Saltwater Intrusion in Nigeria: A Review

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Across some areas in Nigeria such as; Lagos State and the Niger Delta region, freshwater supplies have been negatively impacted by saltwater intrusion, a growing environmental hazard that has affected coastal aquifers worldwide. The causes, effects and mitigating techniques of saltwater intrusion in the coastal areas of Nigeria are examined in this review. Excessive groundwater extraction, climate change-related sea level rise, oil and gas exploration, poor land-use practices and rapid rate of urbanisation are some of the main contributing factors. In addition to providing case examples that illustrate the extent of groundwater salinization, this review also described the hydrogeological features of the southern coastal aquifers in Nigeria. The implications of saltwater intrusion are far-reaching, including poor water quality for domestic, agricultural and industrial usage, unfavourable public health outcomes, lower agricultural production, and larger economic as well as societal difficulties. Monitoring methods which include; remote sensing, water quality indicator analysis, and groundwater modelling were covered, as were management approaches like artificial recharge, sustainable groundwater usage, regulatory reform as well as public involvement. The lack of coordinated water resource strategies and the paucity of long-term data are research gaps that have been explored in this review. To safeguard Nigeria's delicate coastal aquifers and guarantee water security in the face of continuous environmental and human pressures, this review has also emphasised the necessity of coordinated, science-based as well as policy-driven actions.
Keywords: Aquifer, coastal areas, elevated chloride, freshwater, groundwater extraction, Southern Nigeria

Introduction

Nigeria, a West African country, is known to feature a varied topography that includes plateaus, river basins, hills and coastal lowlands. Coastal states including Lagos, Ondo, Delta, Bayelsa, Rivers, Akwa Ibom and Cross River make up the 853-kilometer southern border with the Atlantic Ocean (Idris *et al.,* 2024). Low-lying topography, vast wetlands, estuaries, and river deltas, especially in the Niger Delta region, are characteristics of these coastal zones. In addition to being heavily inhabited, the coastal regions serve as centres for economic activity such as urbanisation, fishing, agriculture as well as oil and gas operations (Abam & Nwankwoala, 2020).

Millions of people in southern Nigeria, especially in the Niger Delta and Lagos area, are known to be reliant on substantial aquifer systems for their domestic water supply. With their high permeability and storage capacity, these aquifers are mostly sedimentary in character, with alternating layers of sand, gravel, silt, and clay (Tijani, 2023). In the Niger Delta, the alluvial deposits and the coastal plain sands (sometimes called the Benin Formation) are important aquifer systems. These aquifers, which are usually unconfined or semi-confined, are replenished by infiltration, rivers, and rainfall (Tijani, 2023; Idris *et al.,* 2024). Their proximity to the ocean is known to expose them to the effects of tides and the rising sea levels brought about by climate change (Oladele *et al.,* 2023). Disrupting the equilibrium between freshwater and ocean, anthropogenic factors including excessive groundwater extraction for residential, agricultural, and industrial uses can promote the inland passage of salty water (Aghogho *et al.,* 2024).

Water is a crucial resource for life on earth. It occurs as freshwater (inland waters and groundwater), saline water (the seas and oceans) and estuarine environments contain a mix of both (Moustafa *et al.,* 2024). Saltwater intrusion is the process wherein saline water encroaches into freshwater aquifers, typically due to an imbalance between freshwater recharge and extraction, or changes in sea levels as well as hydrological pressures (Agoubi, 2021; Cantelon *et al.,* 2022). The occurrence of salt water intrusion has been documented to pose a serious danger to coastal groundwater supplies, particularly in areas where groundwater is the main supply for industrial, agricultural, and drinking water (Tully *et al.,* 2019).

Rising sea levels, climate change, overuse of groundwater resources as well as the rapid urbanization of coastal areas has made saltwater intrusion a more pressing environmental concern worldwide (Guerra-Chanis *et al.,* 2019). This trend, which can negatively affect freshwater supplies as well as also contribute to water insecurity, is a serious issue for a lot of nations such as the United States, Bangladesh, Vietnam and tiny island states (Bellafiore *et al.,* 2021; Cantelon *et al.,* 2022). The consequences are exacerbated in many developing countries by

inadequate regulatory and monitoring frameworks, therein increasing the vulnerability of human populations to the negative effects of salt water intrusion (Xiao *et al.,* 2021).

With a coastline that stretches about 853 km along the Atlantic Ocean, Nigeria is especially vulnerable to saltwater intrusion, particularly in low-lying, heavily populated areas such as Lagos state, the Niger Delta region and sections of the southeastern states (Callistus *et al.,* 2024). The degradation of coastal aquifers has been attributed to several activities which include; petroleum exploration, rapid urbanisation, excessive groundwater abstraction and poorly managed land use activities (Foster & Chilton, 2004). Since a large amount of the water used in homes and farms is abstracted from groundwater sources, saltwater intrusion is a serious problem for food security, public health as well as economic growth (Obakhume, 2022; Aghogho *et al.,* 2024). Several studies have examined the incidence of saltwater intrusion in various parts of Nigeria (Olabode *et al.*, 2021; Yusuf *et al.*, 2021; Obakhume *et al.*, 2022). This is a paucity of available reviewed scientific literature pertaining to the issue of saltwater intrusion occurrence in Nigeria.

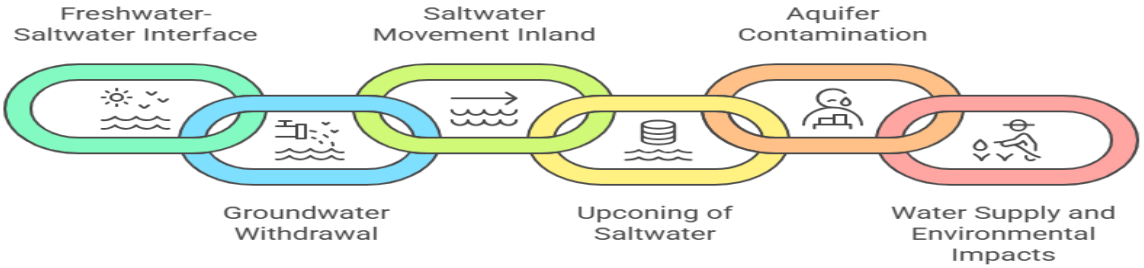

Figure 1: Saltwater intrusion process

This review attempted to present an organised written documentary of available data on the issue of saltwater intrusion in the Nigerian environment. In addition to identifying the main causes and affected areas, it will also analyse the geographical and hydrogeological factors that affect incursion, evaluate the socioeconomic and environmental effects, and reveals current monitoring procedures and mitigation techniques.

In preparing this study, the authors utilized a desktop research, which entailed drawing data from a comprehensive review of peer-reviewed articles and institutional reports related to saltwater intrusion and water resource management in Nigeria. A systematic approach was used to identify, select and compile relevant literature, focusing on case studies and documented interventions. Key themes were synthesised to evaluate strategies such as public water supply systems, groundwater regulation, and environmental monitoring.

Causes of Saltwater Intrusion in Nigeria

Excessive groundwater extraction

Excessive groundwater extraction is one of the main reasons for saltwater intrusion in Nigeria (Moulton, 2021; Callistus *et al.,* 2024). Reliance on boreholes and wells is common in large cities with limited access to treated surface water, such as Lagos and Port Harcourt (Callistus *et al.,* 2024). In coastal aquifers, excessive pumping lowers the freshwater pressure, which can permit denser saltwater to migrate inland and upward into freshwater zones (Badmus *et al.,* 2021). Water sources get contaminated when the normal contact between fresh and salty water is disrupted by this hydraulic imbalance (Abd-Elaty *et al.,* 2019).

Sea level rise and climate change

Sea levels have gradually increased as a result of melting polar ice and thermal expansion of seawater which has been occasioned by global climate change (O'Sullivan, 2021). The low-lying coastal areas of Nigeria are particularly susceptible to this occurrence (Isiaka, 2023). Coastal aquifers have increased hydrostatic pressure due to rising sea levels, which encourages saltwater infiltration (Ohwoghere-Asuma *et al.,* 2023; Ghomsi *et al.,* 2024). The freshwater shortage is further exacerbated by irregular rainfall patterns and protracted dry seasons, which lower aquifer recharge (O'Sullivan, 2021).

Oil and gas exploration

Exploration and drilling operations are known to cause significant land disturbances in the Niger Delta, which is known to serve as a primary focal point for the Nigerian oil and gas sector (Atuchukwu *et al.,* 2022). The risk of salt water intrusion is increased by these operations, which frequently change the hydrological routes and underlying geology (Ohwoghere-Asuma *et al.,* 2021). Brine and other waste disposal, as well as unintentional spills, deteriorate water quality and cause groundwater to become salinized (Callistus *et al.,* 2024).

Poor land-use practices and deforestation

Unregulated land use, including deforestation and unsustainable farming methods, can decrease the natural capacity of the soil to absorb and filter

precipitation (Omokaro *et al.,* 2024). This trend has led to lower groundwater recharge and increased surface discharge (Fashae *et al.,* 2022). In coastal aquifers, a lack of recharge is known to cause the freshwater lens to contract, which makes it easier for saltwater to migrate inland (O'Sullivan, 2021).

Urbanization and infrastructure development

Roads, buildings and drainage systems that block natural surfaces and interfere with groundwater recharge processes have been built as a result of the rapid urban growth characteristic of the coastal cities (Callistus *et al.,* 2024). Infrastructure projects frequently overlook hydrological effects and lack adequate environmental studies (Olabode & Comte, 2024). Water shortage problems are exacerbated by the ensuing strain on groundwater supplies, which speeds up saltwater intrusion into freshwater aquifers (Ibrahim *et al.,* 2024).

Case Studies and Affected Areas

Lagos State

Lagos State which is currently the most populated state and commercial centre of Nigeria, is located in a low-lying coastal region and is heavily reliant on groundwater for both domestic and commercial/industrial use (Fason *et al.,* 2023). Across the State, groundwater abstraction rates have dramatically increased due to increasing urbanisation and population expansion, resulting in a negative pressure gradient that is known to facilitate saltwater intrusion (Abd-Elaty *et al.,* 2019; Callistus *et al.,* 2024).

The existence of salt water in shallow aquifers across Lagos has been documented by several reports. Researches have revealed that groundwater samples from Lagos Island and the Lekki Peninsula had higher than normal quantities of chloride, which was an indication of seawater intrusion (Yusuf & Abiye, 2019; Asiwaju-Bello *et al.,* 2021; Yusuf *et al.,* 2021; Callistus *et al.,* 2024). Water quality has been reported to be declining in several areas which include; Victoria Island, Ajah and Eti-Osa, affecting households, businesses as well as water sellers (Okeke, 2022; Olabode & Comte, 2024).

Niger Delta region

Another area where saltwater intrusion is common is the Niger Delta, which includes the states of Rivers, Bayelsa, and Delta. The extensive system of rivers, estuaries as well as wetlands in the area makes it especially vulnerable to the effects of tides and the rise in sea levels (Edet, 2021; Oyegun *et al.,* 2023). Additionally, saline intrusion is a result of oil exploration activities upsetting groundwater flow regimes and natural landforms. Residents of Rivers State often complained about saline-tasting water from boreholes, especially in the areas close to Port Harcourt and Bonny Island (Fidelis & Harry, 2020). Total dissolved solids (TDS) and electrical conductivity levels in groundwater in several Niger Delta regions were higher than WHO drinking water bench mark values, according to several studies (Fidelis & Harry, 2020; Wali *et al.,* 2021; Atuchukwu *et al.,* 2022; Omokaro *et al.,* 2024), which could be indicative of salty water intrusion.

Flooding, land subsidence from oil development, and poor drainage infrastructure all exacerbate saltwater intrusion in the Bayelsa and Delta States. The intrusion is known to impact freshwater ecosystems and agricultural production in addition to endangering the purity of drinking water (Omokaro *et al.,* 2024), especially in lowland regions where tidal waves reach inland during high tides or storm surges, farmers have complained of reduced crop yields as a result of elevated soil salt content (Oyegun *et al.,* 2023). Table 1 below presented a summary of studies that have evaluated saltwater intrusion incidences in Nigeria.

Table 1: Case Studies of Saltwater intrusion assessment in Nigeria

Author (Year)	Methods	Findings
Olabode *et al.* (2021)	Electrical resistivity tomography (ERT) with dipole–dipole array method. Groundwater physicochemical analysis. Field survey covering 7 major communities was conducted.	Saltwater intrusion was more pronounced during the dry season due to reduced groundwater levels and higher extraction rates. Significant saltwater intrusion was detected in Imakun-omi, Irokun, Isekun, and Ode-omi areas. Water quality index (WQI) indicated good-to-excellent water quality in most areas, except the southern part which had poor-to-very poor water quality. ERT results confirmed aquifer contamination in some areas.
Aladejana *et al.* (2021)	Groundwater chemistry analysis for ionic ratios. Hydrochemical facie evolution diagram (HFE-D), saltwater mixing index (SMI) and groundwater quality index for SWI.	This study revealed increased salinity in areas near the coastline, caused by seawater intrusion. Higher salinities in the dry season due to seawater, and industrial/municipal effluents affecting the wet season. HFE-D and GQIswi highlighted the sensitivity of groundwater within 3 km from the coastline to saltwater intrusion. The study presented valuable data for groundwater management in the Eastern Dahomey Basin.
Edet (2021)	Geological and hydrogeological data used to delineate aquifers. Groundwater classification based on electrical conductivity.	The results of this study revealed that about 95% of groundwater samples were fresh, while a small percentage were brackish and saline. Seawater intrusion was detected in the A aquifer. Poor

		water quality in A aquifer for drinking and irrigation, while B and C aquifers had better quality water.
Aghogho *et al.* (2024)	Geophysical and geochemical techniques used to investigate saltwater intrusion in Delta State. Resistivity data from Vertical Electrical Soundings (VES).	The study revealed that the observed resistivity values were indicative of saline intrusion with groundwater having high electrical conductivity, salinity, and dissolved solids which exceeded WHO standards. Hydraulic resistance values indicated low and moderate vulnerability in the study area. Elevated chloride, sodium, and potassium concentrations confirmed saltwater intrusion.
Yusuf *et al.* (2021)	Borehole log analysis, including natural gamma and electrical resistivity logs. Integration of hydrophysical data to evaluate subsurface lithology and seawater intrusion.	The study identified complex lithology with alternating sand and clay layers. Seawater intrusion was observed at varying depths (14–157 m), with low resistivity indicating saline water presence. Groundwater at Apapa and Island showed high electrical conductivity, confirming seawater intrusion in coastal aquifers. The authors reported that geophysical borehole logs were effective in differentiating freshwater and saline zones.
Obakhume *et al.* (2022)	Integrated geophysical methods: ERT, Induced Polarization (IP), and Well Logging. Five traverses for ERT and IP with Wenner electrode configuration.	ERT, IP, and borehole data revealed freshwater-saline water interface and the extent of saltwater intrusion in Oniru area. Sandy topsoil had high resistivity, with low resistivity indicating saltwater presence. Saline water-bearing zones intermixed with freshwater sand layers. The study provided a reliable database for groundwater management in Lagos State.
Oloruntola *et al.* (2019)	Two-dimensional electrical resistivity tomography (2D-ERT) and physical parameter analysis of water samples. Data processing with DiProWin software.	Freshwater-saline water interface was detected at varying depths (10 m near coast, >50 m further inland). Brackish and freshwater sands observed near the coast. Water samples were mostly slightly acidic with varying total dissolved solids (TDS) and electrical conductivity (EC). Fresh groundwater was identified even near the Atlantic Ocean, which confirmed the occurrence of freshwater aquifers close to the coast.
Callistus *et al.* (2024)	Geophysical investigation using Vertical Electrical Soundings (VES) and Induced Polarization (IP). Groundwater samples analysed for physiochemical parameters.	This study identified the extent of saltwater intrusion in coastal aquifers. Salinity and electrical conductivity values were elevated in areas affected by seawater intrusion. Elevated concentrations of sodium, chloride, and potassium confirmed saltwater contamination. The results of this study provided critical data for sustainable groundwater resource management in the region.
Badmus *et al.* (2021)	Geophysical investigation using Electrical Resistivity Tomography (ERT) with dipole–dipole array. Groundwater samples analysed for physicochemical parameters and Water Quality Index (WQI).	ERT results documented in this report revealed low resistivity (<20 Ωm) in Imakun-omi, Irokun, Isekun, and Ode-omi, indicating saltwater intrusion, especially during the dry season. Physicochemical analysis confirmed higher ionic concentrations and poorer water quality in the dry season, supporting ERT findings.

Table 1 provided a summary of several saltwater intrusion focused studies conducted across Nigeria's coastal region, particularly during the dry season. Multiple geophysical techniques especially Electrical Resistivity Tomography (ERT), Vertical Electrical Soundings (VES), and Induced Polarization (IP) alongside groundwater physicochemical analyses, effectively identified saline zones. Areas such as Imakun-omi, Irokun, Oniru, and Apapa are particularly vulnerable, with salinity, electrical conductivity as well as ionic concentrations exceeding safe limits. The studies also highlighted seasonal variation, with studies conducted during the dry seasons revealing intensified saltwater intrusion rates due to reduced groundwater recharge as well as increased abstraction. Fresh-saline water interfaces are known to vary spatially, sometimes occurring very close to the coastline. The integration of hydrochemical indices, geophysical logging as well as water quality indices can confirm aquifer contamination, therein emphasizing the need for strategic groundwater monitoring and management.

Impact of Saltwater Intrusion

Water quality degradation

The deterioration of groundwater quality is among the most direct consequences of saltwater intrusion especially in areas where groundwater is the main supply, salinization invariably makes water unfit for drinking, cooking, and sanitation (Callistus *et al.,* 2024). Elevated concentrations of sodium, chloride and other salts alter the chemical composition of water and routinely exceed both Nigerian and World Health Organisation (WHO) drinking water limits (Yusuf *et al.,* 2021; Atuchukwu *et al.,* 2022). Food processing, textile manufacture and beverage manufacturing are

among the industries that incur more running costs as salty water is known to damage machinery and interferes with production processes. Likewise, crop viability and soil structure are impacted by excessive salt in surface water supplies utilized for irrigation purposes (Omokaro *et al.,* 2024).

Public health effects

The effects of saltwater intrusion on human health are particularly worrisome as the consumption of salty water has been linked to higher risks of developing renal disease, gastrointestinal problems as well as hypertension (Shammi *et al.,* 2019). Children, expectant mothers as well as the elderly are among the vulnerable groups that are the most vulnerable. Long-term usage of saline-contaminated water has been associated with dental problems, gastrointestinal distress, and skin irritations in coastal regions (Eyankware & Ephraim, 2021; Ugwu & Ofomatah, 2022). Many are forced to rely on unclean surface water due to a lack of alternate water sources, which increases their risk of contracting waterborne illnesses (Aghogho *et al.,* 2024).

Agricultural productivity and food security

Saltwater intrusion can also increase soil salinity and this trend is known to hinder plant development, crop output as well as seed germination with a consequent reduction in agricultural productivity and yield (Demo *et al*. 2025). Examples of crops that are particularly vulnerable to salty environments include; vegetables, rice, maize and cassava (Agbasi *et al.,* 2025). Many farmers in the Niger Delta region, where subsistence farming is prevalent, have reported crop failures and diminishing yields attributed to increased saline soil content. As salt water can decrease feed quality as well as causing dehydration and poor animal health, livestock are also directly affected (Linh & Bleys, 2024).

Economic and social implications

The socioeconomic effects are extensive, and it is more expensive for households and businesses to purchase purification equipment, build deeper boreholes, or source alternative water from suppliers (Olabode *et al.,* 2024). Food insecurity and poverty have been made worse in rural areas by declining crop yields and the loss of arable land. Access to scarce freshwater resources may cause social unrest, and migration from impacted regions may put a burden on public services and urban infrastructure (Tran *et al.,* 2024).

Monitoring and Assessment Techniques

Groundwater modelling and GIS

Predicting the migration of saltwater fronts under various extraction and recharge scenarios and simulating aquifer behaviour is heavily reliant on groundwater modelling in conjunction with Geographic Information Systems (GIS) (Abd-Elaty *et al.,* 2019). The inter-relationship between freshwater and saltwater zones have been assessed, and regions at high risk of intrusion are identified, utilizing models such as MODFLOW and SEAWAT (Dunlop *et al.,* 2019; Nasiri *et al.,* 2021). By helping with the geographical mapping and visualisation of groundwater quality trends, GIS technologies permit decision-makers rank interventions with respect to regional vulnerability (Idowu *et al.,* 2020).

Utilization of water quality indicators (WQIs)

Saltwater intrusion is usually evaluated by direct groundwater sampling and analysis. Total dissolved solids (TDS), electrical conductivity (EC), and ion concentrations such as sodium (Na^+) and chloride (Cl^-) are important water quality markers (Bayabil *et al.,* 2021). Elevated concentrations of these indicators are stand out signs of salt water intrusion, especially chloride values over 250 mg/L. Monitoring these data on a regular basis can make it easier to identify early indications of salt water intrusion and follow changes over time (Aladejana *et al.,* 2021).

Remote sensing and hydrochemical techniques

The utilization of remote sensing technology to supplement ground-based surveillance is growing. Aerial photography and satellite data can identify changes in land use, variations in sea level, and hydrological changes that could affect saltwater intrusion (Azizi *et al.,* 2019). To distinguish between freshwater and saltwater sources and to comprehend the mechanisms influencing water quality, hydrochemical techniques such as ion-ratio analysis and isotopic research are also utilized (Agbasi *et al.,* 2025).

Management and Mitigation Strategies

Regulatory frameworks and water policies

Controlling actions that worsen saltwater intrusion is known to require the strengthening of existing regulatory systems in Nigeria. River Basin Development Authorities (RBDAs) and the Water Resources Act has provided some control measures, albeit the enforcement of these measures is sometimes lax (Ukpai, 2024). It is necessary to establish precise rules on the limits of groundwater abstraction, well building requirements, and the usage of coastal land. Although groundwater regulatory laws have begun to be developed in states such as Lagos, there is still a lack of national enforcement and integration with plans for climate adaption (Omokaro *et al.,* 2024).

Sustainable groundwater management

Encouraging sustainable groundwater usage is one of the best long-term tactic. This approach is known to encompass the creation of networks for monitoring groundwater, routine evaluations of the condition of aquifers as well as the application of regulated abstraction methods (Lal, 2019). Borehole metering and licensing, especially for industrial users, can

lessen over-extraction. The utilization of alternate water sources, such as treated surface water and rainfall collection, can also reduce the burden on coastal aquifers (Agbasi *et al.,* 2025).

Artificial recharge and barrier techniques

The freshwater-saltwater balance can be restored with the utilization of engineering interventions such as artificial recharge, which is known to involve directing surface water into aquifers *via* injection wells or infiltration basins (Motallebian *et al.,* 2019). To stop saltwater from flowing or migrating inland, subsurface barriers can be utilized which can be hydraulic (such as injecting freshwater to create a pressure barrier) or physical (such as clay walls) (Abd-Elaty *et al.,* 2022). Although, they have not yet gained much traction in Nigeria, they have the potential to be utilized locally in high-risk areas.

Public awareness and stakeholder engagement

With respect to the control of saltwater intrusion, public involvement is essential. The causes and effects of excessive abstraction, as well as the need of conserving water, must be taught to communities (Egbueri *et al.,* 2025). The involvement and participation of stakeholders such as Government organisations, researchers, civil society organisations as well as water consumers may promote inclusive decision-making and sustainable practices. Other developing countries have found success with community-based water management initiatives (Agbasi *et al.,* 2025).

Implementation of public water supply systems

The implementation of public water supply systems can be an effective strategy for reducing or lowering the likelihood of saltwater intrusion taking place in parts of Southern Nigeria especially the coastal areas (Abiola & Adeyeye, 2018). Through reduction in the dependence on overexploited groundwater, particularly in coastal regions, these systems can aid in the sustainable management of utilized freshwater aquifers (Asiwaju-Bello *et al.,* 2021). The use of treated surface water, supported by robust infrastructure and institutional oversight, can ensure sustainable water access (Eyankware *et al.,* 2021). This approach can contribute to long-term groundwater management and enhances resilience against the advancing threat of saltwater intrusion.

Conclusion

The study revealed that saltwater intrusion in Nigeria was exacerbated by poor groundwater management, climate change as well as unregulated urbanization. Public water supply systems emerge as a viable mitigation strategy. This study has reinforced the relevance of integrated water resource management (IWRM) theory in coastal resilience planning. Practically, the study highlights the need for policy reforms and infrastructure investment. However, the reliance on secondary data limits context-specific insights, necessitating field-based validation to enhance applicability and inform localized interventions. There is an immediate need for integrated strategies that incorporate remote sensing, hydrological modelling, and socioeconomic evaluations. Policy changes that coordinate groundwater management with land-use planning and climate adaption plans are also desperately needed. Building resilience against saltwater intrusion and guaranteeing water security in the coastal regions of Nigeria would require bolstering institutional capacity, funding research infrastructure, and encouraging cooperation among stakeholders.

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