identified, or the transition between typologies, have not been identified.

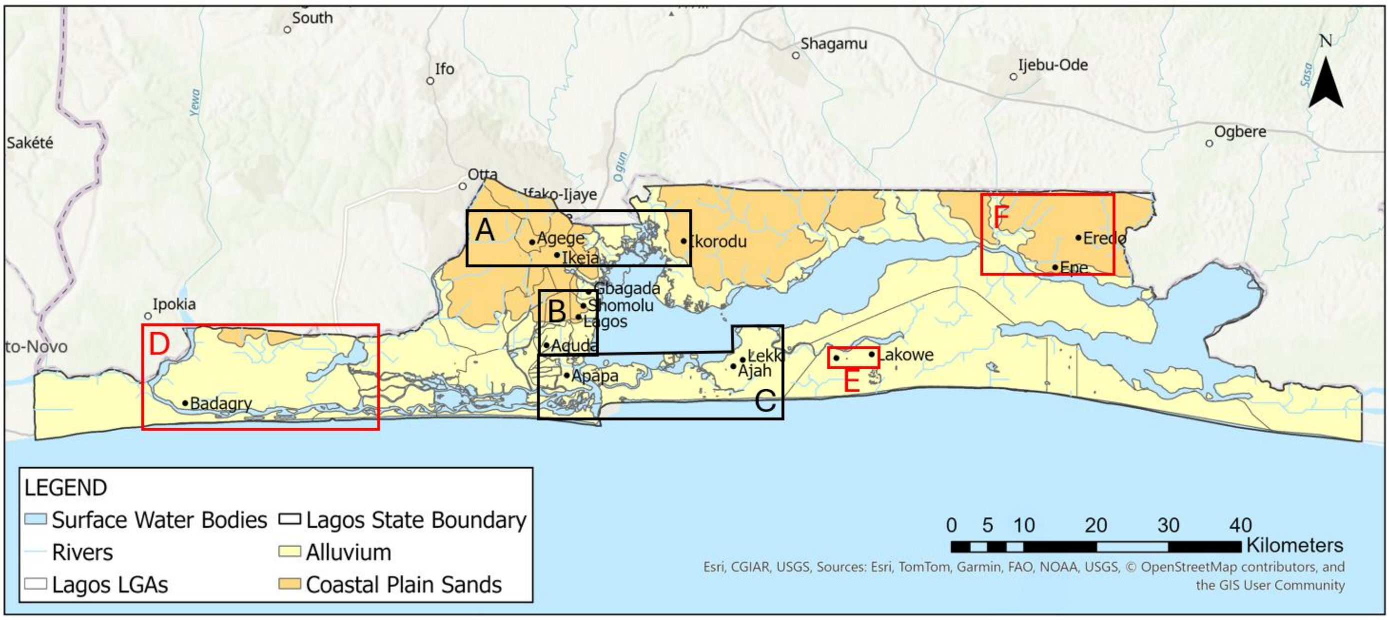

Figure 11: Location of major (black) and minor (red) groundwater typologies within Lagos State (geological shapefile modified after Olabode & Comte, 2024). Basemap: Esri, CGIAR, USGS, TomTom, Garmin, FAO, NOAA, USGS © OpenStreetMap contributors and the GIS User Community. BGS © UKRI 2025.

4.1 MAJOR TYPOLOGIES

4.1.1 Typology A – Inland Northwest

This typology describes the aquifer systems in the north-west of Lagos State, from Agege to Ikorodu. It comprises of heavily urbanised and industrialised zones. Groundwater in this region is used for both domestic and industrial water supplies, sourced from shallow wells and a mixture of low-volume motorised boreholes operated by households and high-volume motorised boreholes operated commercially. Both the CPS aquifers and the Abeokuta Formation are utilised in this area, although only industrial boreholes tend to tap from the Abeokuta Formation due to its depth (> 460 mbgl). The alluvium is generally absent, other than in river floodplains. The UCPS here comprises of up to 30 m of sand with intercalated clays and is occasionally semi-confined. Groundwater is generally fresh, although where locally brackish appears associated with further anthropogenic contamination. The confined and more sand-dominated LCPS, bearing fresh groundwater, is separated from the UCPS by an up to 60 m thick clay aquitard, and is encountered typically at depths from ~ 70 to ~ 120 mbgl. The Abeokuta Formation is encountered at depths below ~ 450 mbgl, with 10 to 30 m thick sand horizons providing deeper groundwater resources, expected to be fresh and of good quality.

The unconfined UCPS aquifer, primarily fine to medium grained, poorly sorted sands, intercalated with clay lenses, is generally found between 0 to 30 mbgl, and can be overlain by semi-permeable clay and sands, including at Agege and Shasha. Reported aquifer thickness ranges from 5 to 22 m (Longe et al., 1987; Coode-Blizard, 1996; Oladepo et al., 2014). There is no information regarding yield or hydraulic properties of the shallow aquifer within this typology. Spatial variations in the average monthly elevation of the water table have been recorded by the UNI-IBADAN monitoring network between 2022 and 2024 (Figure 13), ranging from 2.8 to 27.7 masl (0. to 27.5 mbgl). North of Lagos Lagoon, toward Ikorodu and eastward, significant spatial variations in groundwater level are observed at sites of similar elevation and proximity to the lagoon (e.g. Aga Community and Igbogbo-Bayeko). Further information is therefore needed to explain the dominant controls on groundwater level variation across the UCPS, e.g. the horizon being monitored, localised abstraction regimes, other surface water controls. Although some seasonal trends are evident in **Error! Reference source not found.**, most temporal groundwater level f luctuations are fairly subdued. This is likely indicative of a relatively high-storage aquifer, but longer-term groundwater level data, along with rainfall and abstraction data is needed to fully understand the controls on groundwater level changes. There is no widespread evidence of groundwater depletion in the UCPS – the groundwater level decline seen in early 2022 at Abesan appears to be localised.

Saline intrusion within the shallow aquifer does not appear to be a concern for this typology. RIGGS and UNI-IBADAN data (Figure 12) indicate groundwater to generally be fresh (EC < 717 µS/cm), confirming the results of previous studies (Adelana, 2004; Adelana et al., 2005; Soladoye & Yinusa, 2012; Soladoye, 2014). Localised brackish (EC 1002 to 1092 µS/cm) groundwater coincides with elevated nitrate levels (44.3 to 53.2 mg/l), suggesting anthropogenic contamination sources. Other localised instances of anthropogenic contamination are evident (Adelana et al., 2005; Soladoye & Yinusa, 2012; Soladoye, 2014; Balogun, 2019), with EC, heavy metals, nitrate, potassium, chloride and E. Coli locally reported to exceed WHO and NSDWQ limits. Spatial variation in quality will be influenced by proximity to domestic and industrial contamination sources. Reports of ferruginous sands (Olaruntola et al., 2019) pose a potential geogenic source of iron contamination, although this would only have taste and colour impacts, rather than health related.

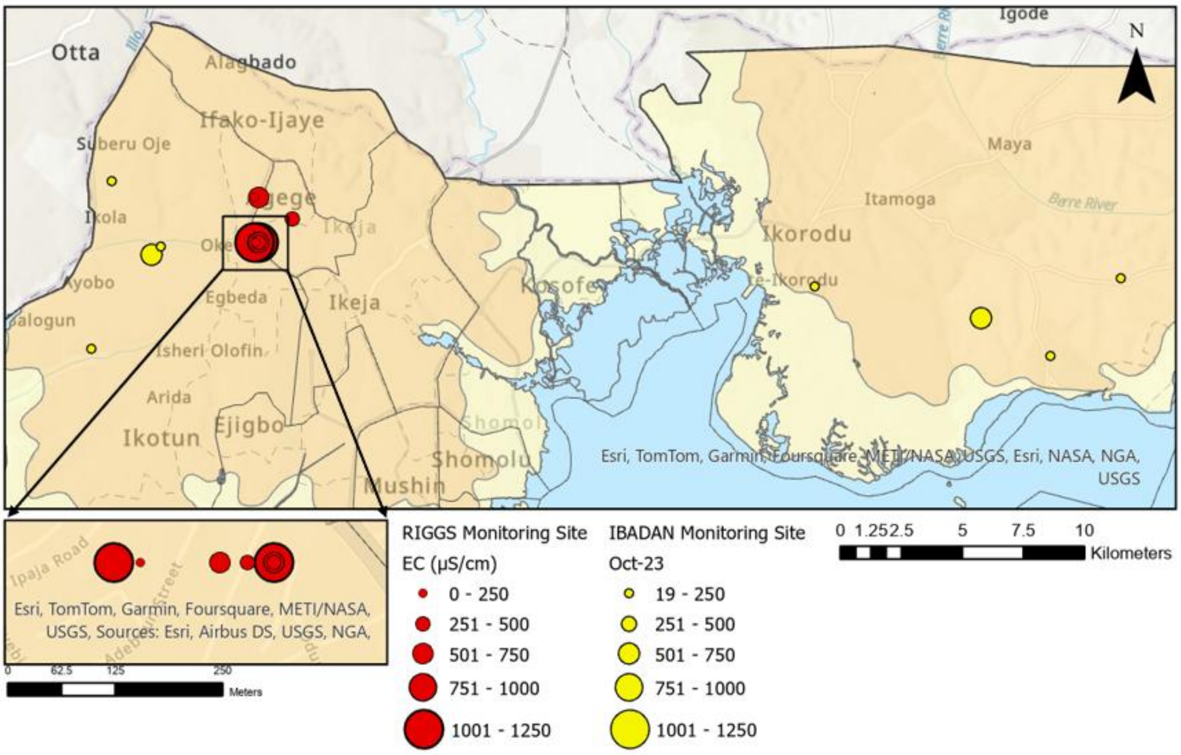

Figure 12: Spatial variations in EC across typology A from the RIGGS dataset (red) and the UNI-IBADAN dataset (yellow), Oct 2023 value (geological shapefile modified after Olabode & Comte, 2024). Inset shows zoom in of data points round Agege. Basemap: Esri, TomTom, Garmin, Foursquare, METI/NASA, USGS, NGA, Airbus DS. BGS © UKRI 2025.

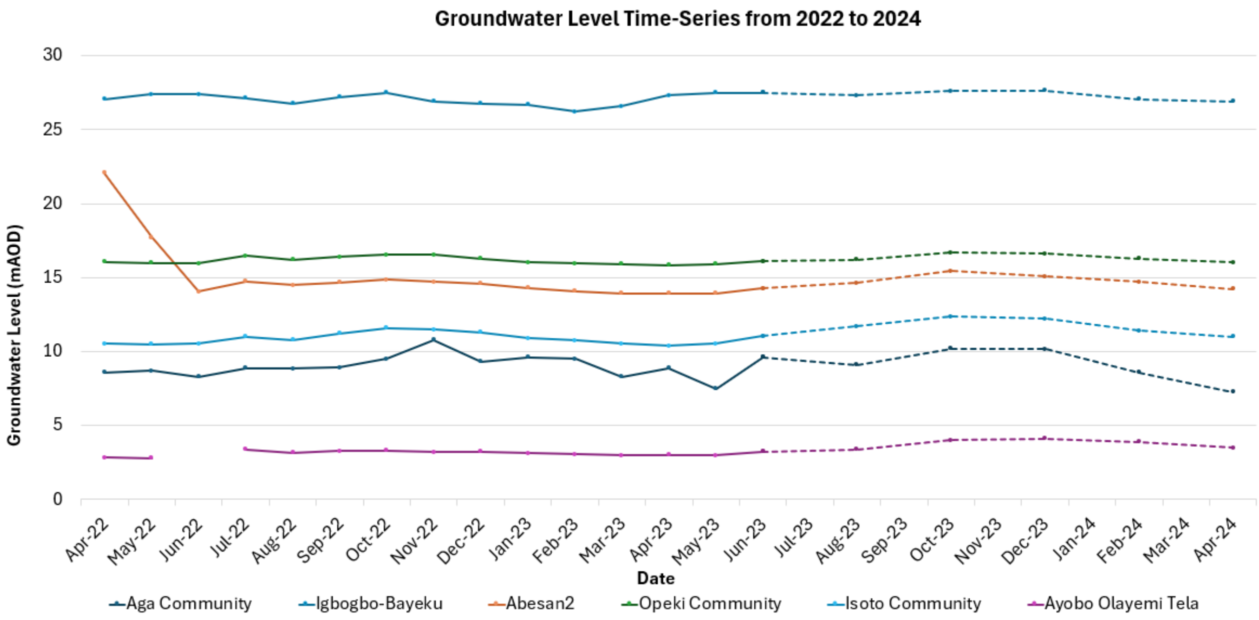

Figure 13: Groundwater level time series for UNI-IBADAN monitoring network within the UCPS at Typology A 2022 to 2024. Solid line indicates monthly data; dashed line indicates bi-monthly data. BGS © UKRI 2025.

According to borehole logs reported by Longe et al. (1987) for the areas of Agege and Shasha, the system appears clay dominated below 30 mbgl. This thick clay-dominated horizon (up to 60 m thick) acts as an aquitard, separating the UCPS and LCPS. Occasionally, thin (typically < 5 m, but sometimes up to 10 m) lenticular sand bodies are intercalated within this clay zone (Longe et al., 1987; Coode-Blizard, 1996; Oladepo et al., 2014).

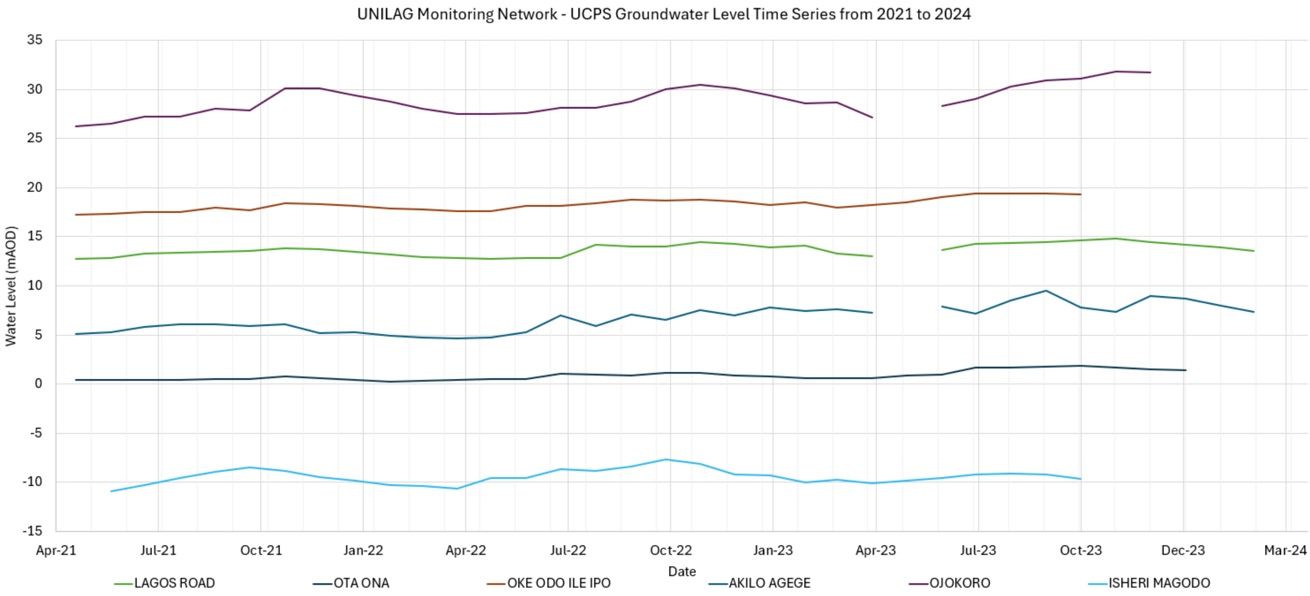

Figure 14: Groundwater level time series for UNILAG monitoring network within the LCPS at Typology A from 2021 to 2024. BGS © UKRI 2025.

The confined LCPS aquifer, which is more sand-dominated, begins around 70 mbgl and consists of poorly to fairly-well sorted, fine to coarse grained sands, intercalated with lenticular clay and clayey-sand lenses (< 10 m thick). The sands are typically horizontally and vertically connected between the sequences of clay, and extend to depths of 100 to 120 mbgl, deepening southwards (Longe et al., 1987; Coode-Blizard, 1996; Oladepo et al., 2014). Water quality data is not widely available, although UNILAG dataset indicates the system to be fresh (EC < 216 µS/cm). Due to being overlain by thick, confining clays it is expected to be largely protected from anthropogenic contamination. The aquifer is reported to be moderately productive, producing yields of 54.4 to

70.8 m^3/hour. Transmissivity ranges from 129.6 to 337.0 m^2/day; specific capacity from 3.0 to 3.7 m^3/h/m; permeability from $7.5x10^{-5}$ to $1.0x10^{-4}$ m/s; and storage coefficient of 2.5 (Longe et al., 1987). Data from the UNILAG monitoring network (Figure 14) indicates groundwater levels vary from 10.9 mbsl to 31.8 masl. Groundwater levels generally increased across all sites between October 2021 and October 2023, with overall increase ranging from 1.0 to 3.3, although localised sensitivity to abstraction is observed. Comparison between water level (< 40.9 mbgl) and start depth of LCPS aquifer (>70 mbgl) indicates the aquifer to be confined at this typology in the Agege-Shasha region. Although local recharge is likely limited due to the overlying clay aquitard, it is expected the LCPS will be recharged by high volumes of rainfall (~ 2000 mm/year) further north where the LCPS is at near-surface. Groundwater appears to follow the topographic gradient, flowing towards Lagos lagoon, with some localised variations attributed to abstraction induced cones of depression.

The CPS is underlain by the Ilaro and Ewekoro formations, consisting of thick shale and argillaceous sediments, extending to depths of 455 to 518 mbgl (Oladepo et al., 2014; Coode-Blizard, 1996). Beneath this, evidence from Ikorodu, shows the Abeokuta Formation containing sandy horizons (10 to 30 m thick) interbedded with clay and occasional limestone, with continuous sand horizons found below 520 mbgl. However, not all sand horizons are laterally continuous, particularly in the shallower depths (Longe et al., 1987; Coode-Blizard, 1996; Oladepo et al., 2014). Hydraulic properties, water quality and water level data are unavailable, although the aquifer is expected to be moderately to highly productive and of good water quality. Recharge is expected to occur in the north, where the aquifer outcrops at the surface.

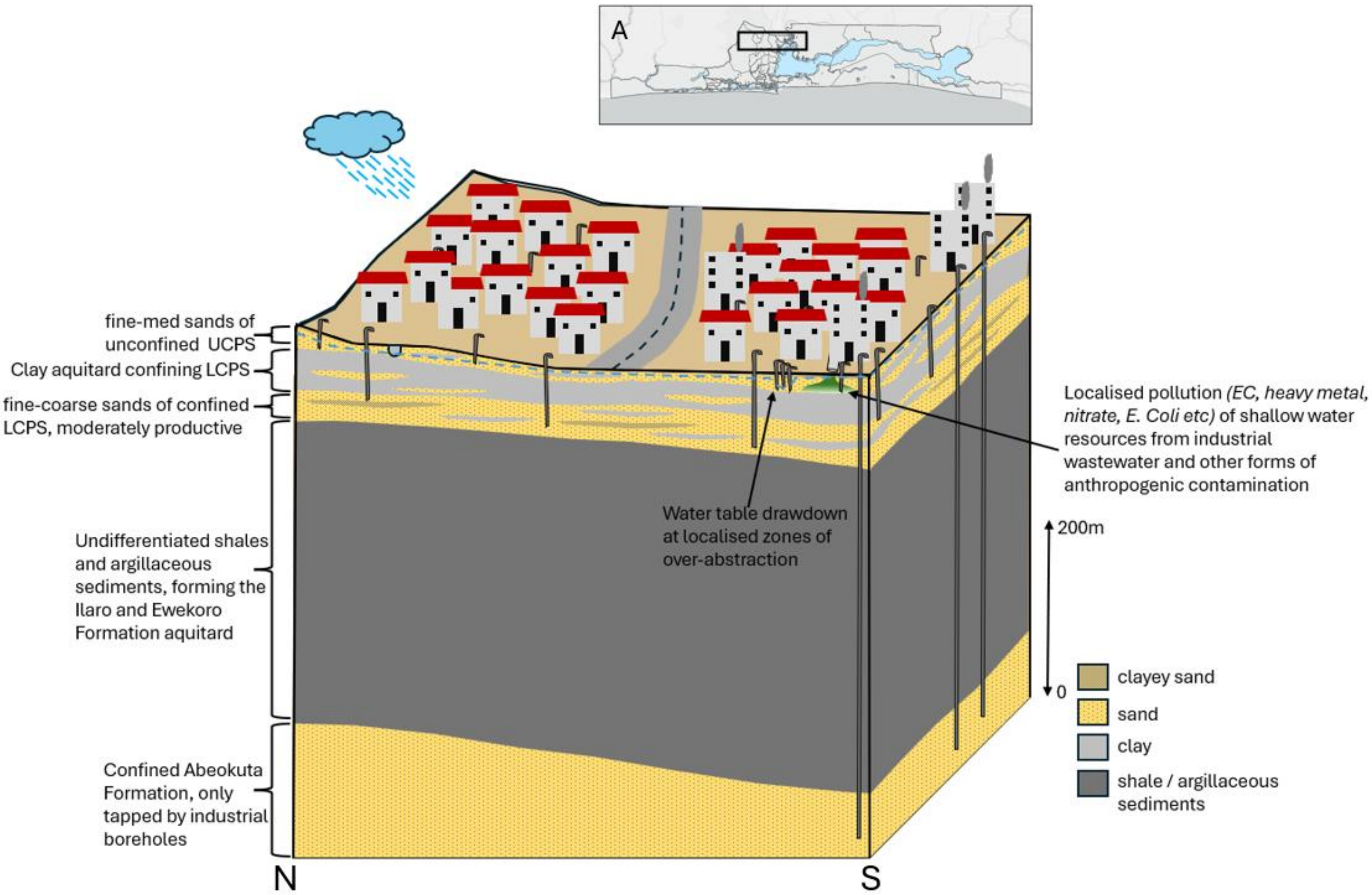

Figure 15: Schematic of the shallow (alluvium/UCPS), LCPS aquifer and deeper Abeokuta Formation typology in the north-west of Lagos State (Typology A). CPS aquifer structure based on borehole logs from Agege and Shasha areas as described in Longe et al. 1987. BGS © UKRI 2025.

4.1.2 Typology B – Lagos Mainland Urban Centre

This typology describes the aquifer systems around Lagos mainland's urban centre, from Gbagada to Aguda. It comprises of high population density, heavy urbanisation and industrialization. Groundwater in this region is used for both domestic and industrial water supplies, sourced from shallow wells and a mixture of low-volume motorised boreholes operated by households and high-volume motorised boreholes operated commercially. Interbedded sands, gravels and clays of the UCPS are found up to depths of 70 mbgl, thinning southward, with evidence of anthropogenic contamination within much of the shallow aquifer across this typology and evidence of saline intrusion towards the lagoon. Here, the LCPS is much better suited for potable water supply systems and is separated from the UCPS by a 10 to 45 m thick clay aquitard, with groundwater generally being fresh and expected to be largely protected from anthropogenic contamination. Found at depths typically below 90 mbgl, water-bearing sand and gravel horizons are typically 6 to 34 m thick and appear to have good potential for abstraction, although localised over-abstraction is evident. The thickness, sand content and productivity of aquifer horizons increases southwards. Information surrounding the Abeokuta Aquifer in this area is unavailable.

The shallow UCPS aquifer is semi-confined, typically overlain by 10 to 30 m of clay or clayey sand (occasionally sand) in the east and south (Longe et al., 1987; Longe, 2011; Oladepo et al., 2014). The aquifer extends to depths of 60 to 70 mbgl, with total thickness varying from 20 to 60 m, thinning southwards. The UCPS functions as a multi-aquifer system, consisting of interbedded sands and gravels, and clays. The system has more sand content than Typology A in the north, though clay layers vary in extent, from thin minor lenses to more extensive beds. Aquifer horizons are generally comprised of poorly sorted sands and gravels, and fine to coarse sands in the shallowest reaches at Shomolu (Longe et al., 1987; Oladepo et al., 2014). At Shomolu, Longe (2011) reported transmissivity to range from 224 to 2333 m^2/day and specific capacity from 5.5 to 32 m^3/h/m, recording yield from 62 to 100 m^3/h across six boreholes. This suggests that despite the clay-rich nature of the system, the aquifer is still very productive, although significant spatial variation is observed, even on localised scales. No up-to-date water level data is available for the UCPS in this region, but it is assumed to be shallow, as is typical across the state. Whilst large volumes of rainfall (~ 2000 mm/year) are available to recharge the aquifer, presence of impermeable urbanised land cover may limit this compared to more rural parts of the state (Olabode and Comte, 2022), reducing recharge volumes and increasing the ratio of recharge received from polluted and brackish surface water bodies (Lagos lagoon, creeks and canals), which may affect water quality.

Groundwater salinity is highly variable across the typology, ranging from 93 μS/cm (very fresh) to 2480 μS/cm (brackish) (Adelana et al., 2004; Adelana et al., 2005; Oladepo et al., 2014; Balogun et al., 2019). Where groundwater is brackish it is often associated with elevated concentrations of heavy metals and nitrates (Adelana et al., 2004; Balogun et al., 2019), indicating salinity to be anthropogenically sourced. However, saline intrusion in proximity to the Lagos Lagoon and brackish creeks has also been reported (Ayolabi et al., 2013), suggesting reversed pressure gradients and potentially significant drawdown at abstraction points. Despite the concerns regarding salinity, there are studies which identify all sampled sites to yield fresh water (Ferreira et al., 2008; Soladoye & Ajibade, 2014). The UCPS suffers from serious localised anthropogenic contamination, attributed to landfill leachate infiltration, sewage and wastewater (Afolabi et al., 2012; Balogun et al., 2019; Ferreira et al., 2023). A variety of contaminants have been reported to exceed WHO and NSDWQ limits across the zone, including EC, TDS, E. Coli, fluoride, ammonia, nitrate, arsenic, copper, zinc, nickel, lead, iron, manganese, aluminium, potassium, chromium, hydrogen sulphide and cadmium (Adelana et al., 2004; Adelana et al., 2005; Afolabi et al., 2012; Soladoye & Ajibade, 2014; Balogun et al., 2019; Ferreira et al., 2023), although these contaminants were not observed at all sites. Geogenic iron contamination has also been reported (Longe et al., 1987). Whilst there are localised zones of good water quality, even in proximity to potential contamination sources (Ferreira et al., 2023), the system here can generally be deemed a high-risk source of water supply with regards to adverse effects on human health. It is possible that towards Aguda, where thick clays overly the UCPS, there may be some level of protection from surface pollution. However, further investigation is required to identify 'safe' zones.

A clay aquitard of variable thickness (~ 10 to 85 m), thinning southward, appears to separate the UCPS from the LCPS, terminating between ~ 85 to 140 mbgl. Minor, non-laterally extensive sand horizons (generally < 5 m, up to ~ 10 m) are found within this clay layer. (Longe et al., 1987; Longe et al. 2011). Aside from north-west Shomolu, where the clay aquitard appears thickest, the confined LCPS aquifer typically extends from depths of 90 mbgl. It comprises of interbedded sand, clay, and peat, forming a multi-horizon system with a higher sand content than the UCPS. Bed thickness ranges from 6 to 34 m and grain size is coarse. Total aquifer thickness increases southward, while clay and peat layers are thinner (<10 m) and less frequent than in the UCPS. Investigation by Longe et al. (1987) indicates a productive aquifer system with good potential for abstraction. Although limited, results suggest southerly-increasing transmissivity and yield, which corroborates with the idea of the LCPS system thickening southwards, along with increasing sand content (Table 4).

Table 4: Average value of aquifer characteristics reported by Longe et al (1987) from a) step-drawdown tests and **b) long-term constant rate tests using Theis (in bold).**

Location	Yield (m^3/hour)	Specific Capacity (m^3/h/m)	Transmissivity (m^2/day)	Permeability (m/s $x10^{-5}$)	Storage Coefficient ($x10^{-4}$)
Shomolu	80.1	14.9	2315.52 **1900.8**	37	**4.9**
Aguda	97.2	28.6	5115.52 **2571.72**	245.8	**3.8**

Since 2021, the UNILAG monitoring network indicates average monthly water table is near or below sea level, ranging from 4.9 masl to 13.7 mbsl (Figure 16; equivalent of 0.13 to 36.74 mbgl). Despite concerns of over-abstraction and observed cones of depression in areas like Itire Ikate and Isolo, groundwater levels generally increased during 2021 to 2024, indicating recharge exceeded abstraction and the resource did not appear to be suffering from depletion. Although local recharge is likely limited due to the overlying clay aquitard, it is expected the LCPS will be recharged by high volumes of rainfall (> 2000 mm/year) further north where the system is at near-surface.

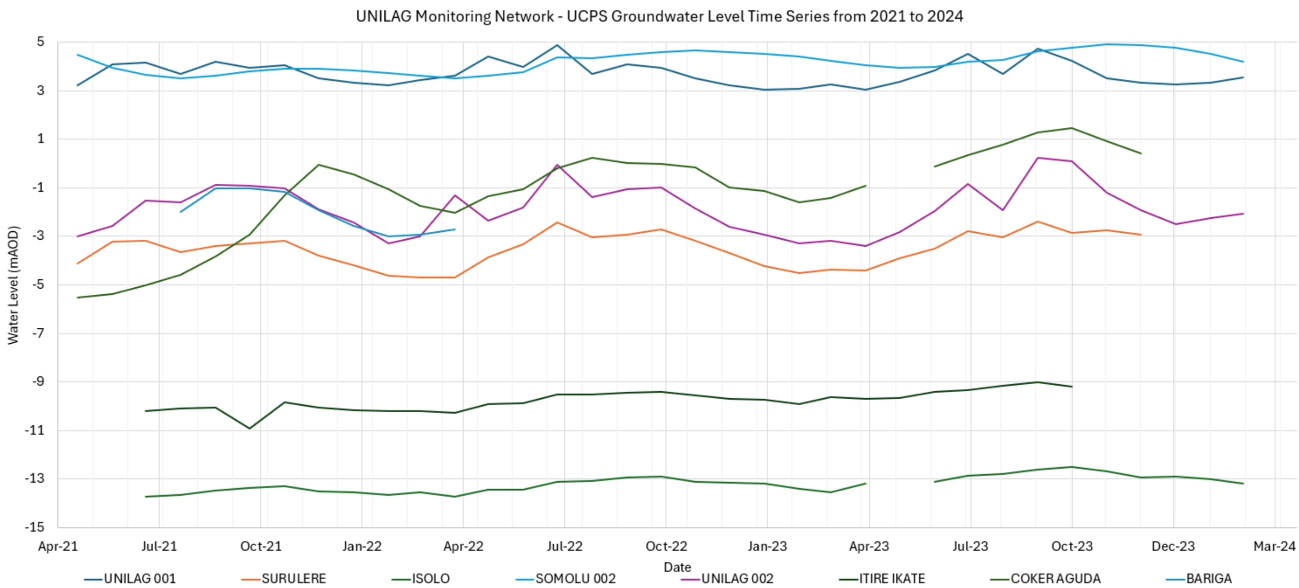

Figure 16: Groundwater level time-series for the UNILAG monitoring network, targeting the LCPS aquifer from 2021 to 2024. BGS © UKRI 2025.

As with the majority of the state, the LCPS is expected to be protected from anthropogenic contamination and poor water quality by the overlying thick clay aquitard, although limited information is available to ascertain its lateral continuity. The LCPS appears to be fresh water bearing (EC < 450 µS/cm) (UNILAG dataset), even at sites where the UCPS sands are producing saline water (Oladepo et al., 2014). However, brackish salinity (EC 1246 to 2446 µS/cm) has been recorded at Bariga (UNILAG dataset), although lack of borehole construction information creates uncertainty regarding which aquifer is being screened. Further investigation is required.

The LCPS's full extent is uncertain across this typology, as logs appear to terminate (at 220 mbgl) before the final sand horizon is encountered (Oladepo et al., 2014), necessitating further investigation. There is no data on the Abeokuta, Ilaro, or Ewekoro Formations in this region.

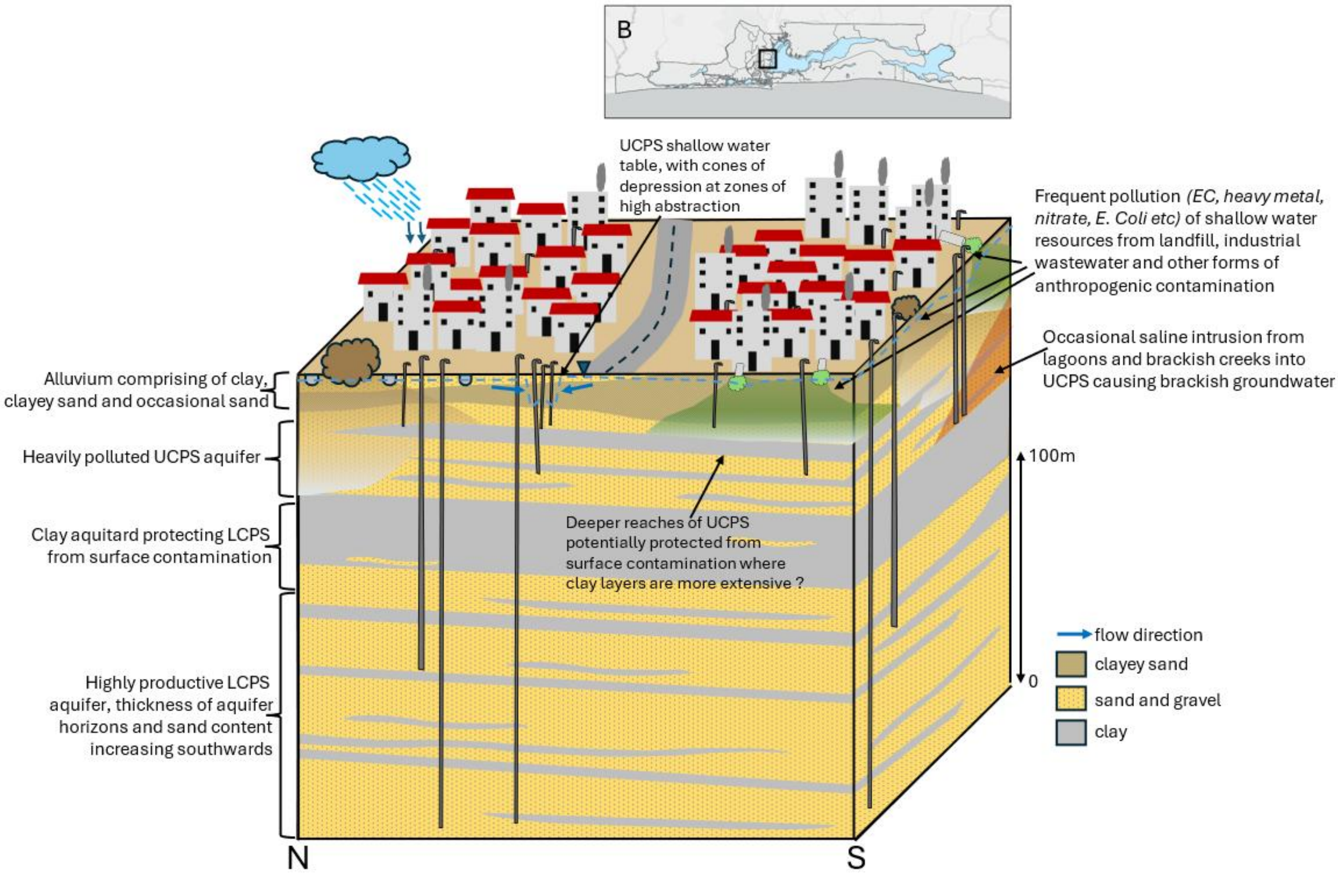

Figure 17: Schematic of the shallow (alluvium/UCPS) and deeper LCPS aquifer typology surrounding the urban centre of Lagos Mainland (Typology B). BGS © UKRI 2025.

4.1.3 Typology C – Urbanised Central Coastline

This typology covers the aquifer systems along the central coastal belt from Apapa to Lekki, characterized by high population density, urbanization, and industrialization. Groundwater in this region is used for both domestic and industrial water supplies, sourced from shallow wells and a mixture of low-volume motorised boreholes operated by households and high-volume motorised boreholes operated commercially. Overlain by alluvium, the UCPS reaches depths of up to 190 mbgl and consists of 10 to 60 m thick beds of medium to coarse grained sands and gravels, intercalated with clayey sand and clay layers of up to 75 m thickness. Here, the UCPS faces localized anthropogenic contamination and saline intrusion, resulting in borehole abandonment. Small-scale domestic supply relies on a shallow freshwater lens within the UCPS, which risks upconing of saline water if over-exploited, although there is also risk of degraded water quality from anthropogenic sources within this shallow lens. Generally found at depths of below 160 mbgl, the medium to coarse grained sand and gravel aquifer horizons of the LCPS are hydraulically disconnected by the UCPS by a 5 to 15 m thick clay aquitard. Better protected from saline intrusion and anthropogenic contamination, the LCPS is reported to produce fresh water, hence is more suitable for potable water supply and large-scale abstraction. Data from the Abeokuta Formation is lacking, but it is likely too deep for abstraction to be economically viable.

Geological mapping indicates alluvium covers the UCPS, but it is not differentiated in geological logs and is thus grouped with the UCPS as part of the shallow aquifer. The base of the UCPS increases southward and eastward, from 124 to 190 mbgl, generally reaching depths of 140 to 160 mbgl (Longe et al., 1987; Coode-Blizard, 1996; Oladepo et al., 2014). The aquifer consists of poorly to moderately sorted medium to coarse-grained sand and gravel (fining upwards), with thicknesses ranging from roughly 10 to 60 m. These are intercalated with clayey sand and clay layers of variable thickness (~5 to 75 m) and continuity. A belt of brackish to saline groundwater exists within the UCPS at this typology, with the base of this belt deepening southwards and eastwards as the thickness of the UCPS increases. This represents saline intrusion induced by reversed pressure gradients from over-abstraction of the coastal aquifer, (DEPA, 1998; Oteri and Atolagbe, 2003; Ola et al., 2008; Olufemi et al., 2010; Babatunde, 2012; Oyeyemi et al., 2015; Akinlalu & Afolabi, 2018; Jimoh et al., 2018; Adiat, 2019; Popoola et al., 2020). The upper fresh-saline interface is typically shallower than 70 mbgl (ranging 20 to 100 mbgl), while the lower interface is generally below 150 to 160 mbgl (ranging from 110 to 190 mbgl) (Akinlalu & Afolabi, 2018; Adiat, 2019), although these depths vary across the typology (Ola et al., 2008; Oladepo et al., 2014; Akinlalu & Afolabi, 2018; Jimoh et al., 2018). Concentrations of faecal coliforms, E. Coli, nitrate, iron, lead, zinc, arsenic, nickel, copper, manganese, cadmium, chromium, magnesium are also reported to exceed WHO or NSDWQ limits (Soladoye, 2014; Sogbanmu, 2020; Ajani et al., 2021; Akerele et al., 2023; Ezechinyere and Stanislaus, 2023), pointing to anthropogenic contamination from industry and domestic waste. Therefore, even freshwater lenses are at risk of poor water quality, with sources of contamination linked to polluted surface water, seepage from storage tanks, oil wells, septic tanks, landfills, and agricultural runoff (Adewuyi et al., 2010).

A ~5 to 15 m thick clay aquitard separates the UCPS and LCPS, acting as a sharp boundary between the brackish and freshwater-producing sands.

The LCPS generally has a higher sand-to-clay ratio than the UCPS, comprising of medium to coarse sand and gravel, though sand content, grain size and sorting varies across the typology. Sand horizons range from ~5 to 45 m in thickness, while clays and clayey sands range from ~2 to 25 m (typically <10 m). The LCPS base varies from 237 mbgl at Badore to 290 mbgl at Lekki Phase I, but many logs terminate within sand horizons at 280 mbgl, suggesting the LCPS may extend deeper. Water quality data is lacking for the LCPS, although is reported to water with low levels of salinity (Kampsax-Kruger, 1977; Oyadele & Meshida, 2004; Oladepo et al., 2014; Akinlalu & Afolabi, 2018; Adiat, 2019). This is attributed to a continuous clay aquitard beneath the brackish zone of the UCPS, protecting the LCPS from saline intrusion. Successful drilling typically targets beyond 200 mbgl (Oyadele & Meshida, 2004). No further water quality information is available for the LCPS system.

There is no typology specific information regarding groundwater level, flow or hydraulic properties. However, it is expected that the UCPS has a shallow water table, and that the LCPS displays artesian or semi-artesian conditions, due to the presence of confining clay. It is highly likely that water level is below sea level, causing reversed pressure gradients, and hence the saline intrusion across this belt. Both systems are assumed to be highly productive (compared to Typologies A and B), due to greater aquifer thickness and sand content in the south of the state.

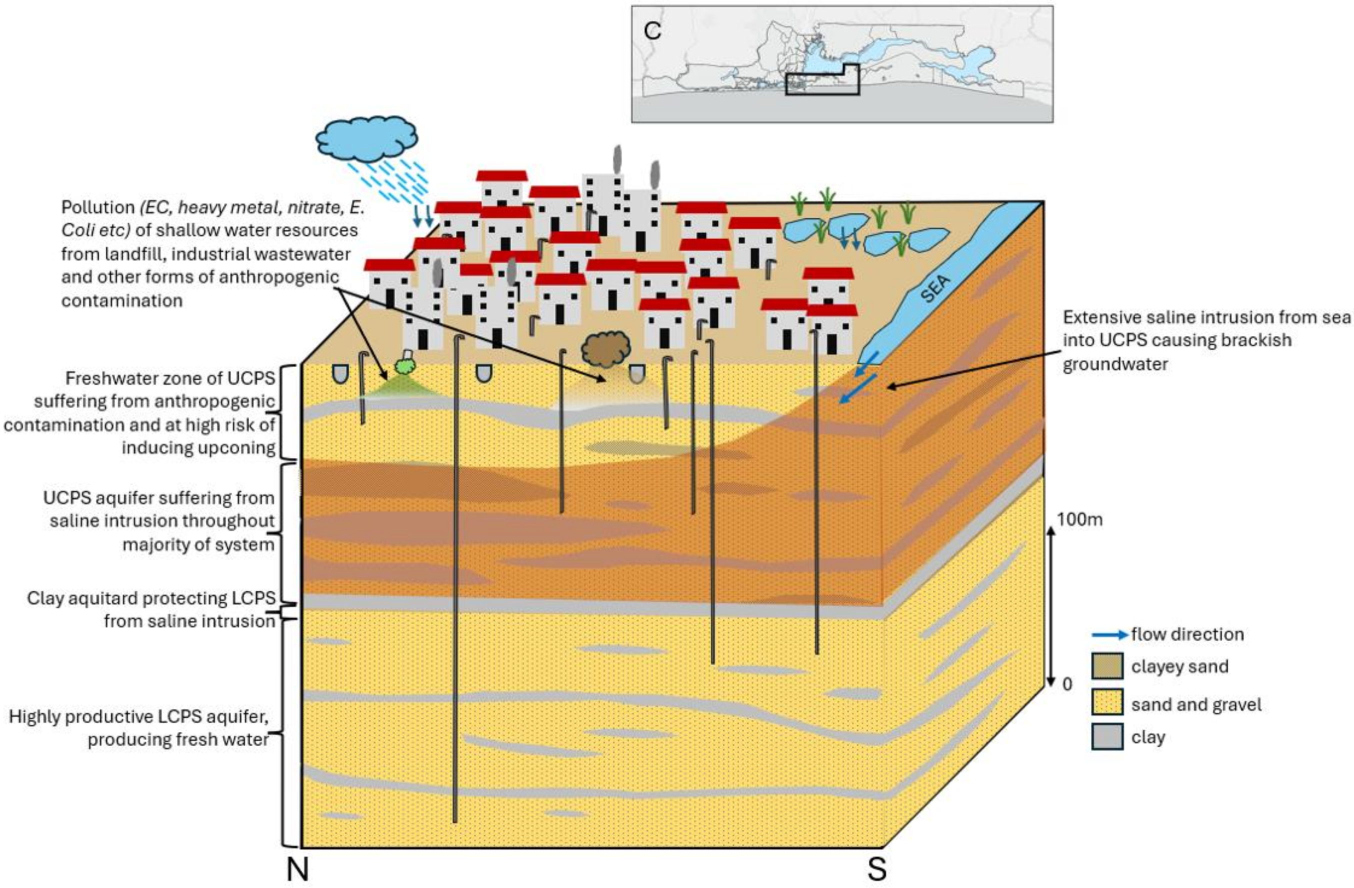

Figure 18: Schematic of the shallow (alluvium/UCPS) and deeper LCPS aquifer typology along the heavily urbanised central coastal belt (Typology C). BGS © UKRI 2025.

4.2 MINOR TYPOLOGIES

4.2.1 Typology D – Coastal Southwest at Badagry

This typology describes the aquifer systems across Badagry LGA, a coastal area situated between Lagos City and the Benin border. It comprises an urban centre and surrounding rural communities. Groundwater in this region is predominantly used for domestic supply, sourced from hand-dug wells and motorized boreholes, mainly drawing from the shallow aquifer system (sandy clay alluvium and UCPS), which extends to ~ 100 mbsl. Localised anthropogenic contamination, attributed to the shallow water table is evident, although there appears to be limited evidence of saline intrusion. Found at depths from 300 to 400 mbsl and separated from the UCPS by a ~ 200 m aquitard, the sand-dominated LCPS aquifer system appears more suitable for water supply due to the presence of more extensive sands and is expected to be highly productive with good water quality. The Abeokuta Formation aquifer is found beyond 958 mbgl, making it unsuitable as an economically viable aquifer system in the area, therefore it is not included within this typology.

The shallow aquifer is composed of sandy clay alluvium at the surface, overlying the UCPS. The UCPS is clay-dominated and extends to about 100 mbsl, with two primary water-bearing fine to medium sand horizons identified between 35 to 55 mbsl and 75 to 100 mbsl (Aladejana et al., 2020). The first sand horizon appears more laterally extensive, while the second is likely a discrete lenticular sand body within the clay. Recharge to the system occurs mainly via rainfall (~2000 mm/year), surface water bodies (e.g. Badagry Creek and associated wetlands), and flood flow. The shallow aquifer is likely well-recharged due to the high volumes of precipitation.

The water table in the UCPS is typically shallow (<12 mbgl), with low elevations making this close to sea level (< 6.5 masl). Water level within UNI-IBADAN monitoring boreholes (Figure 19) at

Badagry rose by 0.2 to 0.6 m between April 2022 and April 2024. A shallow water table makes the shallow aquifer vulnerable to anthropogenic contamination, with lead, cadmium, chromium, copper and *E. Coli* all found to exceed WHO (2022) drinking water standards at various localities across the LGA (RIGSS dataset; Olaruntola, 2021; Tunde et al., 2023). This contamination is likely caused by poor management of a variety of domestic and industrial waste, and poorly sited or protected wells and boreholes.

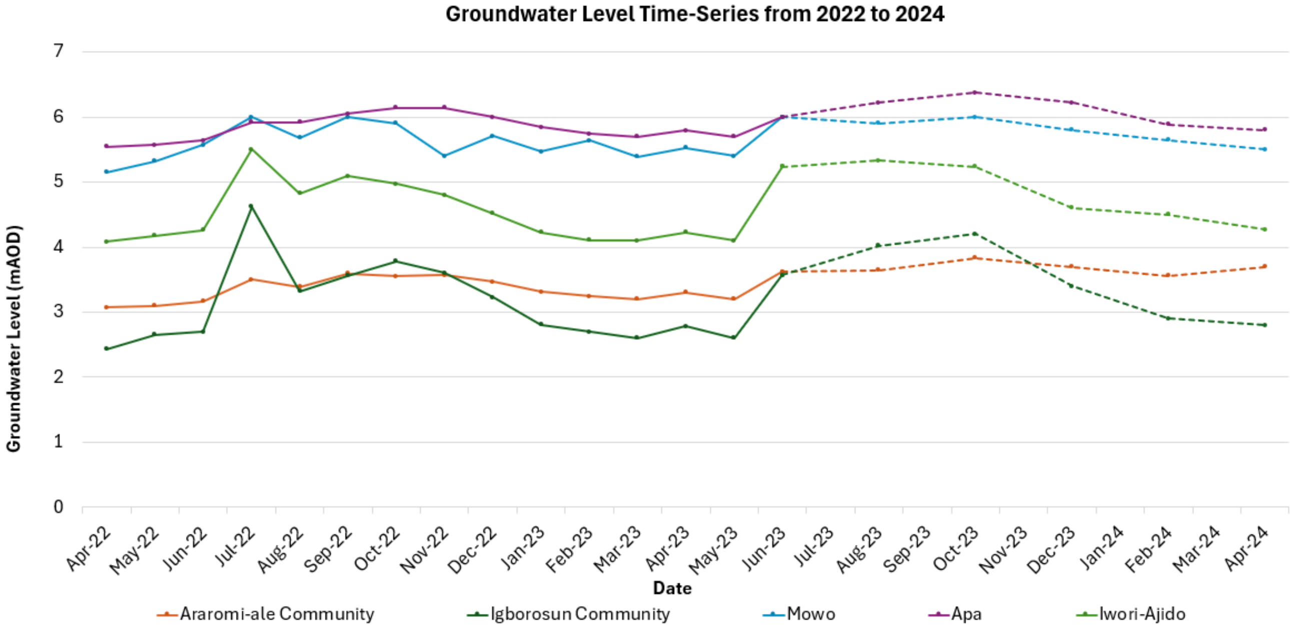

Figure 19: Groundwater level time-series for UNI-IBADAN monitoring boreholes in Badagry region. Solid line indicates monthly data; dashed line indicates bi-monthly data. BGS © UKRI 2025.

Despite models suggesting presence of a thin brackish lens within the UCPS here (Adelana et al. 2008), groundwater data consistently indicates fresh water, with no evidence of saline intrusion in this zone. RIGSS and UNI-IBADAN datasets indicate EC ranging from 30 to 290 µS/cm from boreholes, whilst Olaruntola et al. (2019) found all 91 shallow wells sampled produced fresh water (TDS < 520 mg/l), with 84% of samples having TDS < 250 mg/l. RIGSS data indicates hand dug wells have slightly elevated EC in comparison (typically 412 to 571 µS/cm), although remains predominantly fresh. At the one brackish site (EC = 1257 µS/cm), presence of elevated nitrate levels (44.75 mg/l), suggests local anthropogenic contamination rather than saline intrusion. However, due to low elevations, coastal proximity and a water table close to sea level, there is a possibility that coastal saline intrusion may affect shallow groundwater in this area if abstraction is not suitably managed.

The LCPS aquifer is located at depths of approximately 300 to 400 mbsl and is hydraulically separated from the UCPS by a 200 m thick layer of clay, peat, and shale, which acts as an aquitard (Aladejana et al., 2020). The upper boundary of the LCPS aquifer may become shallower eastward. The LCPS is mainly sand dominated, with peat lenses at the base and is underlain by limestone or sandy shale (Aladejana et al., 2020; Onuoha & Ofoegbu, 1988). Limited hydraulic property data has been reported for the LCPS in Badagry, but its greater sand content and thickness suggest that it is likely more productive than the UCPS at this locality, suggesting high yields may be supported here. At Ijanikin, transmissivities ranging from 656 to 2286 m^2/day have been estimated from pumping tests (GTS Ltd, no date). Currently, there is no water quality or level data available for the LCPS at this site. Due to its confined nature, the LCPS is expected to be near-artesian, with good water quality. The thick overlying aquitard provides protection from potential surface contamination, making it a more reliable potable source of groundwater than the UCPS. This clay aquitard will likely prevent local recharge, and it is expected the LCPS will be recharged by high volumes of rainfall (> 2000 mm/year) further north where the system is at near-surface

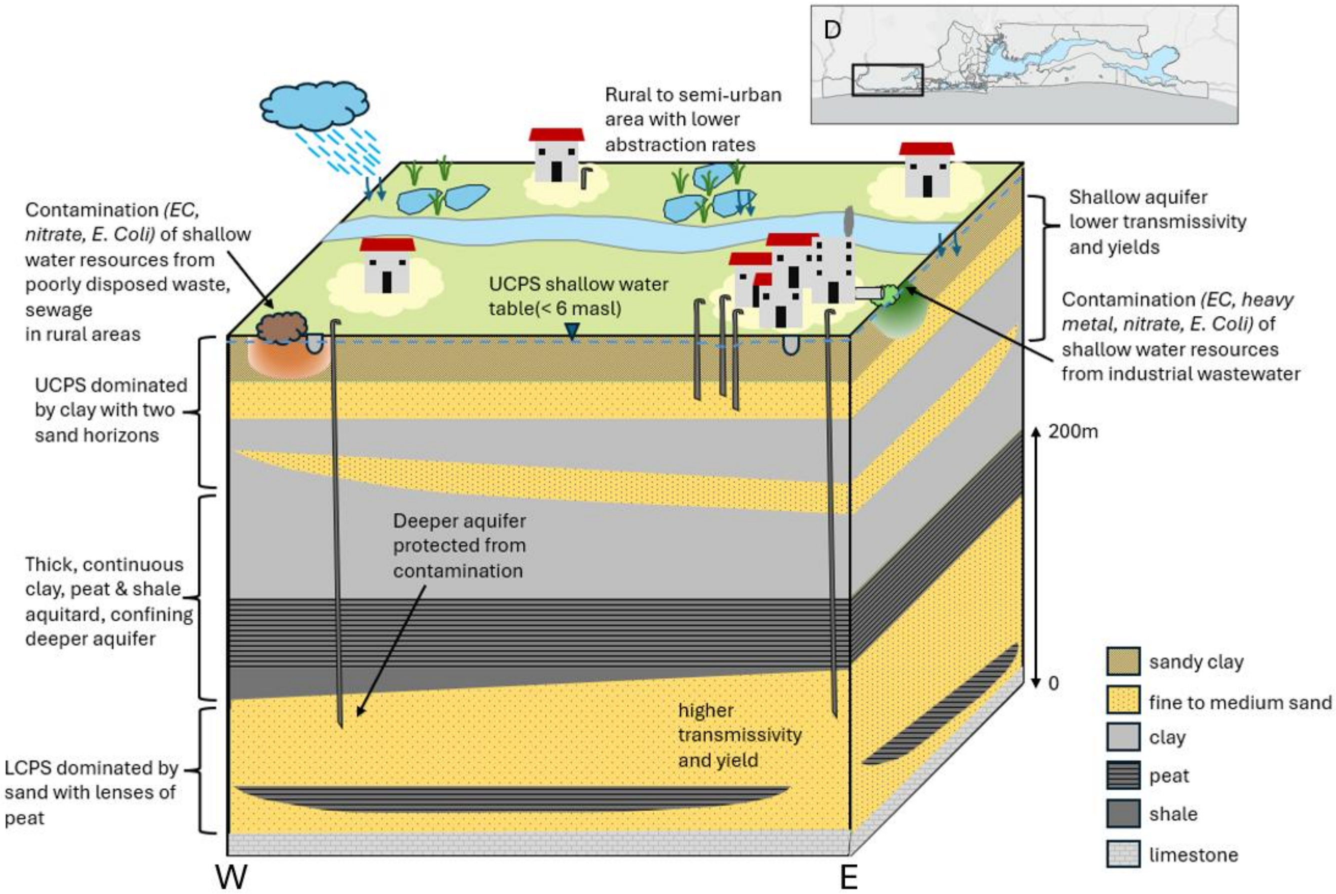

Figure 20: Schematic of the shallow (alluvium/UCPS) and deeper LCPS aquifer typology at Badagry LGA (Typology D). BGS © UKRI 2025.

4.2.2 Typology E – Lithological Anomaly at Lakowe

This typology describes the lithological anomaly observed within the aquifer systems between Awoyaya and Lakowe in Ibeju-Lekki, situated between Lagos Lagoon and the coastline, east of Lagos. This lithological anomaly is the defining feature of the typology. The area, less developed than the Lagos mainland, Victoria Island, and Lekki, has experienced rapid urbanization in recent years, transitioning into a growing commercial and residential zone. Within this typology, aquifer systems do not appear to be suitable for any significant water supply, due to the UCPS and LCPS being clay dominated. Shallow UCPS sand horizons suffer anthropogenic contamination, whilst deeper sand horizons bear brackish water.

Coode-Blizard (1996) and Oladepo et al. (2014) identify a geological anomaly in the Awoyaya and Lakowe region. Coode-Blizard (1996) suggest the Lower Coastal Plain Sands (LCPS) are absent, and the Ilaro Formation dominates from depths as shallow as 45 mbgl, with this attributed to large-scale faulting. Such large-scale faulting is unlikely due to no evidence of significant structure elsewhere across the state, and it is possible that the anomaly identified around Lakowe could reflect a clay-dominated lithological variation within the LCPS or perhaps may reflect a borehole logging anomaly. This results in a high level of uncertainty as to the nature of this typology.

Groundwater supply here appears to be limited to freshwater-bearing sands which extend to depths of up to 100 mbgl, thickening and deepening westward. These sands are intercalated with clay and clayey sand layers, with the shallowest clays being relatively uniform and laterally continuous, and deeper layers thickening westward. Groundwater in the shallow aquifer is predominantly fresh (Oladepo et al., 2014). However, the UNI-IBADAN record from Lakowe shows seasonal fluctuations between fresh and brackish groundwater (EC 361 to 1448 μS/cm) and brackish water is encountered between 70 and 100 mbgl at Awoyaya. No specific studies are available on the water quality of the shallow aquifer (Alluvium/UCPS), but it is assumed to be vulnerable to anthropogenic contamination, particularly near domestic and commercial waste sources, as observed in similar regions like Badagry. Groundwater level data from a shallow UNI-IBADAN borehole at Lakowe shows seasonal fluctuations between 3.3 mbgl (6.7 masl) in the dry season and 0.9 mbgl (9.1 masl) in the wet season, with a recorded 0.9 m decline over a two-year period (April 2022 to April 2024). No hydraulic data is currently available for the area. Recharge to the CPS system occurs mainly via rainfall (~2000 mm/year), although influences from the small lagoon to the north of Lakowe may be possible. Below these shallow sands, the clay-dominated LCPS extend to depths exceeding 360 mbgl.

Within the deeper LCPS, brackish sand and clayey sand horizons are present between 260 and 315 mbgl at Lakowe, and between 230 and 350 mbgl at Awoyaya. The thick overlying clay-dominated aquitard will seriously limit recharge to these horizons. EC reach up to 6000 µS/cm, which is likely geogenic, rather than saline intrusion or anthropogenic contamination. The lateral extent of sand horizons is uncertain but likely limited.

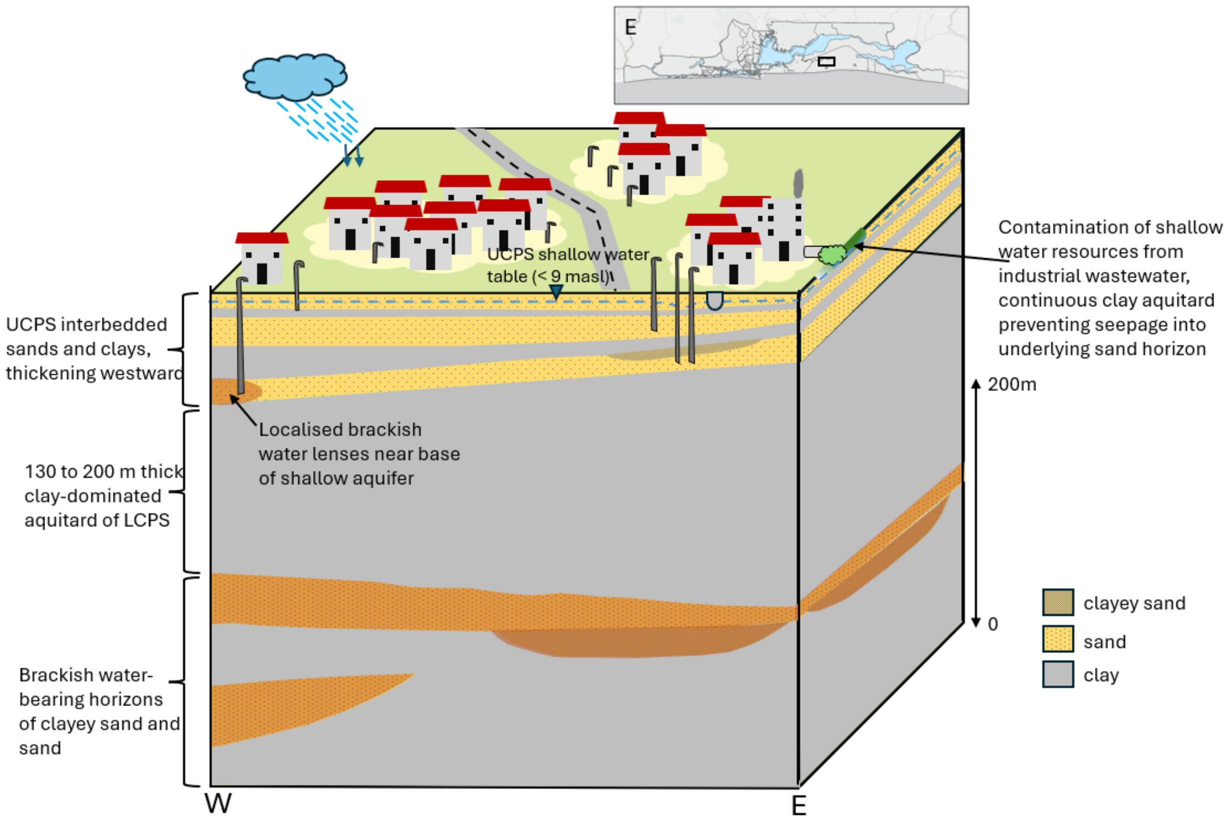

Figure 21: Schematic of the hydrogeological anomaly at Lakowe (Typology E). BGS © UKRI 2025.

4.2.3 Typology F – Inland Northeast at Epe

Typology F is located in northeastern Lagos, extending from Epe town and Itoikin northward to the border. This area includes both urban and rural zones, with urbanization concentrated around Epe town and near the lagoons. Protected wetlands are increasingly threatened by development, sand-mining and uncontrolled land reclamation. Water usage is for domestic, industrial and agricultural purposes, including irrigation (cassava, pineapple, rice). Here, the undifferentiated CPS aquifer is clay-dominated, with only thin (~ 5 m) and non-laterally extensive sand horizons, hence only appears suitable for small-scale domestic supply. Found at relatively shallower depths (from 211 mbgl) than the rest of the state, the sandstone horizons of the Abeokuta Formation may be more appropriate for larger-scale abstraction or public water supply and is expected to be highly productive and of good quality. However, further hydrogeological investigation is required, as current data for the area is limited.

The shallow aquifer in the Coastal Plain Sands (CPS) is predominantly composed of clay and clayey sand up to 70 mbgl, with thin, non-laterally extensive sand horizons (~5 m) (Coode-Blizard, 1996). Recharge to the system is mainly from rainfall (~2000 mm/year), surface water bodies (e.g., Lagos, Epe, and Lekki lagoons, wetlands), and flood flow. Although the IBADAN dataset (Figure 22) indicates there is a general trend of rising water levels from 2022 to 2024, at Ibowon in the north, an overall decline of 6.23 m was observed, with a notable 13.2 m drop during the 2022 wet season, followed by a 7 m rise from late 2022 to 2024. Similarly, water level at Ejirin, near Lagos Lagoon is below sea level, increasing risk of intrusion from the brackish lagoon into the aquifer system due to reversed head gradients, as well as further indicating vulnerability to over-abstraction despite receiving substantial recharge.

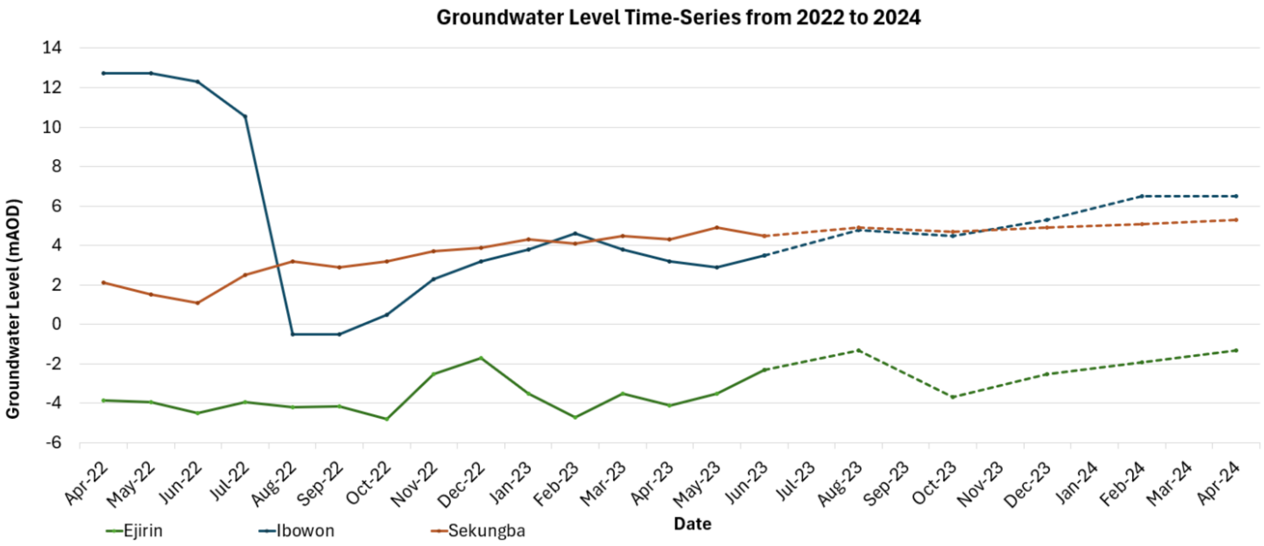

Figure 22: Hydrograph for UNI-IBADAN monitoring boreholes in Epe region, from 2022 to 2024. Solid line indicates monthly data; dashed line indicates bi-monthly data. BGS © UKRI 2025.

Large volumes of recharge into the system are possible, due to high amounts of rainfall (~2000 mm/year) and through wetlands, swamps and other surface water bodies, including Epe Lagoon. However, as the system is clay-dominated, this may limit recharge to the deeper parts of the CPS system. The shallow aquifer is predominantly fresh, with no evidence of saline intrusion, though slightly elevated EC and nitrate levels (within WHO and NSDWQ limits) have been recorded in shallow wells (RIGSS, IBADAN datasets). E. coli, iron, and zinc concentrations can exceed WHO limits (Soladdoye & Ajibade 2014), indicating vulnerability to anthropogenic contamination, as is typical across the state. Given the low permeability of the clay-dominated CPS, deeper sand horizons within the CPS are expected to be less susceptible to contamination. No hydraulic data is available. However, transmissivity and yield are expected to be low due to the clay-rich composition of the system and the limited presence of significant sand horizons.

The shallow CPS is underlain by a 140 to 230 m thick aquitard, composed of clay, limestone, and shale (Ilaro and Ewekoro Formations). Below this, the sandy aquifer of the Abeokuta Formation is encountered at relatively shallow depths (> 211 mbgl) compared to other state localities. Due to the thick overlying aquitard, hydraulic connectivity between the shallow and deeper aquifers is expected to be limited, and recharge to the Abeokuta Formation is expected to occur further north near its outcrop in Ogun State. This aquifer is protected from local anthropogenic contamination in Epe. While no specific data on water levels, quality, or hydraulic properties are available for the Abeokuta Formation in this area, geophysical logging suggests fresh groundwater to at least 326 mbgl (Coode-Blizard, 1996). These sands are anticipated to have high transmissivity and yield potential.

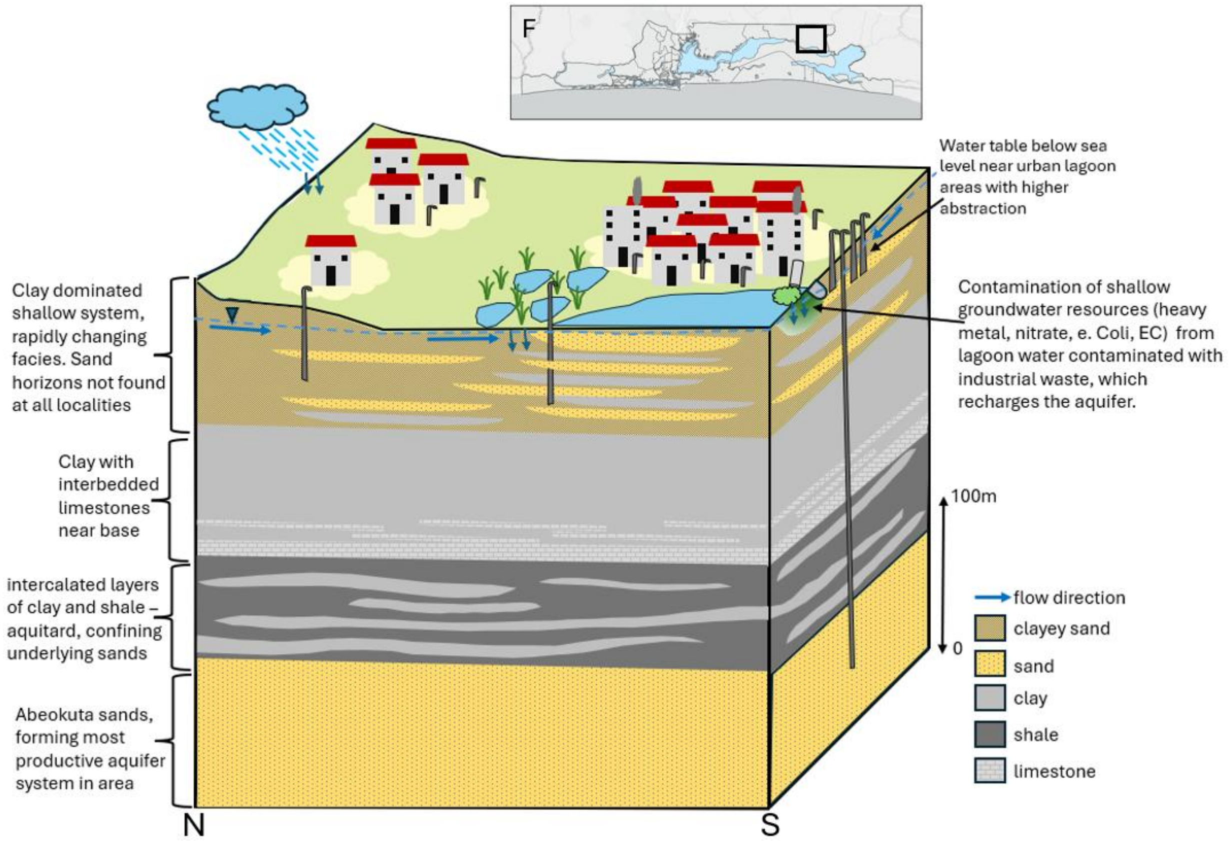

Figure 23: Schematic of the coastal plain sands aquifer and Abeokuta aquifer typology at Epe Zone F. BGS © UKRI 2025.

5 Conclusions and Recommendations

Groundwater is currently the primary source of domestic, commercial and industrial water supply across Lagos State. In the absence of reliable public piped water supplies, groundwater is accessed through a distributed network of shallow wells and motorised boreholes drilled to varying depths and of differing productive capacities.

Existing knowledge of the aquifers of Lagos is fragmented, leading to a partial and inconsistent record of groundwater conditions, characteristics and trends over time. In the absence of robust and up-to-date datasets, the prevailing anecdotal concern is one of widespread contamination, salinity and falling groundwater levels due to over-abstraction. However, this concern of widespread degradation and depletion appears to be stemming from insufficient or outdated data and evidence; based on research, data and evidence that suggests aquifer degradation and depletion to be more localised.

This report combines existing literature about the groundwater system of Lagos with new insights derived from the Lagos Groundwater Demonstrator, a network of groundwater monitoring sites across Lagos State. It provides a summary of the groundwater system of Lagos and uses this to advance a preliminary conceptual model of the key aquifer systems and a summary of some of the associated major typologies.

5.1 SUMMARY OF KEY AQUIFER SYSTEMS

A preliminary conceptual model, providing a simplified overview of hydrogeological typologies underlying Lagos State is presented in Figure 24. However, the UCPS and LCPS aquifers are both highly heterogeneous, due to rapidly changing geological facies, giving a high level of variability within the aquifer systems even at a local scale. Within this more regional overview, six initial typologies have been identified, and are presented in Section 4. Further investigation is required to refine these typologies and better define the transitions between them allowing for more robust conceptualisation of the groundwater system at the state-scale.

Regionally, aquifers can be summarised into three key systems of varying potential and vulnerability in terms of water supply:

1. The shallow aquifer system, consisting of ***alluvium and UCPS***, contains multiple water bearing horizons of variable productivity. The system is highly vulnerable to anthropogenic contamination and over-abstraction, although only shows localised depletion and quality issues. Within the central coastal belt, from Apapa to Lekki, saline intrusion is evident, and whilst some freshwater lenses can be targeted, any significant abstraction will likely induce further intrusion. Outside of this area, the system can support small-scale domestic supply with low access costs if contamination risks can be managed.
2. The ***LCPS*** appears to be a moderately to highly productive aquifer system, comprising of multiple aquifer horizons. The LCPS is largely protected from anthropogenic contamination and saline intrusion due to the presence of a near-continuous clay-dominated horizon of variable thickness across the region, limiting hydraulic connectivity between the LCPS and the shallow aquifer and surface water system. Productivity is not widely reported, although transmissivity values suggest the aquifer has the potential to support larger-scale public and industrial water supply if adequately planned and managed. Further investigation is required for full characterisation and to fully understand contamination risks. Whilst historically there has been a dialogue of over-abstraction and declining water levels, recent monitoring data suggests that water levels in some parts of the aquifer beneath Lagos city might be slowly rebounding. However, despite more recent, consistent rises in groundwater level, the LCPS aquifer is still vulnerable to over-exploitation and changing abstraction patterns, demonstrating the need for robust monitoring and adequate management to ensure long-term sustainability. Strategic long-term monitoring is essential.
3. The deep ***Abeokuta Formation*** contains multiple aquifer horizons and is expected to be high yielding and of general good quality, but further investigation is needed to fully characterise this system within Lagos State. Depending on depth, it may present an economically viable resource for larger-scale abstraction, more likely so in the north of the state where the system is shallower. Due to the ferruginous nature of some sandstone horizons within the formation, there is a risk of elevated iron concentrations, although this can be treated and poses minimal risk to human health.

Whilst a simplified overview of these aquifer systems can be made across the state, due to geological complexity, the UCPS and LCPS aquifers are heterogeneous and display a high level of hydrogeological variability, even at a local scale. Therefore, within this more regional overview, six initial typologies have been identified, reflecting variations between the three main aquifer systems, with each typology presenting differing opportunities and risks. These typologies can be broadly summarized as:

- ***Typology A: Inland Northwest*** describes the aquifer systems in the north-west of Lagos State, from Agege to Ikorodu. It comprises of heavily urbanised and industrialised zones. Groundwater in this region is used for both domestic and industrial water supplies, sourced from shallow wells and a mixture of low-volume motorised boreholes operated by households and high-volume motorised boreholes operated commercially. Both the CPS aquifers and the Abeokuta Formation are utilised in this area, although only industrial boreholes tend to tap from the Abeokuta Formation due to its depth (> 460 mbgl). The alluvium is generally absent, other than in river floodplains. The UCPS here comprises of up to 30 m of sand with intercalated clays and is occasionally semi-confined. Whilst saline intrusion is not evident, localised anthropogenic contamination is apparent within the shallow aquifer. The confined and more sand-dominated LCPS, bearing fresh groundwater, is separated from the UCPS by an up to 60 m thick clay aquitard, and is encountered typically at depths from ~ 70 to ~ 120 mbgl. The Abeokuta Formation is encountered at depths below ~ 450 mbgl, with 10 to 30 m thick sand horizons providing deeper groundwater resources, expected to be fresh and of good quality.
- ***Typology B: Lagos Mainland Urban Centre*** describes the aquifer systems around Lagos mainland's urban centre, from Gbagada to Aguda. It comprises of high population density, heavy urbanisation and industrialization. Groundwater in this region is used for

both domestic and industrial water supplies, sourced from shallow wells and a mixture of low-volume motorised boreholes operated by households and high-volume motorised boreholes operated commercially. Interbedded sands, gravels and clays of the UCPS are found up to depths of 70 mbgl, thinning southward, with evidence of anthropogenic contamination within much of the shallow aquifer across this typology and evidence of saline intrusion towards the lagoon. Here, the LCPS is much better suited for potable water supply systems and is separated from the UCPS by a 10 to 45 m thick clay aquitard, with groundwater generally being fresh and expected to be largely protected from anthropogenic contamination. Found at depths typically below 90 mbgl, water-bearing sand and gravel horizons are typically 6 to 34 m thick and appear to have good potential for abstraction, although localised over-abstraction is evident. The thickness, sand content and productivity of aquifer horizons increases southwards. Information surrounding the Abeokuta Aquifer in this area is unavailable

- ***Typology C: Urbanised Coastal Centre*** covers the aquifer systems along the central coastal belt from Apapa to Lekki, characterized by high population density, urbanization, and industrialization. Groundwater in this region is used for both domestic and industrial water supplies, sourced from shallow wells and a mixture of low-volume motorised boreholes operated by households and high-volume motorised boreholes operated commercially. Overlain by alluvium, the UCPS reaches depths of up to 190 mbgl and consists of 10 to 60 m thick beds of medium to coarse grained sands and gravels, intercalated with clayey sand and clay layers of up to 75 m thickness. Here, the UCPS faces localized anthropogenic contamination and saline intrusion, resulting in borehole abandonment. Small-scale domestic supply relies on a shallow freshwater lens within the UCPS, which risks upconing of saline water if over-exploited, although there is also risk of degraded water quality from anthropogenic sources within this shallow lens. Generally found at depths of below 160 mbgl, the medium to coarse grained sand and gravel aquifer horizons of the LCPS are hydraulically disconnected by the UCPS by a 5 to 15 m thick clay aquitard. Better protected from saline intrusion and anthropogenic contamination, the LCPS is reported to produce fresh water, hence is more suitable for potable water supply and large-scale abstraction. Data from the Abeokuta Formation is lacking, but it is likely too deep for abstraction to be economically viable.
- ***Typology D – Coastal Southwest at Badagry*** describes the aquifer systems across Badagry LGA, a coastal area situated between Lagos City and the Benin border. It comprises an urban centre and surrounding rural communities. Groundwater in this region is predominantly used for domestic supply, sourced from hand-dug wells and motorized boreholes, mainly drawing from the shallow aquifer system (sandy clay alluvium and UCPS), which extends to ~ 100 mbsl. Localised anthropogenic contamination, attributed to the shallow water table is evident, although there appears to be limited evidence of saline intrusion. Found at depths from 300 to 400 mbsl and separated from the UCPS by a ~ 200 m aquitard, the sand-dominated LCPS aquifer system appears more suitable for water supply due to the presence of more extensive sands and is expected to be highly productive with good water quality. The Abeokuta Formation aquifer is found beyond 958 mbgl, making it unsuitable as an economically viable aquifer system in the area, therefore is disregarded within this typology.
- ***Typology E: Lithological Anomaly at Lakowe*** describes the lithological anomaly observed within the aquifer systems between Awoyaya and Lakowe in Ibeju-Lekki, situated between Lagos Lagoon and the coastline, east of Lagos. The area, less developed than the Lagos mainland, Victoria Island, and Lekki, has experienced rapid urbanization in recent years, transitioning into a growing commercial and residential zone. Within this typology, aquifer systems do not appear to be suitable for any significant water supply, due to the UCPS and LCPS being clay dominated. Shallow UCPS sand horizons suffer anthropogenic contamination, whilst deeper sand horizons bear brackish water.
- ***Typology F: Inland Northeast at Epe*** is located in northeastern Lagos, extending from Epe town and Itoikin northward to the border. This area includes both urban and rural zones, with urbanization concentrated around Epe town and near the lagoons. Protected wetlands are increasingly threatened by development, sand-mining and uncontrolled land reclamation. Water usage is for domestic, industrial and agricultural purposes, including

irrigation (cassava, pineapple, rice). Here, the undifferentiated CPS aquifer is clay-dominated, with only thin (~ 5 m) and non-laterally extensive sand horizons, hence only appears suitable for small-scale domestic supply. Found at relatively shallower depths (from 211 mbgl) than the rest of the state, the sandstone horizons of the Abeokuta Formation may be more appropriate for larger-scale abstraction or public water supply and is expected to be highly productive and of good quality. However, further hydrogeological investigation is required, as current data for the area is limited.

Further refinement of these typologies, and their transition zones, are still required for more robust conceptualization of the groundwater system at the state-scale.

Based on the limited available data, within the UCPS and LCPS the overarching trends across Lagos State appears to reflect:

- Increased aquifer thickness from north to south;
- Increased sand content from north to south;
- Increased productivity (yields and transmissivities) from north to south.

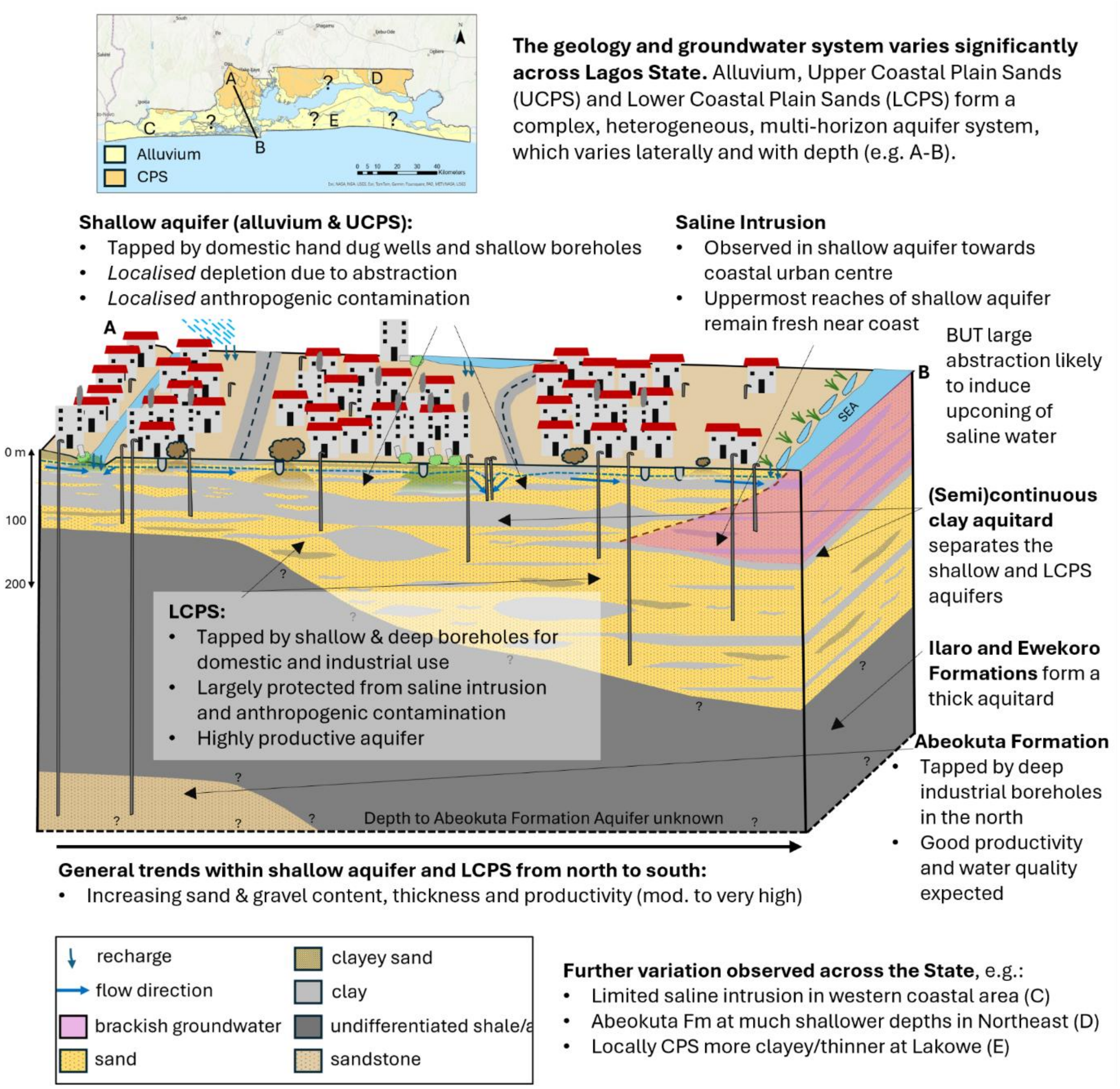

Figure 24: Regional conceptual model for groundwater systems across Lagos State. Please note that this regional conceptual model is an over-simplification of each aquifer-forming formation. Given the highly heterogeneous nature of the system and rapidly changing facies, that localised variations in presence of sand and clay horizons are expected to vary significantly. Basemap: Esri, CGIAR, USGS, TomTom, Garmin, FAO, NOAA, USGS © OpenStreetMap contributors and the GIS User Community. BGS © UKRI 2025.

5.2 UNCERTAINTY

The current understanding is developed from pre-existing literature of varying quality, quantity and reliability, therefore significant uncertainties remain in our conceptualisation of the groundwater systems underlying Lagos State, including:

- **Geological Framework**
  - Given the limited availability of direct lithological logs from drilling records, conceptualisation has relied upon geological logs that have been pre-interpreted from geophysical data. At this stage, the raw geophysical data has not been reinterpreted; therefore, any potential ambiguity of interpretation has not been identified. This creates uncertainty when developing the framework, particularly with regards to a) the true depth and geological composition of key (hydro)geological formations, and b) the extent of the clay layer that separates the UCPS and LCPS.
  - There is a limited spatial coverage of available lithological information, including borehole records or geophysical data, limiting the certainty of inferred typologies. Furthermore, it is not currently possible to fully understand the lateral variations within aquifer systems, the extent of water-bearing horizons, and how the various typologies interact with each other.
  - Around Lakowe, limited pre-existing literature suggests a geological anomaly, either inferred as presence of the Ilaro Formation at much shallower depths due to large scale faulting, or a zone where the LCPS is clay-dominated. Further geological and geophysical data is required to fully define and understand this inferred anomaly.

- **"*Lagos Groundwater Demonstrator*" Monitoring Networks**
  - As groundwater level and quality monitoring efforts are not strategic and widespread, it is possible that zones of concern have not yet been identified, and that observed groundwater level decline or water quality concerns are less localised than currently understood. Monitoring and sampling efforts therefore need to be expanded.
  - Where water level data is available, there is little knowledge of local abstraction regimes, so a complete understanding of how abstraction affects groundwater decline is not currently possible. This is needed to define sustainable limits to future groundwater abstraction.
  - There are uncertainties in the borehole information (particularly elevation available for monitoring sites within the IBADAN monitoring network. Comparisons between surveyed and remote sensed site elevations show deviations of up to 27 m. Future re-surveying of site elevations is planned, using suitably calibrated GPS equipment, to confirm actual elevation for each site, allowing for more reliable validation of water table elevations.
  - For both monitoring networks, borehole records are incomplete (including total depth, screened intervals, geological logs). Therefore, there is a level of uncertainty as to which aquifer horizons are being monitored, particularly for the IBADAN network, where there are no associated total depths, and therefore may be monitoring different aquifer systems.

Recommendations outlined in Section 5.4 aim to tackle these data gaps and uncertainties, improving the existing knowledge base.

5.3 GROUNDWATER FUTURES

Groundwater dominates existing domestic and industrial water supply in Lagos, and has the potential to support increased, strategic abstraction if adequate regulation and management can be implemented. Existing narratives of a forthcoming crisis in groundwater quality and quantity have localised validity. However, based on available evidence, these concerns do not appear accurate at the State level, particularly for the immediate future. It is possible that groundwater studies focused on sites of known contamination risk have provided a platform for a more general negative narrative.

Recharge appears to be maintaining groundwater levels in the face of extensive abstraction across Lagos State, with some evidence of a potential groundwater 'rebound' in key aquifers, although areas of localised over-abstraction remain. Recharge of the various aquifers will be affected by future urbanisation patterns, land use changes and climate change, but the effects of these remain uncertain. The shallow unconfined aquifers (RA and UCPS) are recharged directly through precipitation and secondary recharge across the state. The more confined LCPS is believed to receive recharge from high volumes of rainfall in the north, where the system is at or near the surface. Groundwater then generally flows north to south, demonstrating the reliance of aquifers in the south of Lagos State on maintained recharge in the north. The Abeokuta Formation remains outside of the scope of this report, but recharge of this potentially important aquifer may be focused in areas that lie outside of Lagos State, notably in Ogun State.

Lack of abstraction data limits the certainty with which groundwater futures can be determined. Similarly, in the absence of a more comprehensive monitoring network, the risk of more widespread contamination and abstraction issues cannot be entirely ruled out. The significance of groundwater abstractions for the ongoing economic and social resilience of Lagos State emphasises the imperative of maintaining a comprehensive groundwater monitoring network over time.

5.4 RECOMMENDATIONS

This report compiles current openly available data and literature to update and refine a hydrogeological framework for Lagos State and provide a benchmark of previous efforts undertaken to understand the system. As a result, an initial pathway of future investigation has been identified to allow for current data gaps to be addressed and a more comprehensive understanding of the groundwater systems underlying Lagos State to be developed, including their significant spatial variations.

Given the dependence of Lagos on its groundwater systems **we recommend the implementation of a comprehensive programme of activities designed to safeguard this essential resource into the future**. The proposed programme is designed to establish the resilience of the aquifer systems and identify a sustainable future for groundwater supply across the region. In turn, this will support efforts to site, design and develop boreholes, improve access to drinking water across the state, and support the development of groundwater resource regulation and management strategies.

The four key stages of this programme comprise of:

1) Stakeholder engagement and collation/management of pre-existing data.
2) Development of a robust and targeted groundwater monitoring network.
3) Hydrogeological investigation and refinement of the conceptual model.
4) Improvement of groundwater practice, policy and management to secure future water supplies.

5.4.1 Stakeholder Engagement and Data Collation

Significant additional value could be obtained from existing data to further refine and expand the hydrogeological conceptualisation provided in this report. The collation and analysis of data held by, for example, Lagos Water Corporation and private consultants should be prioritised to prevent duplication of efforts and further refine data gaps, before commencement of any further field investigations.

We recommend that Lagos State initiate a 'Big Conversation on Groundwater', engaging professionals, practitioners, policy officials and the public.

We propose that Lagos State develop a groundwater database that collates available data on groundwater conditions and provides a means to use and display this data in the future to inform groundwater governance and decision-making.

This stage of works would include:

- Stakeholder engagement (from policy makers to groundwater users and the wider public) to build awareness of groundwater resources and encourage its stewardship and sustainable usage. This would form part of a "Love Lagos, Love Groundwater" campaign.

- Quality assessment and compilation of pre-existing data into a well-designed groundwater database.
- Encourage the sharing of borehole records to strengthen knowledge and understanding of the groundwater resource. This could be managed by an independent third-party if such information was deemed sensitive.
- Where possible, open access sharing of groundwater data between stakeholders, including policy makers and groundwater users.

5.4.2 Develop Robust and Strategic Groundwater Monitoring Networks

Recent groundwater monitoring data collected as part of the *Lagos Groundwater Demonstrator* contests the prevalent narrative of significant groundwater depletion, poor water quality and widespread saline intrusion that is often described in literature. Rather, it appears that groundwater depletion, poor water quality and elevated salinity are often localised, rather than statewide.

Collection of both water level and quality data is essential for developing a baseline understanding to inform proactive regulation and management of future groundwater abstraction. Whilst the UNI-IBADAN and UNILAG monitoring networks provide a good first attempt at developing a consistent spatiotemporal understanding of water resource quality and quantity, more strategic and robust monitoring across all aquifer systems is required statewide. This will allow evidence-informed decisions to be made thus reducing the risk of future groundwater degradation and depletion.

We recommend that a robust, strategic and co-ordinated monitoring network is established and maintained across all aquifer systems, ensuring good spatial coverage.

We propose that this should incorporate adoption of the existing UNI-IBADAN and UNILAG network; engage a cadre of committed and knowledgeable borehole owners and extend future data collection at sites with historic monitoring records.

This stage of works would include:

- Improving the pre-existing UNI-IBADAN and UNILAG networks, to fill data gaps and ensure longevity of the monitoring records, as data of longer time-series are invaluable. This may include topographic surveying of monitoring points; down-hole geophysical surveying; borehole camera (CCTV) surveys to understand borehole construction (depths, screened intervals); and hydro-surveys of local boreholes and wells, particularly those abstracting significant volumes.
- Expansion of existing networks to ensure strategic and good spatial coverage state-wide, incorporating both urban/rural zones, inland/coastal areas and transitionary intermediates. Initial expansion efforts could include but not be limited to a) the Alluvium/UCPS within and around Lagos Megacity (**Lagos Mainland Urban Centre** typology; b) the Alluvium/UCPS and LCPS along the central coastal belt from Apapa to Lekki (**Urbanised coastal centre** typology; and c) commence monitoring of water level and quality within the Abeokuta Formation. The eventual aim should be to ensure strategic monitoring of all systems across all typologies.
- Consideration should be made to ensure multiple monitoring points are installed around high-risk zones such as those near to abstraction centres (e.g. heavily urbanised and industrialised zones) and towards the coast where saline intrusion is a risk.
- Monitoring of water level at the sites previously targeted by Kampsax-Kruger (1977) and Coode-Blizard (1996) would allow for a better understanding of how groundwater quantity and quality has changed over the last ~ 30 years, identifying long term water level decline or rebound across the state.
- Assignment of resources and responsibility to ensure ongoing maintenance and use of the monitoring network, ensuring collected data is adequality processed and analysed to help inform decision-making regarding groundwater-fed supply.
- Urgent consideration should be given to initiating an innovative network of groundwater monitoring utilising existing boreholes operated by households and local businesses.

5.4.3 Further Hydrogeological Investigation

This study has identified a number of uncertainties surrounding the characteristics of the aquifers on which Lagos and its population depends.

We recommend that further hydrogeological investigation be undertaken to more fully understand the groundwater typologies occurring in Lagos State and the connectivity of the aquifers.

We propose that the data collated and collected through the first two phases described above should be used to verify, further refine and expand the conceptual model of the Lagos groundwater system, supporting the planning of further investigation.

This stage of works may include:

- Refinement of the geological framework via geophysical surveying and exploratory boreholes.
- Mapping of groundwater levels, flow, and depletion through strategic groundwater level monitoring.
- Development of a water quality baseline and identification of significant contamination hotspots through strategic water quality sampling.
- Determine hydraulic properties, productivity and sustainable yields of aquifer systems, essential for appropriate design and management of groundwater supply networks, through pumping tests.
- Close the water balance by better understanding groundwater recharge and discharge (including installation of rainfall stations and river flow gauges; monitoring abstraction).
- Conduct socioeconomic surveys to gain a better understanding of how groundwater is utilised across aquifer systems by different sectors, particularly the increasing demands on the resource made by private developers.
- Development of a numerical groundwater model, crucial for enabling informed decision-making to ensure the long-term sustainability and resilience of groundwater resources for water supply, with a handover of the model to relevant authorities and decision-makers supporting water-supply efforts across the state. This handover should include capacity building and training of the model recipient to ensure the model can be utilized to its full capability.

5.4.4 Improvement of groundwater practice, policy and management to secure future water supplies

The development of a more robust understanding of the groundwater characteristics of Lagos provides an essential foundation for developing monitoring and management approaches that can secure this resource as a climate-resilient water supply into the future.

We recommend that the critical role played by small-scale abstractors (households, institutions and small businesses) in maintaining functional water supply infrastructure is formally acknowledged and planned for.

We propose that Lagos State adopt a policy of conjunctive water supply, maintaining the long-term inclusion of groundwater-fed supply in areas where quality and quantity is sufficient. A long-term transition towards strategic medium- to large-scale public water supply schemes could be supported in areas where groundwater is suitable for larger scale abstraction. However, support should be provided to small-scale private users of groundwater, at least in the medium term, recognising the critical contribution they make to water security in the State.

This stage of works may include:

- Acknowledge and act upon the need for evidence-informed policy and well-defined governance structures to enable effective management and regulation of groundwater.
- Establish a unit with the capacity to manage and use a groundwater information system, including the adoption of the monitoring network. This unit would take responsibility for the ongoing management and maintenance of monitoring networks, including subsequent

data processing, calibration and analysis, and raise awareness of groundwater conditions within government and across wider publics.

- Following refinement of groundwater typologies identified in this study, and subsequent reduction of associated uncertainties, utilise these typologies to develop areal groundwater management strategies that reflect local contexts. These strategies would consider:
    - Groundwater productivity and vulnerability mapping to highlight zones at risk to contamination, groundwater depletion and over-abstraction.
    - Source protection strategies for small domestic to large public water supplies.
    - Abstraction regulation (licenses, permits) to prevent over-exploitation and adverse spillover effects on other groundwater users.
- Consider opportunities to augment groundwater supplies through the development of managed aquifer recharge schemes.
- Explore models for the engagement of households in the active management of the collective groundwater resource, including as contributors to monitoring networks, groundwater protection zones and aquifer recharge schemes.
- Launch a public awareness campaign on the theme of: “Love Lagos, Love Groundwater”.

Appendix 1 – Aquifer Typologies

NORTHWEST INLAND – ZONE A

Hydrogeological Framework

The alluvium is absent in the north-west. Borehole logs from Longe et al. (1987), Coode-Blizard (1996), and Oladepo et al. (2014) indicate that the interbedded sands and clays of the CPS systems extend to depths of 100 to 120 mbgl, deepening southwards (Figure 25; Figure 26; Figure 27; Figure 28;Table 6). The sands exhibit spatial variability, with some profiles showing lateral continuity while others exhibit pinching of sands or clay dominance (Olaruntola et al., 2019).

The UCPS sands, primarily fine to medium grain-sized, poorly sorted, and intercalated with clay lenses, are generally found between 0 to 30 mbgl, with aquifer thickness ranging from 5 to 22 m. Below 30 mbgl, the system is clay-dominated with only occasional thin sand horizons, typically < 5 m thick, but can reach 10 m. This thick clay-dominated zone (up to 60 m thick) acts as an aquitard, separating the UCPS and LCPS. The LCPS, more sand-dominated, begins around 70 mbgl and consists of poorly to fairly-well sorted, fine to coarse grained sands, intercalated with lenticular clay and clayey-sand lenses (<10 m thick). The sands are typically horizontally and vertically connected between the intercalations of clay. Typically, the base of the LCPS reaches depths of 100 to 120 mbgl.

The CPS is underlain by the Ilaro and Ewekoro formations, consisting of thick shale and argillaceous sediments, extending to depths of 455 to 518 mbgl (Oladepo et al., 2014; Coode-Blizard, 1996). In Ikorodu, the Abeokuta Formation contains sandy horizons (10 to 30 m thick) interbedded with clay and occasional limestone, with continuous sand horizons found below 520 mbgl. However, not all sand horizons are laterally continuous, particularly in the shallower depths.

Aquifer Characteristics

Here the UCPS is unconfined, whilst the LCPS and Abeokuta Formations are confined. Hydraulic properties within both CPS systems are highly variable due to facies changes and spatial heterogeneity. Longe et al. (1987) report moderate productivity for the LCPS in the north-west (Table 5), though less so compared to the southern coastal areas. While no specific data is available, the UCPS in the north-west, is expected to be less productive than the LCPS in this zone.

Table 5: hydraulic properties reported for the LCPS in the north-west of Lagos state (Longe et al., 1987) from a) step-drawdown tests and b) long-term constant rate tests using Theis.

Location	Yield (m^3/hour)	Specific Capacity (m^3/h/m)	Transmissivity (m^2/s x10^{-3})	Permeability (m/s x10^{-5})	Storage Coefficient (x10^{-4})
Agege	54.4	2.96	1.5	7.5	
Shasha	70.8	3.71	2.8 3.9	10	2.5

Groundwater Level and Flow

Both the IBADAN (UCPS) and UNILAG (LCPS) datasets indicate significant variability in groundwater levels across the typology. In the UCPS (IBADAN), monthly average groundwater levels over the past two years ranged from 2.8 to 27.66mASL (0.34 to 27.52 mbgl). Some sites have shown a slight rise in water table levels, while others have experienced decline including during the wet season. These fluctuations suggest the shallow aquifer system is vulnerable to both anthropogenic and climatic influences. For example, whilst the water table is typically stable in boreholes near Agege, a 7.5 m decline in average monthly groundwater levels occurred at Abesan between April and June 2022, the cause of which remains unclear. In contrast, near Ikorodu and Ijede in the east, water table elevation varies significantly, despite similar topographic elevations and proximity to the lagoon, indicating abstraction-related impacts.

In the LCPS (UNILAG) groundwater levels have fluctuated between 10.89 mbsl and 31.82 mASL (18.11 to 40.90 mbgl). At Isheri Mahodo, water table has averaged 9.4 mbsl since 2021, with observed drawdown effects from nearby boreholes, suggesting sensitivity to abstraction here. However, across all sites with 2-year comparisons (October 2022–2024), groundwater levels have generally increased by 1.04 to 3.29 m, suggesting over-abstraction is not a widespread issue, and in fact the LCPS appears to be recharging. While groundwater flow generally follows the topographic gradient toward the lagoon, localised variations in water levels are likely influenced by abstraction-induced cones of depression. Comparison between water level (< 40.9 mbgl) and start depth of LCPS aquifer (> 70 mbgl) indicates the aquifer to be confined at this typology.

Groundwater Quality

Reports of heavy metal, nitrate, potassium, chloride, and E. coli contamination in the UCPS aquifer around Agege and Ikorodu (Adelana et al., 2005; Soladoye, 2014; Soladoye & Yinusa, 2012; Balogun, 2019) suggest that the shallow aquifer is at risk of anthropogenic contamination, similar to other areas across the state. However, these studies also indicate that the aquifer remains unpolluted at many locations, with spatial variability in quality likely influenced by proximity to domestic and industrial contamination sources.

Olaruntola et al. (2019) reported the presence of ferruginous sands in some localities, but the absence of water quality sampling means that the iron content in groundwater remains unconfirmed. Nevertheless, there is a potential risk of geogenic iron contamination, which could impact the taste and color of drinking water in these areas.

IBADAN and UNILAG datasets indicate that groundwater in both the LCPS and UCPS is predominantly fresh, with EC typically < 200 µS/cm (maximum 666 µS/cm). RIGSS data for the UCPS shows most sites with EC < 717 µS/cm, although three sites exhibit brackish conditions (EC 1002–1092 µS/cm) alongside elevated nitrate levels (44.34–53.24 mg/l), suggesting anthropogenic contamination of shallow resources.

Other water quality studies confirm that groundwater in the region is generally fresh (Adelana, 2004; Adelana et al., 2005; Soladoye & Yinusa, 2012; Soladoye, 2014), with only localized areas showing elevated contaminant levels. For example, Soladoye (2014) reported brackish water (EC 1447 µS/cm) at one site within the CPS, where concentrations of nitrate, iron, zinc, and E. coli also exceeded WHO limits.

Water quality information is limited for the Abeokuta Sands, although is expected to be fresh and of good quality. Investigation is required.

Table 6: Summary of fresh and saline water bearing zones across the north-west of Lagos State (Oladepo et al., 2014).

Location	Elevation (mAOD)	Depth of Freshwater Zone (mbgl)	Depth of Saline Water Zone (mbgl)
Lagos Road Waterworks, Ikorodu	114	15-27, 78-83, 96-102, 105-111, 455-474, 520-544, 566-571, 605-627	none
Egan Gram. School, Egan	19	81-96, 114-129, 132-141, 146-164	none
Iron Market, Igando	66	14-32, 34-39, 46-62, 70-76, 88-93, 106-116	none
Ikeja W/works, Ikeja	64	29-32, 40-48, 74-80, 86-88, 90-96, 104-108	none
Cadbury, Ogba	44	57-62, 65-72, 77-80, 82-100	none
Guiness, Agidingbi	65	14-25, 30-36, 52-60, 82-108	none

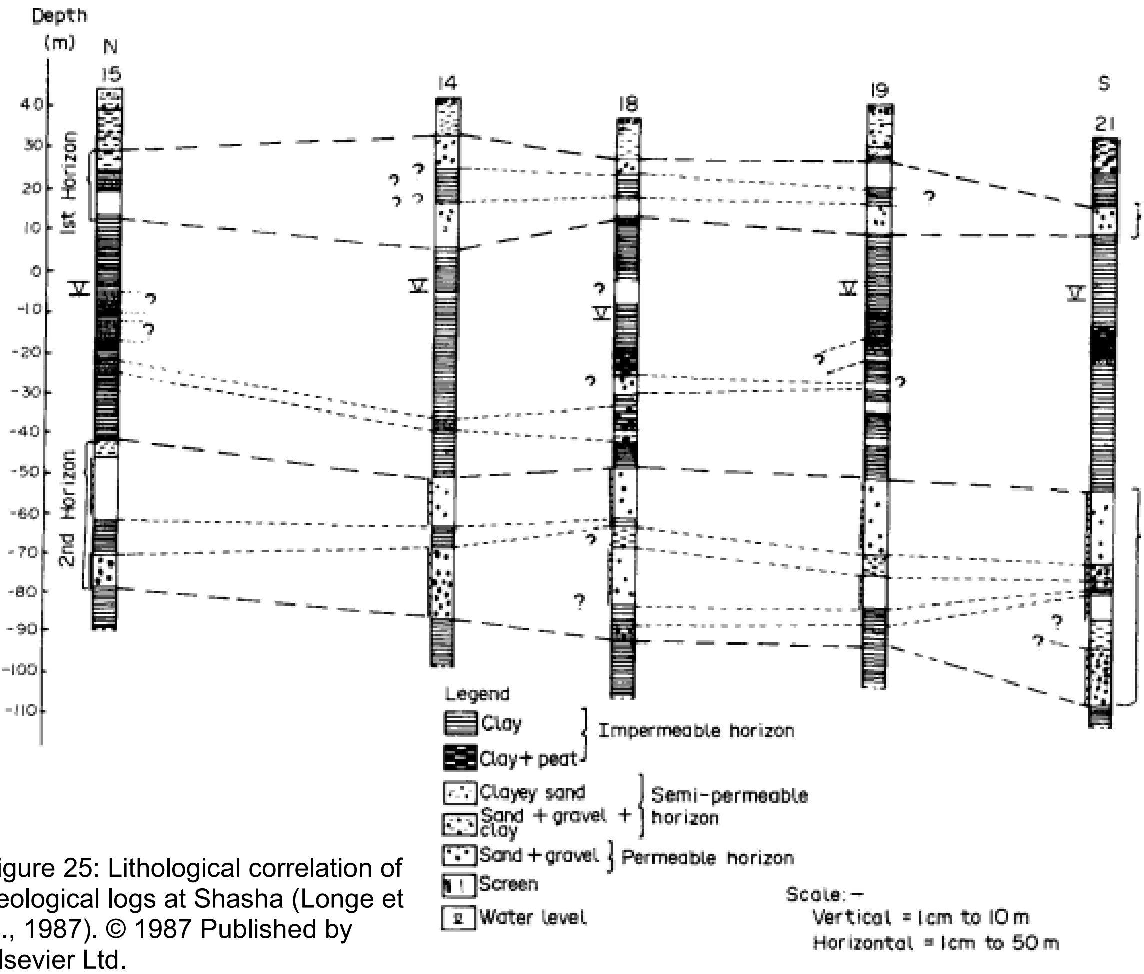

Figure 25: Lithological correlation of geological logs at Shasha (Longe et al., 1987). © 1987 Published by Elsevier Ltd.

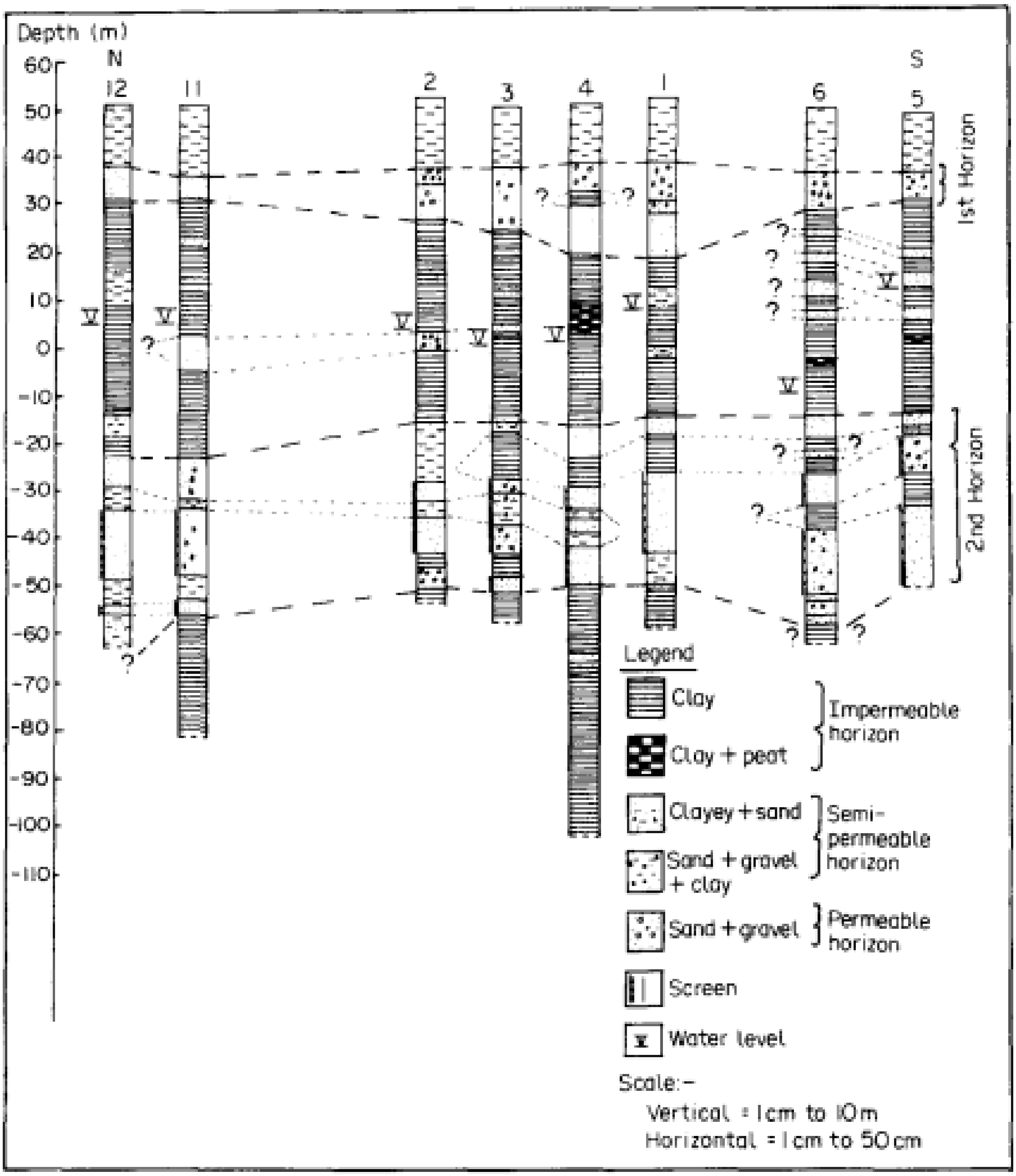

Figure 26: Lithological correlation of geological logs from Agege (Longe et al., 1987). © 1987 Published by Elsevier Ltd.

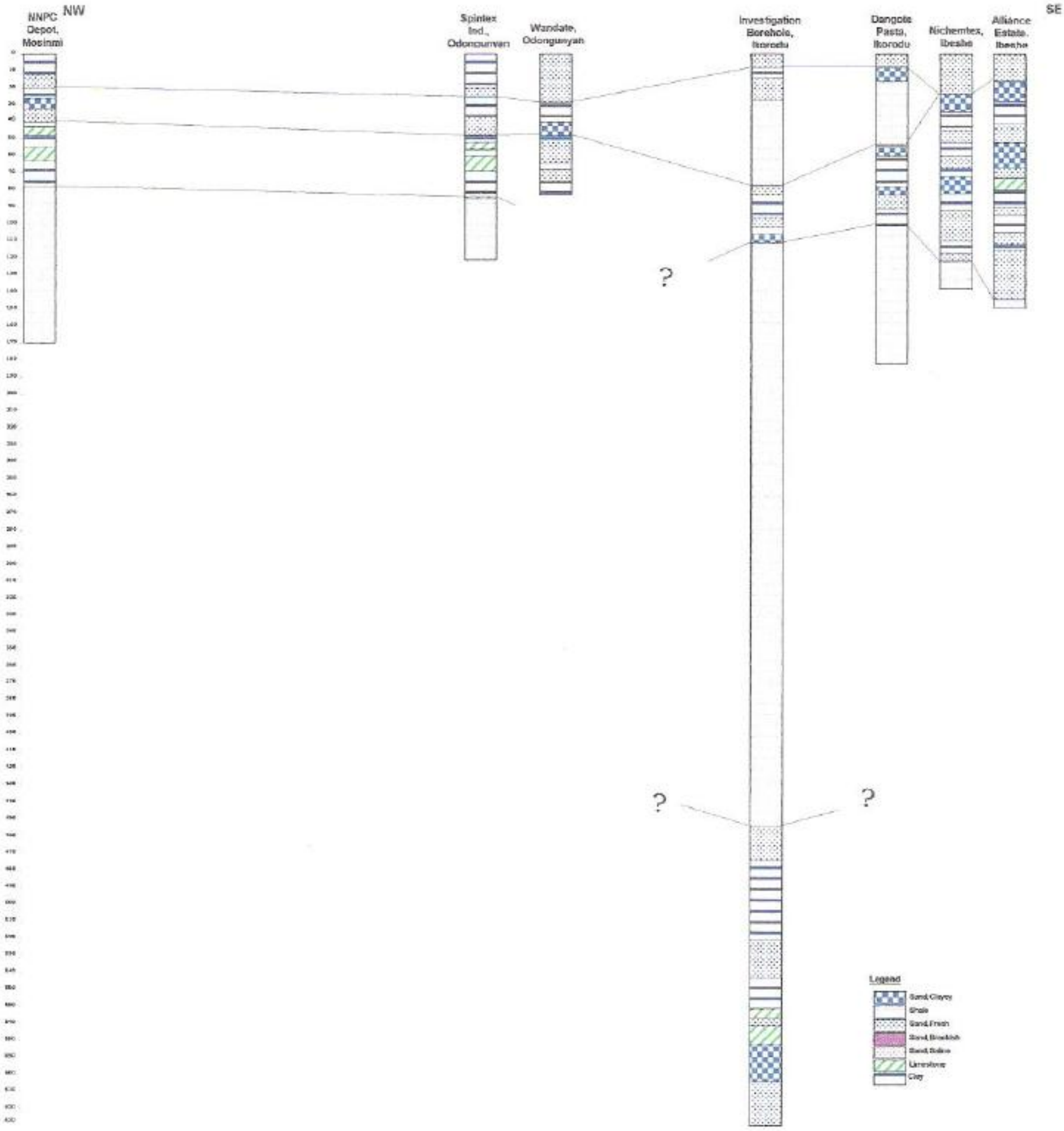

Figure 27: Geo-section from Mosinmi to Ibeshi, through Ikorodu (central deepest log) (reproduced from Oladepo et al., 2014. © 2014 Academic Journals, Licensed under the CC BY 4.0 license).

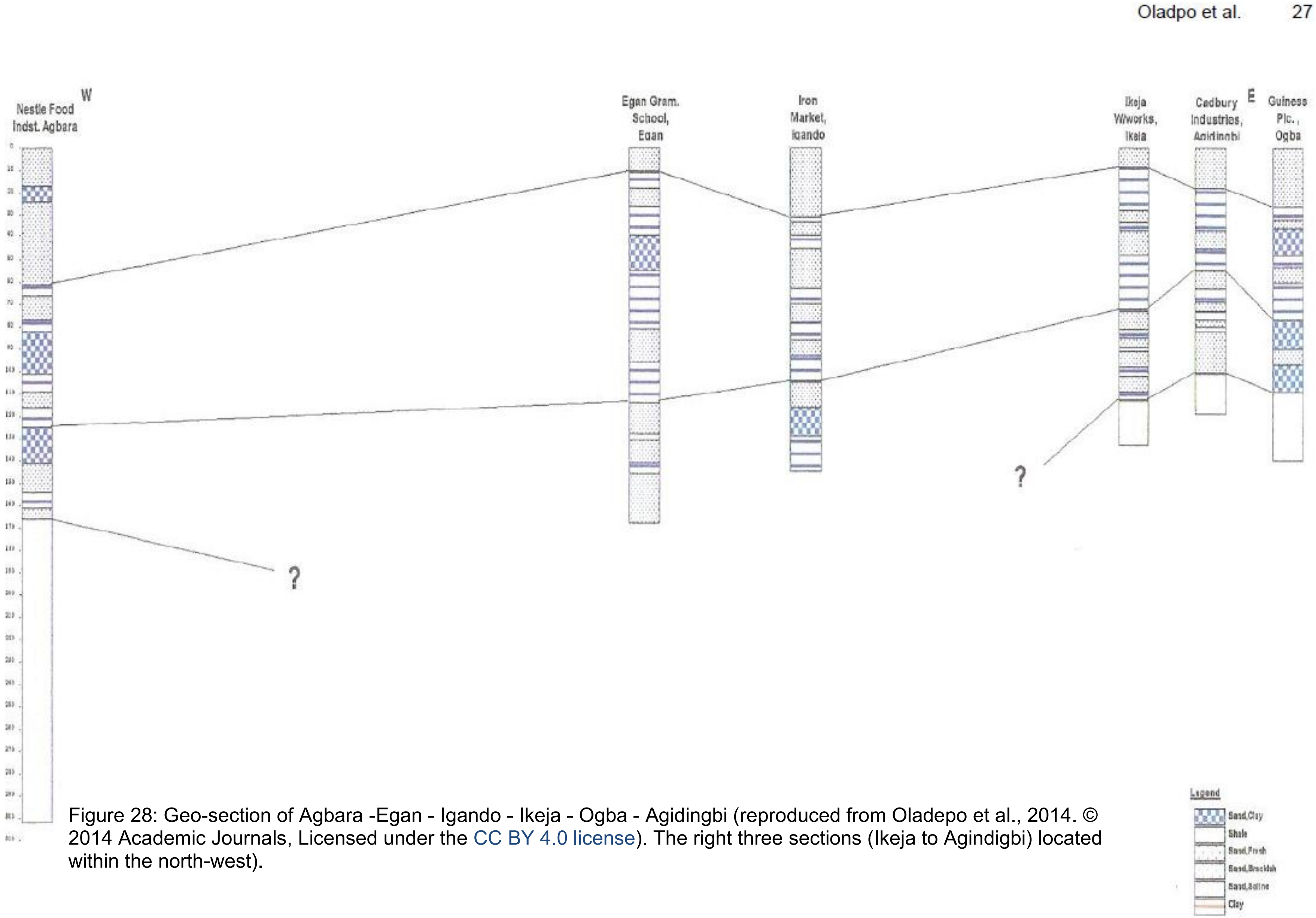

Figure 28: Geo-section of Agbara -Egan - Igando - Ikeja - Ogba - Agidingbi (reproduced from Oladepo et al., 2014. © 2014 Academic Journals, Licensed under the CC BY 4.0 license). The right three sections (Ikeja to Agindigbi) located within the north-west).

LAGOS MAINLAND URBAN CENTRE – ZONE B

Hydrogeological Framework

Aquifer behaviour across Lagos Mainland varies due to spatial inconsistency in sand and clay layers, as shown by geological logs (Figure 29; Figure 30; Figure 31; Figure 32; Longe et al., 1987; Longe, 2011; Oladepo et al., 2014). Alluvium is present in the east and south, typically associated with 10 to 30 m thick clay or clayey sands (Longe et al., 1987; Longe, 2011). In some areas, a 5 to 10 m sand layer overlies these clayey units (Oladepo et al., 2014).

The UCPS aquifer is semi-confined, extending to depths of 60 to 70 mbgl, consisting of interbedded sands and clays, with total thickness varying from 20 to 60 m, thinning southwards. The system has more sand content than Typology A in the north, though clay layers vary in extent, from thin minor lenses to more extensive beds. Two extensive clay beds are logged at Shomolu (Figure 29; Figure 30; Longe et al., 1987; Longe, 2011) with one appearing to continue southwards to Aguda. The UCPS functions as a multi-aquifer system, with poorly sorted sands and gravels, and fine to coarse sands in the shallowest reaches at Shomolu (Longe et al., 1987; Oladepo et al., 2014).

Beneath the UCPS lies a clay aquitard, separating it from the LCPS, terminating between 85-100 mbgl. The aquitard thickness varies from 10 to 45 m, thinning southwards. Minor, non-laterally extensive sand horizons (< 5 m) are found within this clay layer. In the north-west of Shomolu, a second thick clay layer underlies the aquitard, extending to 140 mbgl (Longe et al., 1987; Longe, 2011). The layer is separated from the main aquitard by a 5 to 10 m sand horizon which thickens to the southwest and appears to demarcate the commencement of the LCPS across the remainder of the typology.

Aside from north-west Shomolu, the confined LCPS aquifer typically extends from depths of 90 mbgl, although the upper boundary may be as deep as 106 mbgl in Bariga. It comprises of interbedded sand, clay, and peat, forming a multi-horizon system with a higher sand content than the UCPS. Bed thickness ranges from 6 to 34 m and grain size is coarse. Total aquifer thickness increases southward, while clay and peat layers are thinner (<10 m) and less frequent than in the UCPS. By Aguda most boreholes typically screen the LCPS as the UCPS there is much less significant.

The LCPS's full extent is uncertain across this typology, as some logs terminating at 220 mbgl show sand (Oladepo et al., 2014), while others indicate clay (Longe et al., 1987), necessitating further investigation. There is no data on the Abeokuta, Ilaro, or Ewekoro Formations in this region.

Aquifer Characteristics

Hydraulic information is of limited availability. As with the rest of the state, the hydraulic properties across both systems will vary spatially, due to variable thickness of water-bearing horizons and changing lithologies. Within the UCPS at Shomolu, Longe (2011) reported transmissivity to range from 224 to 2333 m^2/day and specific capacity from 5.5 to 32.2 m^3/h/m, recording yield from 62 to 100 m^3/h across 6 boreholes. This suggests that despite the clay-rich nature of the system, the aquifer is still very productive.

Longe et al. (1987) performed pumping tests targeting the LCPS at one borehole in Shomolu and one in Aguda (Table 7), indicating a productive aquifer system with good potential for abstraction. Although limited, results suggest southerly-increasing transmissivity and yield, which corroborates with the idea of the LCPS system thickening southwards, along with sand content.

Table 7:Average value of aquifer characteristics reported by Longe et al (1987) from a) step-drawdown tests and b) **long-term constant rate tests using Theis (in bold).**

Location	Yield (m^3/hour)	Specific Capacity (m^3/h/m)	Transmissivity (m^2/day)	Permeability (m/s x10^{-5})	Storage Coefficient (x10^{-4})
Shomolu	80.1	14.9	2315.52 **1900.8**	37	**4.9**
Aguda	97.2	28.6	5115.52 **2571.72**	245.8	**3.8**

Groundwater Level and Flow

No up-to-date water level data is available for the UCPS in this region, but it is assumed to be shallow, as is typical across the state. Evidence of saline intrusion from Lagos Lagoon (see *Groundwater Quality*) suggests reversed pressure gradients and potentially significant drawdown at abstraction points. Careful management is needed to prevent further saline intrusion.

The UNILAG dataset for the LCPS aquifer shows the average monthly water table near or below sea level since April 2021, ranging from 4.9 masl to 13.73 mbgl. Despite concerns of over-abstraction and observed cones of depression below 10 masl in areas like Itire Ikate and Isolo, groundwater levels have increased over the past two years, indicating recharge still exceeds abstraction and the resource does not appear to be suffering from depletion.

Groundwater Quality

Across this zone, the UCPS is experiencing significant issues with anthropogenic contamination compared to the rest of the state, likely due to heavy urbanisation and industrialisation. A variety of contaminants have been reported to exceed WHO and NSDWQ limits across the zone, including EC, TDS, E. Coli, fluoride, ammonia, nitrate, arsenic, copper, zinc, nickel, lead, iron, manganese, aluminium, potassium, chromium, hydrogen sulphide and cadmium (Adelana et al., 2004; Adelana et al., 2005; Afolabi et al., 2012; Soladoye & Ajibade, 2014; Balogun et al., 2019; Ferreira et al., 2023), although these studies do also indicate not all sites pose this contamination. The high concentrations of contaminants have been attributed to landfill leachate infiltration, sewage and wastewater (Afolabi et al., 2012; Balogun et al., 2019; Ferreira et al., 2023).

It is possible that towards Aguda, where thick clays overly the UCPS, there may be some level of protection from surface pollution. However, this needs further investigation. Whilst there are localised zones of good water quality, even in proximity to potential contamination sources (Ferreira et al., 2023), the system here can generally been deemed a high-risk source of water supply with regards to adverse effects on human health.

Evidence of iron contamination (0.45 to 5.62 mg/l) has also been reported across Shomolu and Aguda (Longe et al., 1987), where other contamination was not evident, which may suggest a geogenic source and attributed to ferruginous coatings on sand grains.

Whilst the IBADAN dataset does not cover the area, literature indicates groundwater salinity across the UCPS varies across this zone, from 93 µS/cm (fresh) to 2480 µS/cm (brackish) (Adelana et al., 2004; Adelana et al., 2005; Balogun et al., 2019), with logs from Oladepo et al. (2014) suggesting brackish water at some locations and fresh at others. However, the mean EC is fresh across studies that do identify brackish groundwater (Adelana et al., 2004; Adelana et al., 2005; Balogun et al., 2019), and some studies identify EC as fresh at all sites (Ferreira et al., 2008; Soladoye & Ajibade, 2014), suggesting that most localities do produce fresh groundwater. The cause of salinity can be attributed to both anthropogenic contamination and saline intrusion, although it is likely to be more commonly caused by the former. Many instances of high EC do appear to be associated with studies that display elevated concentrations of heavy metals, nitrates etc (Adelana et al., 2004; Balogun et al., 2019). At the University of Lagos, geophysical mapping of saline intrusion up to depths of 50 m within the UCPS, sourced from Lagos Lagon and brackish creeks has been identified (Ayolabi et al., 2013).

As with the majority of the state, the LCPS is expected to be protected from anthropogenic contamination and poor water quality by the overlying thick clay, aquitard, although limited information is available. Oladepo et al. (2014) report that the LCPS is fresh water bearing, even at sites where the UCPS sands are producing saline water. EC is fresh (< 450 µS/cm) at all UNILAG monitoring sites across this zone, apart from Bariga, located on the shore of Lagos Lagoon. Investigation at Bariga is limited, with only three records of EC over the entire monitoring period, with EC values ranging from 1246 to 2446 µS/cm indicating a brackish salinity. There is a level of uncertainty surrounding this site. Notably, Bariga is one of the three UNILAG sites without recorded borehole depth, raising the possibility that it may monitor the UCPS rather than the LCPS. Alternatively, the observed salinity could result from contamination between the UCPS and LCPS due to poor borehole construction. Further investigation is required.

Table 8: Saline and fresh-water zones of the groundwater systems from Satellite Town to Ikorodu (Oladepo et al., 2014). Sections spanning from Mile 2 to Bariga are relevant for Zone B Typology.

Location	Elevation (mAOD)	Depth of Freshwater Zone (mbgl)	Depth of Saline Water Zone (mbgl)
Silcas Ind. Satellite Town	23	82-94, 96-104	0-80
FESTAC Estate, Mile 2	31	18-32, 40-50, 56-64, 66-94, 106-118	None
Cadoso Ind., Kirikiri	27	100-110, 120-132, 134-144, 149-156	0-92
Ijora Badia BH1, Ijora	17	62-68, 72-92	0-54
Nigerian Breweries, Iganmu	23	58-88, 96-128, 152-160, 166-180, 188-194, 198-212	0-40
Surulere w/works, Surulere	49	32-40, 54-66, 84-95, 100-106, 138-198, 194-206	None
Bariga w/works, Bariga	37	14-20, 40-56, 106-114, 122-138, 144-160	None
Lagos Road w/works, Ikorodu	115	15-27, 78-83, 96-102, 105-111, 455-474, 520-544, 566-571, 605-627	None

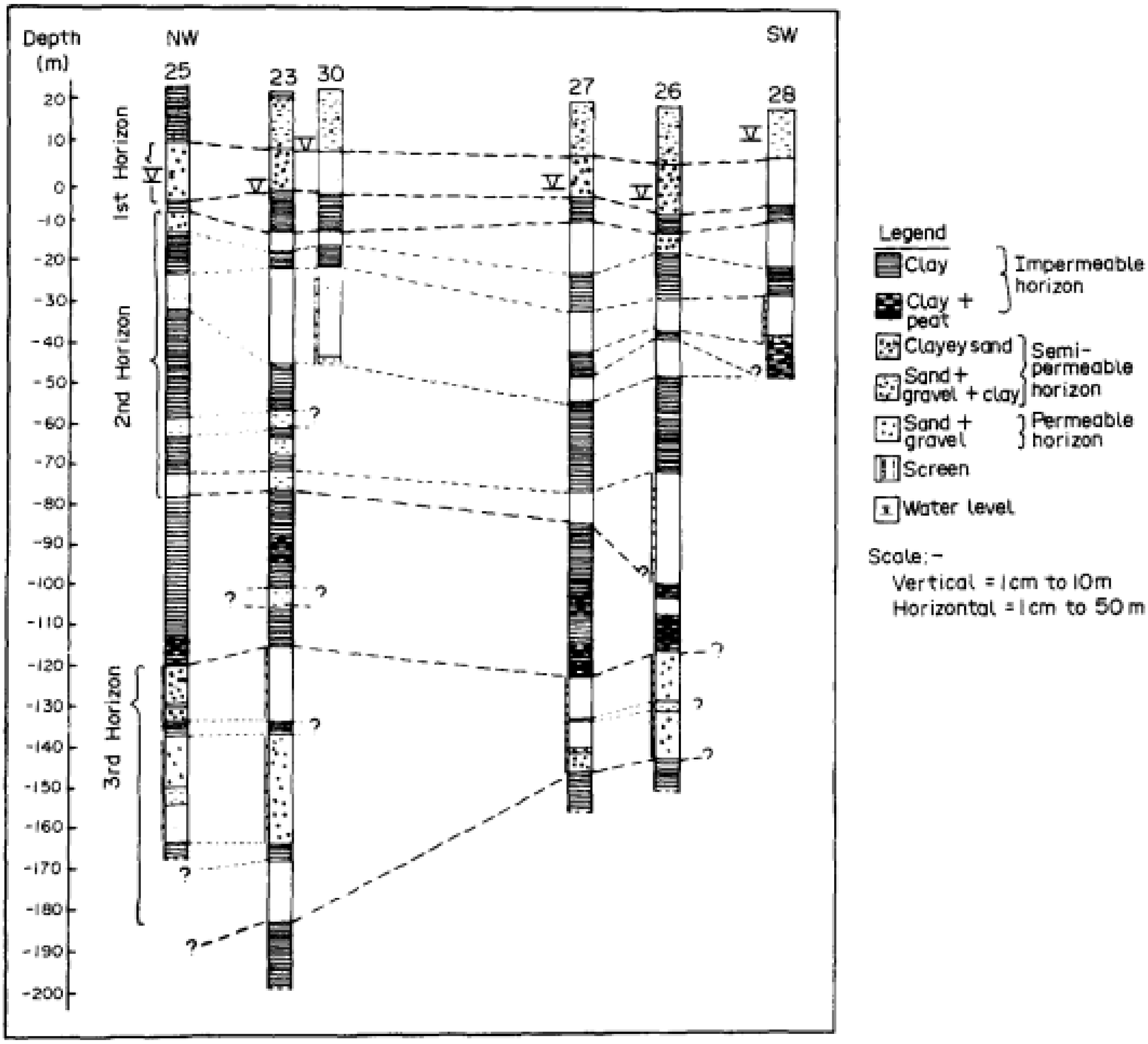

Figure 29: Lithological logs and correlations across Shomolu (Longe et al., 1987). © 1987 Published by Elsevier Ltd.

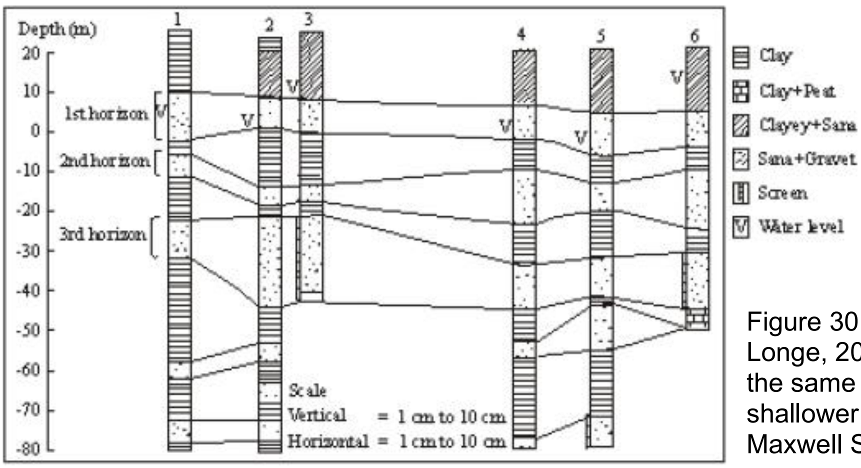

Figure 30: Lithological logs (correlated) from Longe, 2011) for Shomolu. These appear to be the same logs as Figure 1, terminated at shallower depths, focusing on the UCPS. © Maxwell Scientific Organization, 2011.

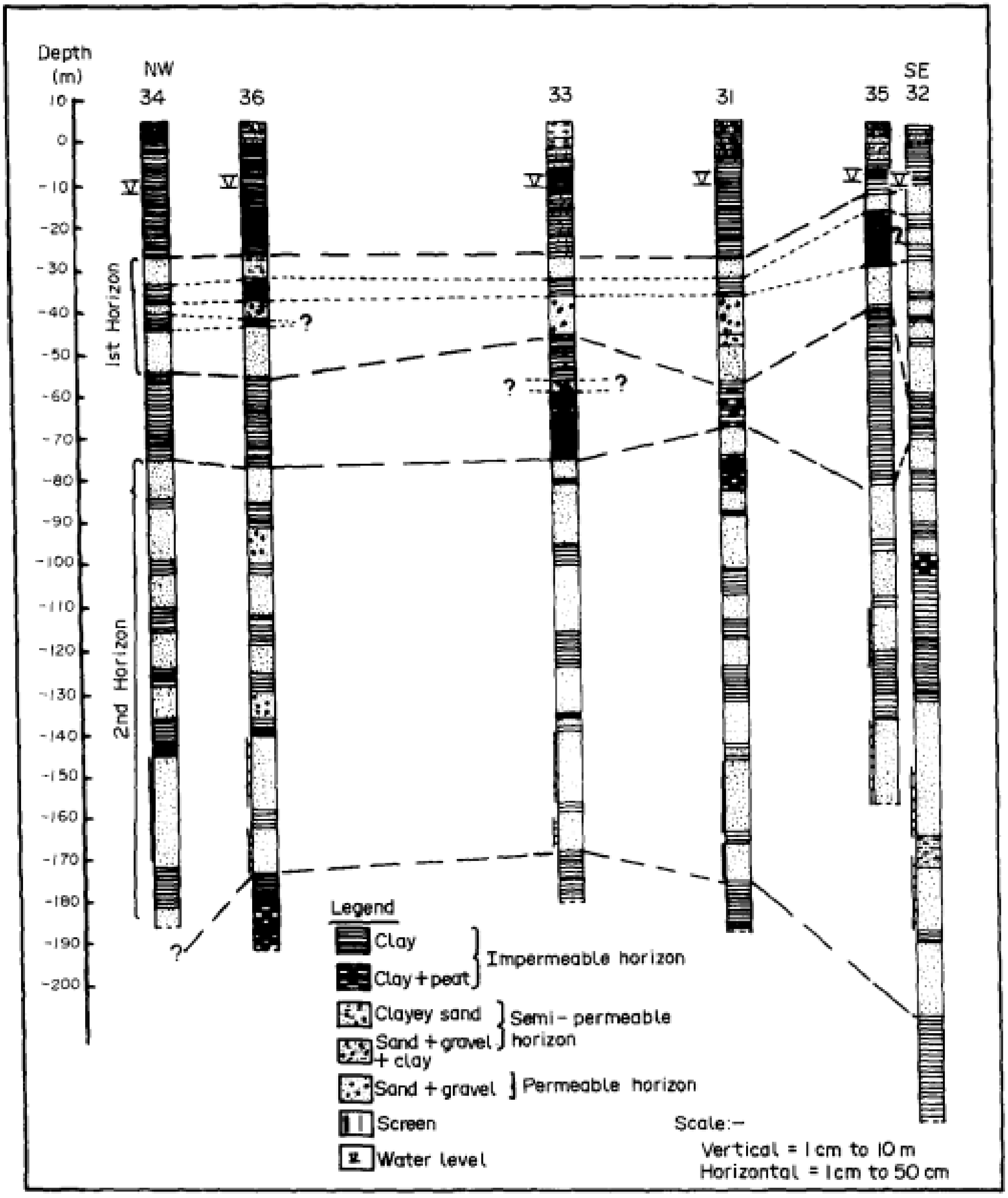

Figure 31: Lithological logs and correlations across Aguda (Longe et al., 1987). © 1987 Published by Elsevier Ltd.

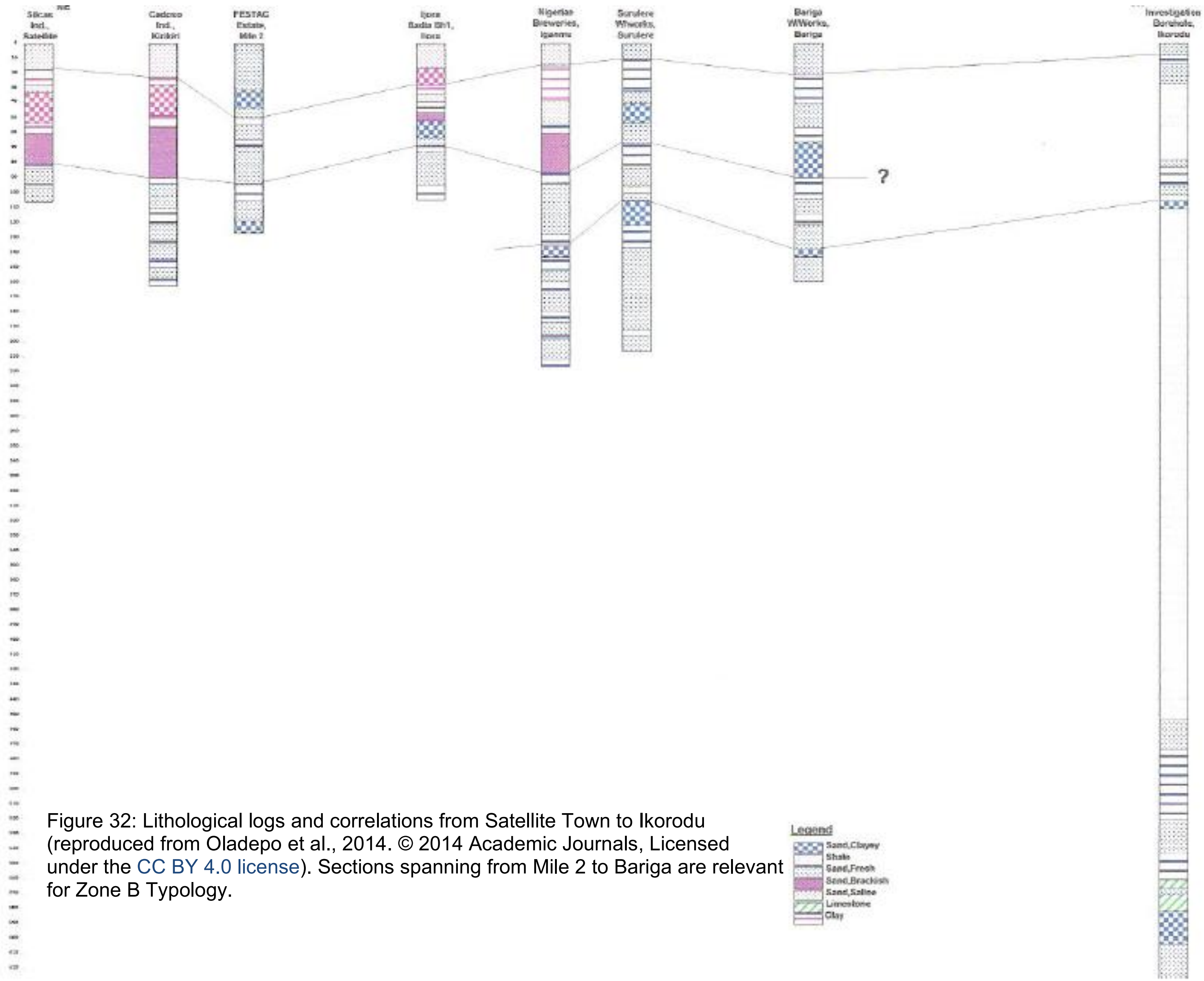

Figure 32: Lithological logs and correlations from Satellite Town to Ikorodu (reproduced from Oladepo et al., 2014. © 2014 Academic Journals, Licensed under the CC BY 4.0 license). Sections spanning from Mile 2 to Bariga are relevant for Zone B Typology.

CENTRAL COASTAL URBAN CENTRE – ZONE C

Hydrogeological Framework

Focused investigations (Longe, 1987; Coode-Blizard, 1996; Aladana et al., 2008; Oladepo et al., 2014; Adalejana et al., 2020) have produced numerous geological logs (Figure 33; Figure 34; Figure 35) and descriptions (Table 9) of the coastal stretch from Apapa to Ajah. Minor studies are also available, for example, Ola et al (2008) identified seven horizons (10 to 45 m thick), with the top four within 126 mbgl, and three deeper. These studies indicate the UCPS and LCPS systems to consist of multiple sand horizons intercalated with continuous and non-continuous clays, with varying thickness and depth. Sand content and horizon thickness are notably greater here than in other areas of the state.

Table 9: Geological descriptions across Zone C (Coode-Blizard, 1996). Italics indicates inferred formation.

Badore		Lekki (2 x BH)	
Depth (mbgl)	**Lithology**	**Depth (mbgl)**	**Lithology**
0 to 54	Clay	0 to 155	Thick sand and gravel, underlain by clay at unreported depth (Alluvium/*UCPS*)
54 to 124	Med-coarse sand and gravel (*UCPS*)	156 to 291	Thick sand and gravel separated by thin clays (*LCPS*)
124 – 148	Clay with thin sand horizons (*aquitard)*	291 to 330	Clay (*Ilaro*)
148 to 196	Very fine sands (*LCPS)*		
196 to 237	Fine silty sand (*LCPS*)		
237 to 325	Clay and fossiliferous shale (*Ilaro*)		

Geological mapping indicates alluvium covers the UCPS, but it is not differentiated in geological logs and is thus grouped with the UCPS as part of the shallow aquifer. The UCPS depth increases southward and eastward, from 124 to 190 mbgl, generally reaching depths of 140 to 160 mbgl (Longe et al., 1987; Coode-Blizard, 1996; Oladepo et al., 2014). The aquifer consists of poorly to moderately sorted medium to coarse-grained sand and gravel (fining upwards), with thicknesses ranging from roughly 10 to 60 m. These are intercalated with clayey sand and clay layers of variable thickness (~5 to 75 m) and continuity.

A ~5 to 15 m thick clay aquitard separates the UCPS and LCPS, acting as the boundary between the brackish and freshwater-producing sands.

The LCPS generally has a higher sand-to-clay ratio than the UCPS, though sand quality varies across the typology (e.g., very fine and fine-silty at Badore to medium-coarse sand and gravel at Lekki Phase I and Apapa). Sand horizons range from ~5 to 45 m in thickness, while clays and clayey sands range from ~2 to 25 m (typically <10 m). The LCPS base varies from 237 m at Badore to 290 m at Lekki Phase I, but many logs terminate within sand horizons at 280 mbgl, suggesting the LCPS may extend deeper.

There are minor contradictions to the general behaviour of the LCPS. Aladejana et al. (2020) reported significant clay and peat horizons from 125 to 350 mbgl at Apapa, where the freshwater aquifer of the LCPS is typically found, with only a minor (~20 m) sand horizon. However, this is not observed in Apapa logs from Oladepo et al. (2014) or Longe et al. (1987), suggesting it is a localized anomaly rather than a typical aquifer characteristic.

Aquifer Characteristics

There are not specific reports of hydraulic properties for either aquifer system in the south of the state, although they are assumed to be highly productive, due to greater aquifer thickness and sand content in the south of the state.

Groundwater Level and Flow

Neither the RIGSS, IBADAN or UNILAG datasets cover this heavily urbanised coastal belt, and there are no recent studies providing groundwater level or flow information. It is expected that the water table remains shallow for the UCPS and that the LCPS is confined and semi-artesian. Recharge to the system will typically be through precipitation (~ 2000 mm/year) and surface water bodies (e.g. Lagos Lagoon, Apapa Lagon, rivers, creeks and the wetlands), although due to impermeable urban cover across much of the zone, recharge may be limited.

Groundwater Quality

Neither the RIGSS, IBADAN or UNILAG datasets cover this heavily urbanised coastal belt.

Numerous studies have identified a brackish-saline groundwater belt within the UCPS from Apapa to Ajah, representing saline intrusion induced by reversed-pressure gradients from over-abstraction of the coastal aquifer, (DEPA, 1998; Oteri and Atolagbe, 2003; Ola et al., 2008; Olufemi et al., 2010; Babatunde, 2012; Oyeyemi et al., 2015; Akinlalu & Afolabi, 2018; Jimoh et al., 2018; Adiat, 2019; Popoola et al., 2020). The upper fresh-saline interface is typically shallower than 70 mbgl, while the lower interface is generally below 150 to 160 mbgl (Akinlalu & Afolabi, 2018; Adiat, 2019). However, these depths vary regionally, with the upper interface ranging from 20-100 mbgl and the lower from 110 to 190 mbgl, deepening southwards and eastwards (Ola et al., 2008; Oladepo et al., 2014; Akinlalu & Afolabi, 2018; Jimoh et al., 2018). For example, Akinlalu and Afolabi (2018) reported the brackish-freshwater interface at Lekki to range from 160 to 162 m in the north to 164 to 166 m in the south, and at Ikoyi and Victoria Island, the interface ranges from 90 to 111 m in the north to 134 to 156 m in the south. Freshwater should typically be found below 126 mbgl at Lagos Island (Ola et al., 2008), 136 mbgl at Apapa (Oladepo et al., 2014), 154 mbgl at Victoria Island (Oladepo et al., 2014; Akinlalu & Afolabi, 2018), 148 mbgl at Ikoyi (Oladepo et la., 2014; Akinlalu & Afolabi, 2018), 160 mbgl at Lekki (Oladepo et al., 2014; Adiat, 2019) and 190 mbgl in Ajah (Oladepo et al., 2014).

Within the main saline lens, smaller freshwater lenses have been identified (Oydele & Meshida, 2004; Adiat, 2019). These freshwater lenses can occur at any depth between 17 and 112 m within the UCPS (Oydele and Meshida, 2004; Oladepo et al., 2014). These spatial variations are attributed to high heterogeneity of clay and sand horizons and complex geology, as well as variations in abstraction and therefore hydraulic gradients and degree of saline induction; hence the location of the saltwater lens may vary across the coastline. Whilst freshwater is typically found within the shallowest reaches of the UCPS, it is typically not suitable for extraction due to upconing risks (Oteri & Atolagbe, 2003), though it may be the only accessible freshwater drinking source for some communities.

Aside from the saline intrusion affecting the UCPS, there are reports of concentrations of faecal coliforms, E. Coli, nitrate iron, lead, zinc, arsenic, nickel, copper, manganese, cadmium, chromium, magnesium exceeding WHO or NSDWQ limits (Soladoye, 2014; Sogbanmu, 2020; Ajani et al., 2021; Akerele et al., 2023; Ezechinyere and Stanislaus, 2023), pointing to anthropogenic contamination from industry and domestic waste. Therefore, even freshwater lenses are at risk of poor water quality, with sources of contamination linked to polluted surface water, seepage from storage tanks, oil wells, septic tanks, landfills, and agricultural runoff (Adewuyi et al., 2010).

Despite the significant saline intrusion of the UCPS, the LCPS produces freshwater, generally from depths below 160 mbgl (Kampsax-Kruger, 1977; Oyadele & Meshida, 2004; Oladepo et al., 2014; Akinlalu & Afolabi, 2018; Adiat, 2019). This is attributed to a continuous clay aquitard beneath brackish zone, with groundwater fresh below this. Successful drilling typically targets below 200 m (Oyadele & Meshida, 2004). No further water quality information is available for the LCPS system.

Table 10: Intercepted fresh and saline water zone depths across this typology (Oladepo et al., 2014).

Location	Elevation (mAOD)	Depth of Freshwater Zone (mbgl)	Depth of Saline Water Zone (mbgl)
Niger Biscuit, Apapa	4	148-159, 162-183, 192-238, 246-258, 264-270, 274-280	0-125
Sugar Indsutries 1, Apapa	6	149-159, 162-184, 208-226, 232-236, 239-248	0-136
Tarkwa Bay Island, Apapa	10	148-155, 158-168, 171-179, 182-186, 188-193, 206-226	0-130
Ikoyi BH1 w/works, Ikoyi	15	161-174, 179-190, 193-204, 215-224, 228-246, 253-259, 261-276	0-138
Dolphin w/works, Ikoyi	5	137-152, 154-162, 169-180, 187-192, 195-214, 218-224, 229-250	0-131
Parkview Estate, Ikoyi	8	156-165, 171-178, 189-198, 201-215, 217-222, 230-235, 240-245	0-138
Osborne Estate, Ikoyi	5	164-172, 176-193, 202-208	0-148
IBTC, V/Island	20	154-191, 203-213, 215-219, 222-242	0-144
Eko Hotel BH4, V/Island	19	153-193, 194-208, 214-237	0-144
Akingbade Close, V/Island	18	148-174, 176-198. 208-220, 224-242	0-140
Femi Okunnu	27	182-129, 206-224	0-140

Estate, Lekki			
Seed Education, Lekki	15	166-188, 192-196, 198-232	0-158
Victoria Garden City Estate, Ajah	17	30-40, 136-141, 152-155, 179-188, 193-212, 217-234	56-116
Royal Garden Estate, Ajah	17	46-50, 57-88, 102-108, 114-136, 190-218, 223-242, 245-252	None
Model College, Badore	31	40-48, 54-64, 76-112, 118-124, 144-154, 180-196	None
Coop Villa BH1, BAdore	28	12-17, 20-24.8, 155-166, 173-186, 188-202	None
Coop Villa BH2, BAdore	27	13-20, 62-70, 150-164, 176-188, 196-202	None

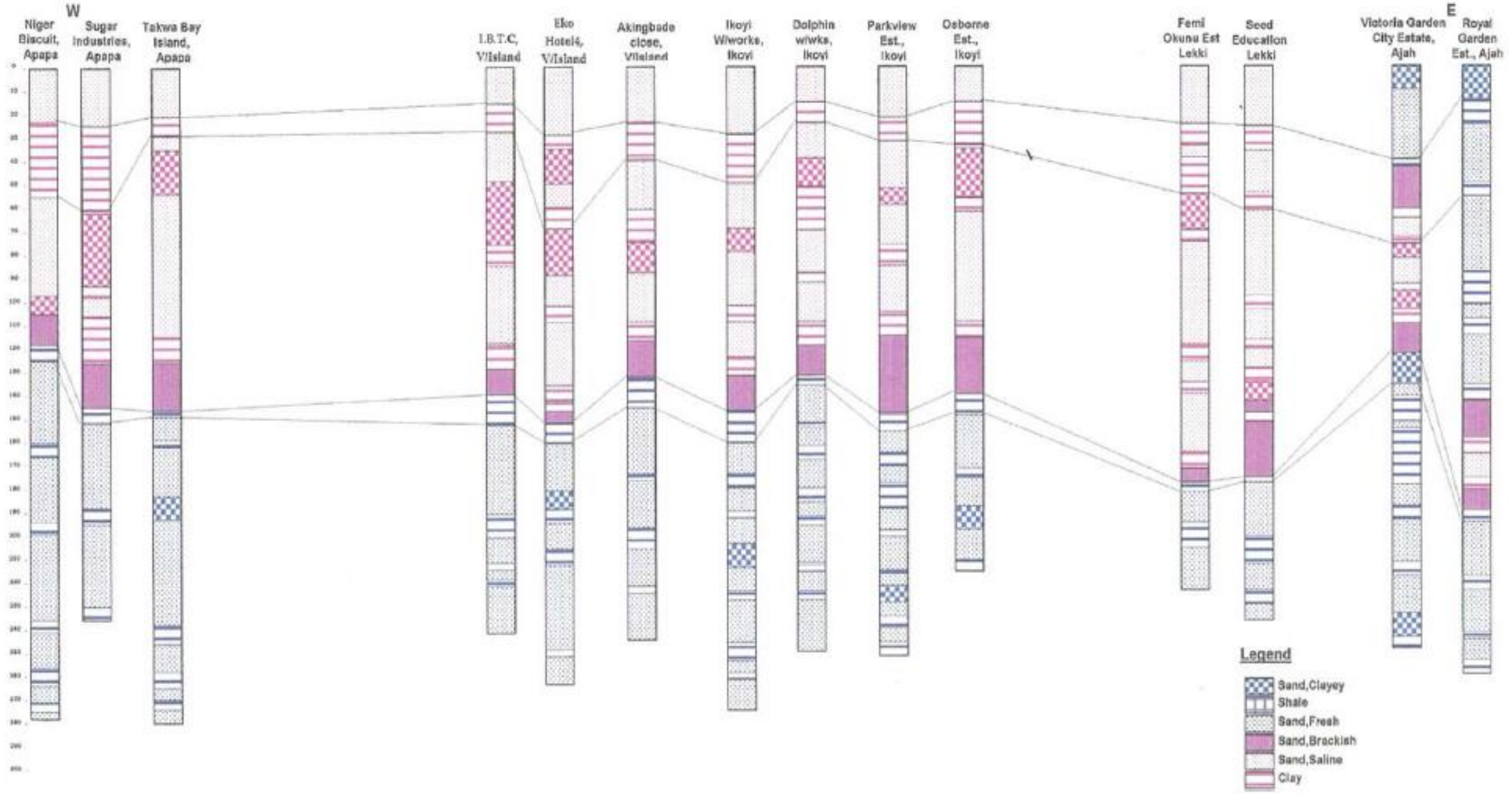

Figure 33: Geo-section from Apapa - Ikoyi - Victoria Island - Lekki - Ajah (reproduced from Oladepo et al., 2014.).

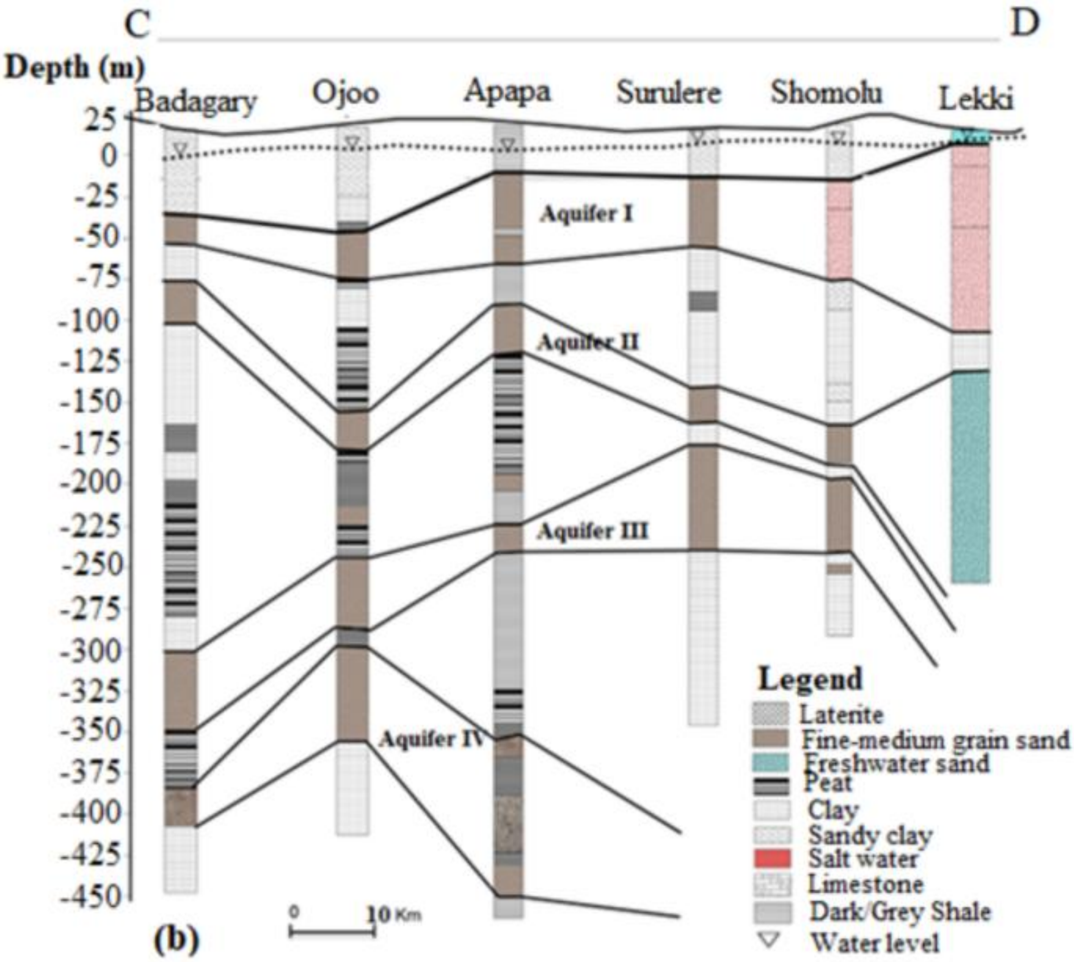

Figure 34: Geological logs across Lagos State coastal belt from Aladejana et al. (2020a). Licensed under the CC BY 4.0 license.

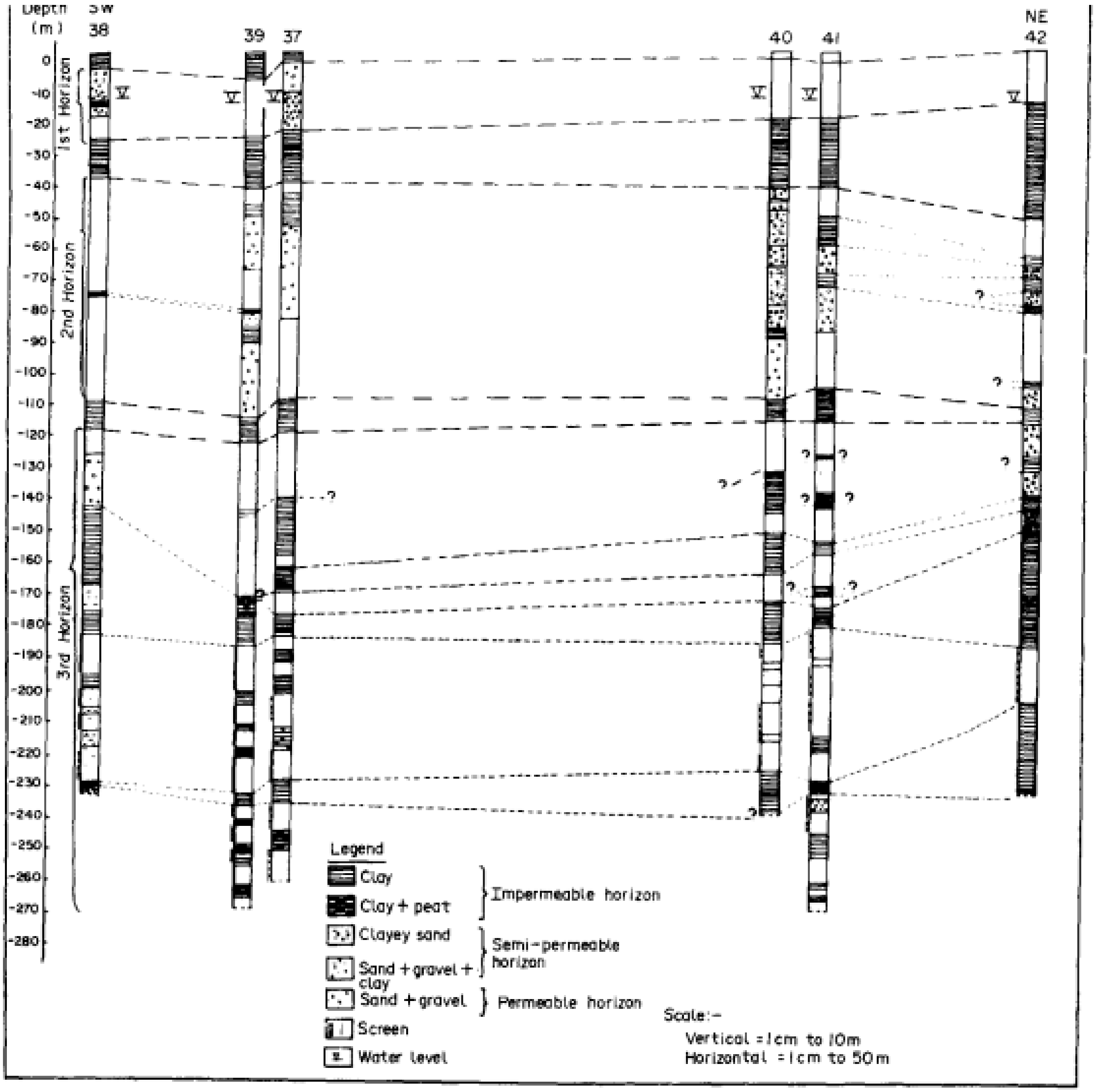

Figure 35: Lithological logs and correlations of aquifer horizons at Apapa (Longe et al.,1987). © 1987 Published by Elsevier Ltd.

BADAGRY – ZONE D

Hydrogeological Framework

Three geological records are available for Badagry LGA: two from Afowo and one from Badagry town:

1. _Afowo geological cross-section (Adelana et al., 2008) –_ this less detailed log reaches 450 mbsl, showing the UCPS down to ~25 mbsl, underlain by a clay aquitard that separates it from the LCPS. The LCPS extends from 35 to 250 mbsl, before the thick clays of the Ilaro Formation are met, reaching to the base of the well. This cross-section presents shallower CPS termination depths compared to Aladejana et al. (2020) and is considered a more generalized, less accurate representation.
2. _Badagry borelog (_Figure 34_; Aladejana et al., 2020)_ - reaching depths of 450 mbsl, this log indicates that clay and sandy clay dominate to 100 mbsl, with two fine-medium sand horizons between 35–55 mbsl and 75–100 mbsl, assumed to be water-bearing layers of the UCPS aquifer. The shallower horizon appears laterally extensive

eastward. However, the second sand horizon is likely a lens within a clay-dominated environment, contrary to the inference of lateral extent by Aladejana et al. (2020). From 100 to 300 mbsl, thick alternating layers of clay, shale(?) and peat form a thick aquitard, separating the UCPS and LCPS. Thick sand layers, assumed to be part of the LCPS, extend from 300 to 410 mbsl, separated by a peat layer. Whilst Adelajana et al. (2020) infer the sand to form two separate horizons, with the peat layer continuous, an alternate interpretation, which is more likely to reflect the typical CPS system would be that the sand horizons are interconnected, with the peats forming lenses. Limestone at ~410 mbsl is likely part of the Ewekoro Formation.

3. *Afowo borelog and record of total sedimentary thickness (*Table 11*; Onuoha & Ofoegbu, 1988)* – reaching depths of 2400 m, this log provides a general overview of the sedimentary sequence in the Dahomey Basin. It confirms that CPS sands reach ~400 m in depth, with deeper sand aquifers in the Abeokuta Formation identified from 958 to 1262 m and 1698 to 2152 m, before basement is met.

Given these discrepancies, the cross-section by Adelana et al. (2008) has been excluded from the typology development, as it contradicts the other logs. Additional data is required to clarify variations in formation and facies thicknesses across Badagry LGA.

Aquifer Characteristics

While hydraulic property data for Badagry is unavailable, the presence of thicker sand horizons and a confined system suggests the LCPS aquifer likely has greater transmissivity and yield than the UCPS.

Groundwater Level

Groundwater level data is limited. However, RIGSS and IBADAN data from the shallow aquifer indicate a very shallow water table, typically <6 masl (maximum 11.57 mbgl) and close to sea level (< 6.37 masl). Over two years (April 2022 – April 2024), water levels rose by 0.19 to 0.63 m at all IBADAN monitoring points, suggesting the aquifer is recharging. No data is available for the LCPS.

Groundwater Quality

Urban areas of Badagry are at higher risk of contamination from domestic and industrial waste in the shallower aquifer, although rural areas also face contamination risks. Tunde et al. (2023) and Olaruntola (2021) detected lead, cadmium, chromium, copper, and E. coli in groundwater across the LGA. Tunde et al. (2023) highlighted the lack of waste management at monitored locations, indicating a significant risk to shallow groundwater.

Data from RIGSS and IBADAN indicate that groundwater produced from boreholes in the UCPS is generally fresh (IBADAN: 30 to 285 µS/cm; RIGSS: 83 to 290 µS/cm). RIGSS data shows slightly elevated EC in hand-dug wells (412 to 571 µS/cm), with one shallow well (<3 m depth) producing brackish water (EC = 1257 µS/cm), likely due to local contamination rather than saline intrusion, as elevated nitrate levels (44.75 mg/l) are present. Olaruntola et al. (2019) found all 91 shallow wells sampled produced fresh water (TDS < 520 mg/l), with 84% of samples having TDS < 250 mg/l. However, Electrical Resistivity Tomography (ERT) data from the same study suggests a brackish/saline lens at 10–50 m depth, contradicting the water quality results. This discrepancy warrants further investigation, although the water quality data is considered more reliable than the ERT interpretation.

The geological profile presented by Adelana et al. (2008) suggests a thin freshwater layer underlain by saline water in the UCPS, with fresh water again in the LCPS below the clay aquitard. However, due to conflicting evidence and a lack of supporting data, the presence of this saline water belt remains uncertain. Further research is needed.

Overall, aside from instances of anthropogenic contamination, groundwater in Badagry's CPS appears predominantly fresh. Given the area's low elevation, coastal proximity, and shallow water table, coastal saline intrusion remains a potential risk to shallow groundwater, necessitating ongoing monitoring.

Table 11: Summary of total sedimentary thicknesses at Afowo-1 deep well (Onuoha & Ofoegbu, 1988. Data originally compiled from Fayose, 1970).

Epoch	Age (Ma)	Horizon Depth (m)	Total Sediment thickness (m)	Dominant composition
Miocene	16	0	2152.0	Sand
	20.6	24.4	2127.8	
Oligocene	23	213.4	1938.8	
	32	396.2	1756.0	Sandy Shale
	37	655.3	1496.9	
Eocene	43	676.7	1474.5	
	52	847.3	1304.8	
Palaeocene	55	853.4	1298.8	Shale
	60	932.7	1219.5	
	63	941.8	1210.4	
Cretaceous	68	958.6	1193.6	Sand
	90	1262.2	739.4	Sandy Shale
	120	1698.0	303.6	Sand
Pre-Barremian Basement	190-250	2152.0	0	Crystalline basement

LAKOWE – ZONE E

Hydrogeological Framework

Coode-Blizard (1996) and Oladepo et al. (2014) describe a unique geological anomaly at Awoyaya and Lakowe compared to the rest of the Lekki Peninsula:

1. Lakowe (Coode-Blizard, 1996) – within the top 45 m, two sand horizons (average thickness 7.5 m) are found, assumed to be CPS. From 45 to 290.5 m are thick clays identified as the Ilaro Formation, with intercalated clayey sand horizons from 290.5 to 293.2 m and 309 to 314 m.

2. Lakowe (Oladepo et al., 2014; Figure 36; Table 12) – two borelogs show intercalated clays and sands (sand-dominated) down to 60 mbgl (CPS), underlain by 210 m of thick shale from 60 to 270 mbgl. Brackish sand and clayey sand horizons are encountered between 260–315 m, beneath which further shale is observed.
3. Awoyaya (Oladepo et al., 2014; Figure 36; Table 12) – A borelog indicates freshwater-bearing sands at 0–24 mbgl and 30–50 mbgl (Alluvium/CPS), intercalated with clay. A brackish sand body is found from 70–100 mbgl. Beneath this, 130 m of shales are present, followed by intercalated brackish sand horizons from 230–350 mbgl.

Whilst Coode-Blizard (1996) suggests the thinning of the CPS is due to the LCPS being absent, and is structurally controlled, inferring faulting to the east and west of the region. Such large-scale faulting required to create such a geological anomaly is unlikely. A more reasonable explanation would be that the Ilaro Formation shale identified is in fact a clay-dominated portion of the LCPS, and that there has been an anomaly within borehole logging at this site.

Oladepo et al. (2014) infer "shale" at these locations, but infer various horizons to extend laterally, pinching out both west and eastward. It is suspected that the low resistivities captured by their geophysical profiling are more likely to represent a clay-dominated LCPS, but that the previous identification of shale by Coode-Blizard (1996) may have influenced interpretation.

Therefore, it is assumed that this geological anomaly reflects clay-dominated LCPS, with limited sand, and that there is no large-scale faulting within Lagos State. Further investigation is required to identify what is happening. It is possible that the clay-dominated typology may span further, though lack of investigation to the north and east of this zone means identifying a typology boundary is not possible.

Aquifer Characteristics

No hydraulic data is available for this area.

Groundwater Level and Flow

Groundwater level data is limited. An IBADAN record for a shallow borehole at Lakowe shows the groundwater level fluctuates between 6.7 masl (dry season) and 9.1 masl (wet season). Over a two-year period, a 0.89 m decline in the water table was recorded.

Groundwater Quality

Coode-Blizard (1996) and Oladepo et al. (2014) suggest that the shallow aquifer (up to 60 mbgl) is predominantly fresh. However, the IBADAN record from Lakowe shows seasonal fluctuations between fresh and brackish groundwater (EC 361–1448 µS/cm). This may indicate saline intrusion, due to the area's coastal proximity, although further investigation is required. A brackish zone is noted in the upper aquifer at Awoyaya, between 70 and 100 mbgl.

Groundwater in deeper horizons within the clay-dominated horizons of the LCPS (below 230 mbgl) is brackish to saline (Oladepo et al., 2014), with Coode-Blizard (1996) reporting EC values of up to 6000 µS/cm. This cause of this anomalously high salinity is unknown and requires further investigation.

Table 12: Reported zones of fresh and saline groundwater near Lakowe (Oladepo et al., 2014).

Location	Elevation (mAOD)	Depth of Freshwater Zone (mbgl)	Depth of Saline Water Zone (mbgl)
Victoria Garden City Est., Ajah	17	30-40, 136-141, 152-155, 179-188, 193-212, 217-134	56-116
Royal Garden Est., Ajah	17	26-35, 46-50, 57-88, 102-108, 114-136, 190-218, 223-242, 245-252	143-190
Golden Park Est., Sangotedo	22	20-36, 44-57, 60-68, 82-100, 112-124	None
Ajayi Apata, Sangotedo	22	16-33, 43-56	None
Eko-Akete, Awoyaya	20	18-24, 30-50	233-355
HFP Cemetry, Lakowe	29	15-54	265-315
Lakowe Gram. School, Lakowe	26	21-27	258-308
Ibeju-Lekki Secretariat, Akodo	10	12-18, 36-46, 108-132, 144-150, 159-168	51-108, 196-308

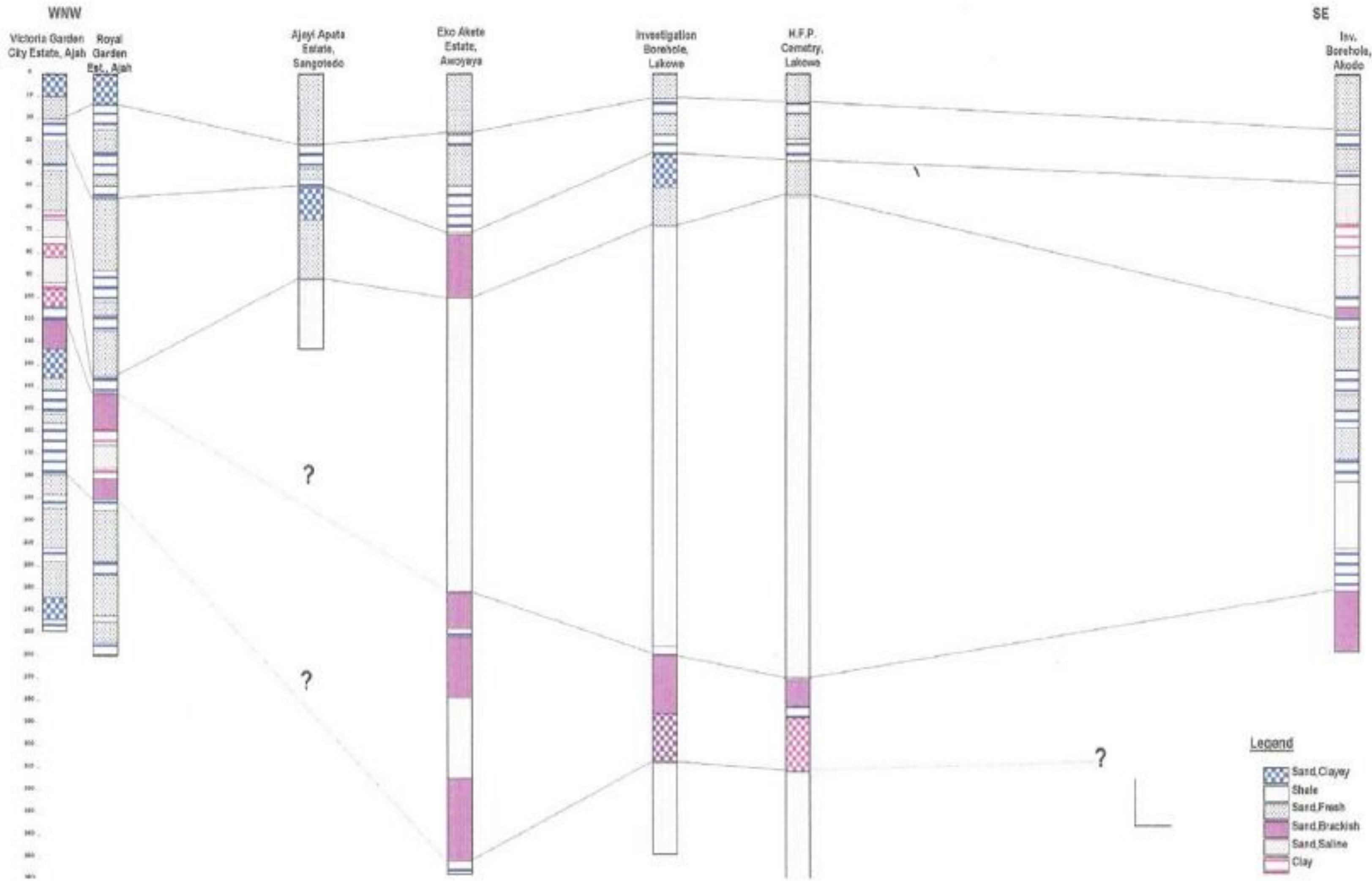

Figure 36: Geo-section and borehole logs across Ajah - Sangotedo - Awoyaya - Lakowe - Akodo (reproduced from Oladepo et al., 2014. © 2014 Academic Journals, Licensed under the CC BY 4.0 license). Clear lithological variations are observed at Awoyaya and Lakowe when compared to the other locations along this axis.

EPE – ZONE F

Hydrogeological Framework

Coode-Blizzard (1996) described borehole lithology from Eredo, north of Epe, which indicates that the Coastal Plain Sands (CPS) in this area are shallow (< 70 m depth) and lack significant sand layers (Table 13). A second borehole log from Itoikin, 20 km northwest of Epe, shows similar shallow CPS depths with thin (5 m) sand intervals, suggesting that discontinuous, thin sand horizons may also be present within the Epe typology area.

Table 13: Geological logs from Coode-Blizard, 1996. Italics indicates inferred information based on general geology of Lagos State.

Eredo		Itoikin	
Depth (mbgl)	**Lithology**	**Depth (mbgl)**	**Lithology**
0 to 70	Sandy clay (*CPS*)	0 to 63	Clay and sand (4 sand intervals, 5m thickness each) (*CPS*)
70 to 150	Clay (*Ilaro*)	63 to 200	Clay (*Ilaro*) w/ interbedded limestone (*moving into Ewekoro?)*
152 to 162	Limestone (*Ewekoro*)	168 to 172	Thickest limestone bed (*Ewekoro*)
162 to 211	? *clay and shale ?*	200 to 297	clay and shale
>211	Sand (*Abeokuta*)	>297	Sand (*Abeokuta*)

The Abeokuta Formation appears to form the most significant aquifer system in Epe. Located from depths of 211 mbgl in Epe, the aquifer is much shallower here compared to its occurrence at Ikorodu in the west (from 460 mbgl). This suggests potential geological controls, such as faulting, unconformities, erosion, or differential basin subsidence between the two areas, which are less than 45 km apart. Further investigation is required.

Aquifer Characteristics

No hydraulic data is available, but due to the significant clay content and the thin (5 m) sand intervals in the Coastal Plain Sands (CPS), it is expected that transmissivity and yield will be limited. In contrast, the Abeokuta Sands are likely to be more transmissive and capable of yielding higher volumes of water.

Groundwater Level and Flow

The IBADAN dataset indicates irregular groundwater level trends in this area. From April 2022 to April 2024, water levels generally rose by 2.57 to 3.17 m, but at Ibowon in the north, a decline of 6.23 m was observed, with a notable 13.2 m drop during the 2022 wet season, followed by a 7 m rise in 2023-2024. This suggests that the shallow aquifer is vulnerable to over-abstraction. There is no additional data on groundwater levels, flow, or abstraction in Epe LGA.

Groundwater Quality

Water quality data for the CPS is limited, with no data available for the Abeokuta Sands. The RIGSS and IBADAN datasets indicate generally fresh groundwater in the area (EC < 767 µS/cm), (average RIGSS: 423 µS/cm, average IBADAN: 115.5 µS/cm). Elevated nitrate levels are reported where EC exceeds 300 µS/cm, although these remain within WHO limits. Elevated EC and nitrate concentrations are more common in hand-dug wells, suggesting possible anthropogenic contamination due to inadequate well protection. No evidence of saline intrusion from brackish surface water has been observed.

Limited investigation (2 sample points) by Soladoye & Ajibade (2014) found evidence of both good water quality and groundwater anthropogenic contamination, with EC, iron, zinc, and E. coli concentrations at one site exceeding WHO limits, and nitrate being elevated. Despite some evidence of contamination, groundwater quality in Epe is expected to be better than in the heavily urbanized and industrialized areas of Lagos megacity.

References

Adebanija, M. A., 2013. Hydrogeological implications of characteristics and features of apparent resistivity curves, River Ogun Flood plain, Ikorodu, Southwestern Nigeria, *International Journal of Scientific & Engineering Research*, vol. 4(10), 352-376.

Adelana, S. M. A., Bale, R. B. and Wu, M., 2003. Quality assessment and pollution vulnerability of groundwater in Lagos metropolis, SW Nigeria. *Proceedings Aquifer Vulnerability Risk AVR03, Salamanca, Mexico*, vol. 2, 1-17.

Adelana, S. M. A., Bale, R. B. and Wu, M., 2004a. Water quality in a growing urban centre along the coast of southwestern Nigeria. In: Ru-Ze Xi, Wei-Zu Gu, K-P Seiler (eds) - *Research Basins & Hydrological Planning, A.A. Balkema, London*, 83-91.

Adelana, S. M. A., Bale, R. B. and Wu, M., 2004b. The impact of anthropogenic activities over groundwater quality of a coastal aquifer in southwestern Nigeria. *Aquifer Vulnerability and Risk, 2nd International Workshop, 4th congress on the Protection and Management of Groundwater, Parma*, 21-23rd September 2005.

Adelana, S. M. A., Olasehinde, P. I., Bale, R. B., Vrkba, P., Edet, A. E. and 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: IAH selected papers. Leiden: CRC Press/Balkema, p171-197*.

Adewuyi, G. O. Oputu, O. U and Opasina, M.A. 2010. Assessment of Groundwater Quality and saline intrusions in Coastal Aquifers of Lagos Metropolis, Nigeria, *J. of Water Resource and Protection*, vol. 2, 49-853.

Adeyemi, G. O., Akinmosin, A. A., Aladesanmi, A. O. and Badmus, G. O., 2013. Geophysical and sedimentological characterization of a tar sand rich area in south-western Nigeria, *Journal of Environment and Earth Science,* vol. 3(4), 71-83.

Adiat, K. A. N., 2019. Application of geophysical borehole logs for aquifer characterization in coastal environment of Lagos, southwestern Nigeria, *Nigerian Journal of Basic and Applied Science*, vol. 26(1), 31-45.

Afolabi, T. A., Ogbuneke, C. C., Ogunkunle, O. A. and Bamiro, F. O., 2012. Comparative assessment of the potable quality of water from industrial, urban and rural parts of Lagos, Nigeria, *Ife Journal of Science*, vol. 14(2), 221-232.

Agagu, O.K., 1985. A geological guide to bituminous sediments in Southwestern Nigeria, *unpublished report*, Department of Geology, University of Ibadan, Nigeria.

AGR (Akute Geo-Resource Ltd), 2005. Hydrogeological survey of the oil seepage and groundwater pollution in Baruwa community, Ipaja, Alimosho LGA of Lagos State, *unpublished report*, submitted to Pipelines and Products Marketing Company of NNPC, 76pp.

Akerele, D. D., Obunadike, C. and Abiodum, P. O., 2023. Assessment of physicochemical and bacteriological parameters of borehole water: a case study from Lekki, Lagos, Nigeria, *Research Square*, 14pp.

Akanmu, A.; Aladejana, J.; Comte, JC.; Cuthbert, M.; Healy, A.; Holliday, L.; Kolawole, K.; Longe, E.; MacDonald, A.; Olabode, O.; Olatunji, A. ; Oshinlaja, N.; Oteri, A.; Tijani, M.; Upton, K. (2024) *Love Lagos, Love Groundwater: Briefing Paper* December 2024, Briefing Paper, 6pp. Cardiff University,

Akinlalu, A. A. and 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*, vol. 8(15), 17pp.

Akoteyun, I. S., 2013. Hydrochemical studies of groundwater in parts of Lagos, southwestern Nigeria, *Bulletin of Geophysy – Physical Geography Series*, vol. 6, 27-42.

Akoteyun, I. S., 2015. Identifying processes of groundwater chemistry in parts of Lagos, Nigeriai, *Carpathian Journal of Earth and Environmental Sciences*, vol. 10(2), 95-106.

Akoteyon, I. S., Balgoun, I. I. and Soneye, A. S. O., 2018. Integrated approaches to groundwater quality assessment and hydrochemical processes in Lagos, Nigeria, *Applied Water Science*, vol. 8(200), 19pp.

Aladejana, J. A. and Talabi, A. O. 2013. Assessment of groundwater quality in Abeokuta, southwestern Nigeria, *International Journal of Engineering and Science*, vol. 2(6), 21-31.

Aladejana, J. A., Kalin, R. M., Hassan. I., Sentenac, P. and Tijani,M. N., 2020a. Origin and residence time of groundwater in the shallow coastal aquifers of Eastern Dahomey Basin, Southwestern Nigeria, using $\delta^{18}O$ and δD isotopes, *Applied Sciences*, 22pp.

Aladejana, J. A., Kalin, R. M., Sentenac, P. and. Hassan. I., 2020b. Assessing the impact of climate change on groundwater quality of the shallow coastal aquifer of Eastern Dahomey Basin, southwestern Nigeria, *Water*, 19pp.

Ameloko, A. A. and Ayolabi, E. A., 2018. Geophysical assessment for vertical leachate migration profile and physiochemical study of groundwater around the Olusosun dumpsite Lagos, southwest Nigeria. Applied Water Science, vol. 8(142), 15pp.

Arup, n.d. City characterisation report Lagos, 31pp. Accessed at: https://www.arup.com/globalassets/downloads/insights/c/city-water-resilience-approach/characterisation-report/ccr-lagos.pdf.

Asiwaju-Bello, Y. A. and Oladeji, O. S., 2001. Numerical modelling of ground water flow patterns within Lagos metropolis, Nigeria, *Nigerian J. of Min. and Geol.*, vol. 37, 185–194.

Asiwaju-Bello, Y. A., Olabode, O. F., Owoseni, J. O., Daramola, S. O., Ogunsuyi, M. T., Yusuf, L. A., Utulu, B. S., Adiele, T. and Shodeinde, R., 2021. Imprints of sea surge and municipal activities on non-potability of groundwater in shallow coastal sandy aquifer systems of Lagos State, Southwestern Nigeria, *Groundwater for Sustainable Development*, vol. 14, 12pp.

Awomeso, J. A., Ogundairo, E. S., Taiwo, A. M., Idowu, O. A., Gbadebo, A. M. and Oyetunde, O. A. C., 2019. Assessment of water quality of Ogun River in southwestern Nigeria, *Ife J. Sci.,* vol. 21(2), 375–388.

Ayoade, A. A., Sowunmi, A. A., Nwachukwu, H. I., 2004. Gill asymmetry in Labeo ogunensis from Ogun River Southwest Nigeria, *Revol. Biol. Trop.*, vol. 52(1), 171–175.

Ayoloabi E. A., Folorunso, A. F., Odukoya, A. M. and Adeniran, A. E., 2013. Mapping saline water intrusion into the coastal aquifer with geophysical and geochemical techniques: the University of Lagos campus case (Nigeria), *SpringerPlus*, vol. 2(1), 433.

Balogun, I. I. and Akoteyon, I. S., 2012. Assessment of groundwater quality in the Lower Plain Sand Aquifer for varied uses, *Hydrology for Disaster Management*, 299-315.

Balogun I. I., Sojobi, A. O. and Galkaye, E., 2017. Public water supply in Lagos State, Nigeria: review of importance and challenges, status and concerns and pragmatic solutions, *Cogent Eng*., vol. 4.

Balogun, I. I., Akteyon, I.S. and Soneye, A., 2019. Season-induced variation in water table depth and selected chemical parameters of groundwater in Lagos Coastal Plain Sand Aquifer, Nigeria, *Journal of Applied Science and Environmental Management*, vol. 23(8), 1465-1473.

Bankole, A. O., Oluwasanya, G. and Odjegba, E. E., 2022. Evaluation of groundwater suitability in the Cretaceous Abeokuta Formation, Nigeria: implications for water supply and public health, *Groundwater for Sustainable Development*, vol. 19, 17pp.

Billman, A., 1992. Offshore stratigraphy and palaeontology of the Dahomey Basin (Benin Embayment), West Africa, *NAPE Bulletin*, vol. 7, 121-130.

Burke, K., Dessauvagie, T.F.J. and Whitman, A.J., 1971. Opening of the Gulf of Guinea and Geological History of the Benue Depression and Niger Delta, *Nature Physical Science*, vol. 233, 38-51.

Coode-Blizard Ltd, 1996. Hydrogeological investigation of Lagos State, *Report for Lagos State Water Corporation*, 286pp.

Egirani, D. E. and OTor, A. J., 2007. Physical, chemical and biological characteristics of groundwater in some parts of metro Lagos, Nigeria, *Integrated Journal of Environment, Science and Technology*, 3095-3103.

Ezechinyere, C. H. and Stanislaus, O. U., 2023. Investigating the quality of groundwater in Ibeju-Lekki Local Government Area, Lagos State, *Water Science*, vol. 37(1), 409-425.

Fatoba, J. O., Omolayo, S. D., and Adigun, E. O., 2014. Using geoelectric soundings for estimation of hydraulic characteristics of aquifers in the coastal area of lagos, Southwestern Nigeria*, International Letters of Natural Sciences*, vol. 11, 30–39.

FEPA (Federal Environmental Protection Agency), 1998. Present Water Quality Status in Nigeria, Lagos, p.35- 41.

Ferreira, C. S. S., Adama-Ajonye, O., Ikenna, A. E. and Kalantari, Z., 2023. Groundwater quality in the vicinity of a dumpsite in Lagos metropolis, Nigeria, *Geography and Sustainability*, vol. 4, 379-390.

FMWR-NUWSRP (2004): Nigeria Water Sector Reform Program: Lagos. Retrieved, 7th February 2025. https://nwsrp.gov.ng/part.php?n=2.

Geoconsult Technical Services Ltd (GTS Ltd), no date. Chapter 6: Geological and Hydrogeological Context of Agbara Estate, In: Water resources study of Agbara Area and Adjoining Catchment. *Draft final report*, unpublished, 39pp.

Healy, A., Upton, K., Bristow, G., Allan, S., Bukar, Y., Capstick, S., Danert, K., Furey, S., Goni, I., MacDonald, A., Theis, S., Tijani, M. N. and Whitmarsh, L., 2018. Resilience in groundwater supply systems: integrating resource-based approaches with agency, behaviour, and choice, *RIGSS Working Paper*, Cardiff University, UK.

Healy et al., 2020. Domestic groundwater abstraction in Lagos, Nigeria: a disjuncture in the science-policy-practise interface?, *Environmental Research Letters,* vol. 15(4).

Hydro Construction and Engineering Company Ltd., 1993. Borehole Completion Report at Lagos Road Waterworks, Ikorodu, *Completion of Job Report submitted to the Lagos State Water Corporation, Lagos*.

Idowu, O. A., Ajayi, O. and Martins, O., 1999. Occurrence of groundwater in parts of Dahomey Basin, SW Nigeria, *Nigerian Journal of Mining and Geology*, vol. 35**,** 229 – 236.

Jaji, M. O., Bamgbose, O., Odukoya, O. O. and Arowolo, T. A., 2007. Water quality assessment of Ogun River, South-West Nigeria, *Environ. Monit. Assess*., vol. 133(1–3), 473–482.

Jan de Chine, R. E., 1980. Palynological study of the tar sand, Upper Maastrichtian of southwest Nigeria, *Proceedings, IV International Palynological Conference, Lucknow (1976-1977*), vol. 2, 794–799.

Jideonwo, J. A., 2014. Ensuring sustainable water supply in Lagos, Nigeria, *unpublished report (dissertation).*

Jimoh, R. A., Bankle, O. M., Ahmed, K., Christopher, O. A., Adeniji, M. A., Ebhodaghe, J., Sedara, S. O., Obende, P. W., Alebu, O. and 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*, vol. 8(191), 11pp.

Jones, H. A. and Hockey, R. D., 1964. The geology of part of southwestern Nigeria, *Geol. Survey of Nigeria*, Bulletin 31, 101pp.

Kampsax, C.N., Kruger, L. O. and Shwed Associates, 1977. Undergroundwater resources investigation of the metropolitan Lagos, Final Reports, *unpublished*.

Kampsax, C.N. and Kruger, L.O., 1980. Victoria Island Water Supply. Interim report phase 1. Borehole No. 3, *Report submitted to Federal Ministry of Works and Housing*, 256pp.

Kareem, R. O., Adesina, R. B. and Adetu, S. O., 2016. Hydrochemical assessment of groundwater quality in Sagamu area, southwestern Nigeria, *Global Journal of Geological Sciences*, vol. 14, 41-47.

Kogbe, C.A., 1989. The Cretaceous and Paleogene sediments of Southern Nigeria. In: Kogbe, C.A. (Ed), Geology of Nigeria, Rock View (Nigeria) Limited, 325-334.

LWC (Lagos Water Corporation), 2011. Lagos Water Supply Master Plan, 33pp.

Longe, E. O., Malomo, S. and Olorunniwo, M. A., 1987. Hydrogeology of Lagos metropolis, *J. African Earth Sci*., vol. 6(2), 163-174.

Longe, E. O. and Kehinde, M. O., 2005. Investigation of potential groundwater impacts at an unlined w aste disposal site in Agege, Lagos, Nigeria, *Proceeding of 3rd International Conference, Faculty of Engineering, University of Lagos, Lagos*, *May 23-26*, 21-29.

Longe, E. O. and Enekwechi, L. O., 2007. Investigation on potential groundwater impacts and influence of local hydrogeology on natural attenuation of leachate at a municipal landfill, *Int. J. Environ. Sci. Tech.,* vol. 4(1), 133-140.

Longe, E. O. and Balogun, R. M., 2010. Groundwater quality assessment near a Municipal Landfill, Lagos, Nigeria, *Research Journal of Applied Science, Engineering and Technology,* vol. 2(1), 39-44.

Longe, E. O., 2011. Groundwater resources potential in the coastal plain sands aquifers, Lagos, Nigeria, *Res. J. Environ. Earth Sci*., vol. 3(1), 1–7.

Majolagbe, A. O., Anko, S. O., Onwordi, C. T., Sobola, A. O. and Wusu, O. E., 2023. Physicochemical and trace metals characterization: an impact assessment of Badagry Creek on groundwater quality in Ojo community, Lagos, Nigeria, *ChemSearch Journal*, vol. 14(2), 107-117.

Mpanda, S., 1997. Geological development of East African coastal basin of Tanzania, *Acta Universities Stockholmiensis*, vol. 45, 121pp.

Obioram A. N. and Onwuka, O.S., 2005. Groundwater exploration in Ikorodu, Lagos-Nigeria: A surface geophysical survey contribution, *The Pacific Journal of Science and Technology*, vol. 6(1), 86-93.

Odjegba, E. E., Bankole, A. O., Sadiq, A. Y., Busari, I. O. and Layi-Adigun, B. O., 2021. Rapid assessment of the water chemistry of public water supply in Abeokuta, south-west Nigeria, *J. Appl. Sci. Environ. Manage.,* vol. 25(5), 689-693.

Offodile, M. E., 2002. Groundwater Supply & Development in Nigeria, *Mecon Services Ltd, Jos*., 453pp.

Ogbe, F. G. A., 1972. Stratigraphy of the Strata Exposed in the Ewekoro Quarry, Western Nigeria, In: Dessauvagie, T.F.J. and A.J. Whiteman (Eds.), *African Geology, University of Ibadan, Ibadan, Nigeria*, 305-322.

Ojuri, O. O. and Bankole, O. T., 2013. Groundwater vulnerability assessment and validation for a fast growing city in Africa: a case study of Lagos, Nigeria, *Journal of Environmental Protection*, vol. 4, 454-465.

Ola, P. S., Bankole, O. M. and Anifowose, A. Y. B., 2008. Sub-surface geology and groundwater distribution pattern in Lagos Island Environs, South-Western Nigeria, *Environtopica*, vol. 5,6 & 7, 89-103.

Olabode, O.F., 2025. Water scarcity and groundwater security in the fast-growing megacity of Lagos: Aquifer system's conceptualisation, water balance, and opportunities for managed aquifer recharge. PhD Thesis, University of Aberdeen.

Olabode, O.F. and Comte, J.C., 2022. Modelling of groundwater recharge in the megacity of Lagos, Nigeria: preliminary results using WetSpass-M. *Advances in Geosciences*, 59, pp.53-57.

Olabode, O.F. and Comte, J.C., 2024. Water scarcity in the fast-growing megacity of Lagos, Nigeria and opportunities for managed aquifer recharge. *Wiley Interdisciplinary Reviews: Water*, 11(5), p.e1733.

Olabode, S. O. and Mohammed, M. Z., 2016. Depositional facies and sequence stratigraphy study in parts of Benin (Dahomey) Basin SW Nigeria: Implications on the re-interpretation of Tertiary Sedimentary Successions*, International Journal of Geoscience*, vol. 7(2), 210-228.

Oladele, S., Salami,R. and Dauda, R. S., 2023. Petrophysical and hydrogeological characterization of coastal aquifer using geophysical logs in Lekki peninsula, Lagos, Nigeria, *Groundwater for Sustainable Development*, vol. 22, 12pp.

Oladepo, M. I., Ilori, O. B. and Adeoye-Oladapo, O. O., 2014. Geophysical study of saline water intrusion in Lagos municipality, *African Journal of Environmental Science and Technology,* vol. 8(1), 16-30.

Olaruntoba, E. O., Wada, O. Z. and Adejumo, M., 2021. Heavy metal analysis of drinking water supply, wastewater management and human health risk across secondary schools in Badagry coastal community, Lagos State, Nigeria, *International Journal of Environmental Health Research*, vol. 32(9), 1897–1914.

Olarutola, M. O., Adeyemi, G. O., Bayewu, O. and Obasaju, D. O., 2019. Hydro-geophysical mapping of occurrence and lateral continuity of aquifers in coastal and landward parts of Ikorodu, Lagos, Southwestern Nigeria, *International Journal of Energy and Water Resources*, vol. 3, 219-231.

Olatinsu, O. B., Ndukwe-Agu, G. C. and Ozebo, VOL. C., 2022. Joint geophysical and hydrogeochemical assessment of groundwater quality degradation in coastal aquifer systems at a suburb of Kosofe, Lagos, southwest Nigeria, *Sustainable Water Resources Management*, vol. 9(19), 18pp.

Olatunji, A. S., Abimbola, A. F., Oloruntola, M.O. and Odewade, A. A., 2005. Hydrogeochemical evolution of groundwater resource in shallow coastal aquifers around Ikorudu area, southwestern Nigeria, *Water Resources*, vol. 16, 65-71.

Oludeyo, A. A., Chidi, O. V and Kayode, O. F., 2021. Triangulation approach for mapping groundwater suitability zones in coastal areas around Lagos, Nigeria. Using multi-criteria decision-making technique, *NRIAG Journal of Astronomy and Geophysics*, vol. 10(1), 423-442.

Olufemi, A. G., Utieyin, O. O. and Adebayo, O. M., 2010. Assessment of groundwater quality and saline intrusions in coastal aquifers of Lagos Metropolis, Nigeria, *Journal of Water Resource and Protection*, vol. 2, 849-853.

Omosanya, K. O., Akinmosin, A. A., Ikhane, P. R., Mosuro, G. O., Goodluck, I., et al., 2012. Characterization of a bitumen seepage in Eastern Dahomey Basin, SW, Nigeria, *Advol. Appl. Sci. Res*., vol. 3, 2078–2089.

Onuoha, K. M. and Ofoegbu, C. O., 1988. Subsidence and evolution of Nigeria's continental margin: implications of data from Afowo-1 well. *Marine and Petroleum Geology,* v. 5, p. 175 – 181.

Onwuka, M. and Adekile, D., 1986. Demand-recharge study of the groundwater resources of the Ikeja area of Lagos State, Nigeria. Proc. *1st Annual Symp., Nigeria Water and Sanitation Association, Lagos, Nigeria*, 175-197.

Onwuka, M. O. and Amadi, U. M., 1986. Borehole design against saltwater intrusion in the coastal areas of Lagos State, Nigeria, *Nigerian Engineer Conference Paper, Lagos*, 17.1-17.12.

Onwuka, M.O., 1990. Groundwater Resources of Lagos, M.Sc. dissertation. Geol. Dept., U.I., *unpublished*.

Oteri, A. U., 1985. Water pollution in Lagos, *The Nigerian Journal of Engineering*, vol. 20(2), 1-6.

Oteri, A. U., 2013. Groundwater Resources of Lagos State, LSWRC Workshop, June 2013, presentation, *unpublished*.

Oteri, A. U., & Ayeni, R. A., 2016. The Lagos Megacity, *Water, Megacities and Global Change,* 37pp.

Oyedele, K. F. and Meshida, E. A., 2004. Groundwater pollution studies in a coastal environment using surface electrical resistivity method: a case study of Lekki, Lagos, Nigeria, *Global Journal of Geological Science*, vol. 4(1), 1-6.

Oyegoke, E. S., 1986. The hydrogeology of Lagos metropolis, *Proc. 1st Annual Symp. Nigeria Water and Sanitation Association, Lagos, Nigeria*, 69-80.

Oyegoke, S. O., Adeyemi, A. O. and Sojobi, A. O., 2012. The challenge of water supply for a megacity: a case study of Lagos Metropolis, *International Journal of Scientific & Engineering Research*, vol. 3(2), 1-10.

Scanwater (Nigeria) Ltd., 1985. Predrilling report, Lagos State Mini-Waterworks, *Unpublished*.

Shiru, M. S., Sahid, S., Shire,S., Chung, E. S., Alias, N., Ahmed, K., Dioha, E. C.,Sa'adi, Z., Salman, S., Noor, M., Nashwan, M. S., Idlan, M. K., Khan, N., Momade, M. H., Houmsi, M. R., Iqbal, Z., Ishanch, Q. and Sediqi, M. N., 2020. Challenges in water resource of Lagos mega city of Nigeria in the context of climate change, *Journal of Water and Climate Change*, vol. 11(4), 1067-1083.

Sogbanmu, T. O., Aitsegame, S. O., Otubanjo, O. A. and Odiyo, J. O., 2020. Drinking water quality and human health risk evaluations in rural and urban areas of Ibeju-Lekki and Epe local government areas, Lagos, Nigeria, *Human and Ecological Risk Assessment: An International Journal*, vol. 26(4), 1062-1075.

Soladoye, O. and Yinusa, N. O., 2012. Assessment of groundwater quality in shallow wells in Ikorodu Local Government Area of Lagos State, Nigeria, *Asian Journal of Natural and Applied Sciences*, vol. 1(4), 5-15.

Soladoye, O. and Ajibade, L. T., 2014. A groundwater quality study of Lagos State, Nigeria, *International Journal of applied Science and Technology*, vol. 4(4), 271-281.

Storey, B. C., 1995. The role of mantle plumes in continental breakup: case histories from Gondwana land, *Nature*, vol. 377, 301-308

The Guardian, 2010. Our boreholes bring forth fuel –Residents of Diamond Estate, Idimu, Lagos, *The Guardian Newspaper*, February 3, 12.

Tijani, M., Crane, E., Upton, K., Ó Dochartaigh, B.É. and Bellwood-Howard,I. 2018. Africa Groundwater Atlas: Hydrogeology of Nigeria. British Geological Survey. Accessed 26th May 2025 https://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Nigeria

Tunde, O. S., Kehinde, F. O., Adeyinka, O. H. and Chukwuka, N. S., 2023. Quality of groundwater from five different locations in Badagry Local Government Area of Lagos State, Nigeria*, International Journal of Research and Innovation in Applied Science*, vol. 8(4), 232 – 235.

UN News, 2016. Nigeria's megacity, Lagos, face unacceptable water and sanitation crisis, UN expert warns.

Wali, S. U., Dankani, I. M., Abubakar, S. D., Gada, M. A. and Uma, K. J., 2021. Detailed hydrogeological and hydrochemical reassessment of coastal basins of southwestern Nigeria, *Geology, Earth and Marine Sciences*, vol. 3(1), 25pp.

Whiteman, A.J., 1982. Nigeria: Its Petroleum Geology, Resources and Potential, vol. 2, *Grahan and Trontman, London*.

World Bank, (1988): *Nigeria - Lagos Water Supply Project.* Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/695791468098057700. Retrieved, 7th February 2025.

World Health Organization (WHO) and UNICEF., (2006). Rapid Assessment of Drinking Water Quality, *Country Report*, Nigeria, 82.

Yusuf, M. A., Abiye, T. A., Butler, M. J. and Ibrahim, K. O., 2018. Origin and residence time of shallow groundwater resources in Lagos coastal basin, south-west Nigeria: an isotopic approach, *Heliyon 4*, 33pp.

Yusuf, M. A. and Abiye, T. A., 2019. Risks of groundwater pollution in the coastal areas of Lagos, southwestern Nigeria, *Groundwater for Sustainable Development*, vol. 9, 16pp.

Yusuf, M. A., Abiye, T. A., Ibrahim, K. O. and Abubakar, H. O., 2021. Hydrogeochemical and salinity appraisal of surficial lens of freshwater aquifer along Lagos coastal belt, South West, Nigeria, *Heliyon 7*, 18pp.