CHAPTER 24

AN ANALYSIS OF SALINE WATER INTRUSION INTO COASTAL NIGERIA

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ABSTRACT

The present chapter gives an overview of saline water intrusion into coastal Nigeria. This chapter places saline water intrusion into coastal Nigeria in the context of geology, hydrogeology, meteorology, and land use of coastal Nigeria. This chapter suggests ways and means to manage the problem of saline water intrusion into coastal Nigeria.

24.1 INTRODUCTION

Groundwater dynamics that is the movement of groundwater through geological formations and it can be linked to different phenomena that occur in deep aquifers such as the upward advance of saline waters of geologic origin; surface waste discharges into shallow aquifers and the invasion of saline water into coastal aquifers. In recent years, considerable interest has been evinced in the study of flow through porous media, because of their natural occurrence and importance in many engineering problems such as movement of water, oil, and natural gas through the ground, saline water intrusion into the coastal aquifers, flow through packed towers in some chemical processes and filtration. Therefore, the physical understanding of flow through porous media is essential to scientists and engineers working in the related areas. The proposed work as the reported herein is on the movement of groundwater as related to saltwater intrusion into coastal aquifers

and submarine discharge of freshwater into the sea. The mechanism responsible for this phenomenon involves the reduction or reversal of groundwater gradients, which permits denser saline water to displace freshwater and vice-versa. This situation commonly occurs in a coastal aquifer in hydraulic continuity with the sea when pumping of wells disturbs the natural hydrodynamic balance.

Saline water intrusion in fresh groundwater takes place in the vicinity of coastal regions whenever saline water displaces or mixes with freshwater. This situation usually occurs in coastal regions having hydraulic continuity with the sea when the pumping rate in the wells disturbs the natural hydrodynamic balance. The intrusion of saline water into the freshwater coastal aquifer is likely to cause a problem when such aquifer is tapped for domestic water supply or for irrigation. The coast of Nigeria is located in West Africa, part of the Gulf of Guinea. The coastline of Nigeria stretches for about 850km, from the Republic of Benin in the west to Cameroon in the east. It forms part of the West African groundwater region. River Niger discharges into the Gulf of Guinea via a delta as the major river, thereby, dividing the coastline into two parts. Other rivers discharge through estuaries either into the lagoon of directly into the ocean. The surface strata of the coastline of Nigeria consist of unconsolidated coastal plain sands. Lagoons, estuaries, creeks, and delta dominate the Nigerian coastline. The vegetation of the area is mangrove swamp forest that is being cleared for wood and to give room for other economic activities. The western of the coastline is highly populated with total dependence on groundwater to meet domestic and industrial demands. Thousands of private boreholes have been drilled in the area to extract groundwater for drinking. Continuous pumping or heavy extractions of groundwater have led to increment of chloride content in groundwater. The chloride/bicarbonate ratio is a very good indicator of saline water contamination in groundwater. High chloride content in groundwater may also be caused by the presence of chloride-containing minerals in the area, or there are pollutants being discharged into groundwater. The major cause of saline water pollution into groundwater in this area is as a result of saline water intrusion. Upcoming occurs below wells as a result of continuous pumping of freshwater. The entire coastline of Nigeria is divided into seven administrative units (Lagos, Ogun, Ondo, Delta, Bayelsa, Rivers, and Akwa Ibom states).

Saline water intrusion is one of the most common forms of groundwater contamination in coastal areas (Bear et al., 1999). Saline water intrusion is the movement of salty water into an aquifer or surface water with the consequent mixing or displacement of fresh water. When groundwater is

pumped from aquifers that are in hydraulic connection with the sea, and the piezometric surface of the fresh water is lowered, the balance between the saline water/freshwater interface is disturbed, the hydraulic gradients so created induce seawater to encroach the freshwater aquifer (Domenico and Schwartz, 1998; Walton, 1970).

Saline water intrusion has been a major water resource problem in the urban coastal areas of the Niger Delta, and it has therefore been and continues to be a focus of considerable research efforts over time. This is because a scientific understanding of the occurrence of salt and fresh waters in a particular coastal area is essential for the development and management of the water resource. Nigeria has a coastline that is about 1000 km long with the Atlantic Ocean bordering eight States. These are: Rivers, Bayelsa, Akwa Ibom, Cross Rivers State, Delta, Ondo, Ogun, and the Lagos States. Potable water supply to inhabitants in some of the communities in the coastal belt (especially in the saline mangrove swamp) has been a major problem due to saltwater intrusion. Water wells and boreholes drilled have been abandoned in many communities due to high salinity. They, therefore, depend on rain harvesting and purchasing water from water merchants. In Nigeria, there have been few studies aimed at assessing freshwater resources in coastal areas of the country. This forms the main thrust of the proposed research.

The quality of water is the main constraint of groundwater in the coastal aquifers in Nigeria. Like all coastal aquifers worldwide, saline water intrusion into aquifers is the major source of quality impairment in the coastal aquifers in Nigeria. This is followed by pollution from spillages of crude and refined petroleum and lastly by leachates from municipal and other industrial wastes. Most of the confined aquifers in the coastal areas of Nigeria have high iron concentration such that treatment for the removal of iron has to be undertaken. Saline water intrusion into unconfined and confined aquifers occurs in Niger Delta. In Coastal beach ridges or sandy islands within the saline mangrove belt, freshwater lens floating above saline water-bearing sands are found to occur in the unconfined aquifers (Oteri, 1990). The growth of industrial development within the urban coastal areas of the Niger Delta and the attendant population explosion places a very heavy demand on the lean supply of fresh water. According to Frank Briggs (2003) "indiscriminate abstraction of groundwater from the first aquifer has resulted in saltwater intrusion in several coastal wells…." This limits the supply of potable drinking water in the area, which can have detrimental effects on human health, wildlife habitat and increase the cost of water treatment (Domenico and Schwartz, 1998).

24.1.1 GEOGRAPHY AND METEOROLOGY OF COASTAL NIGERIA

In Nigeria, eight states are bounded to the south by the Atlantic Ocean. They include from West to East – Ogun, Lagos, Ondo, Delta, Bayelsa, Rivers, Akwa Ibom, and the Cross River States. The states are contiguous and are in direct contact with the sea. They are located between latitude 7° and 4° 10' N and longitudes 2° 30' and 8 30' East. There are a number of highly populated cities situated within the coastal area of these states which include Port Harcourt, Warri, Yenagoa, Lagos, Uyo, and Calabar. The coastal states of Nigeria fall within the humid tropical zone of the country. Rainfall is copious and lasts for eight to nine months of the year (mid-March to early-November) with a mean annual value often exceeding 3000 mm at the coastal fringes at Akasa and Brass. Seasonal changes of wet and dry are as a result of the interplay of two contrasting air masses – the moisture-laden SW monsoon winds blowing into the country from the Atlantic Ocean and the dry North East Trade winds from the Sahara desert. The two main rivers in the southwestern part of Nigeria are Ogun and Oshun which drain into the ocean.

24.1.2 GEOLOGY OF COASTAL NIGERIA

Geologically, coastal Nigeria is made up of two sedimentary basins-the Dahomey Basin and the Niger Delta Basin separated by the Okitipupa Ridge. The Dahomey Basin covers the southern areas of Lagos, Ogun, and the Ondo States in Nigeria and stretches into the neighboring countries of Benin, Togo, Ghana, and Ivory Coast. The present study is centered on the Niger Delta area of Nigeria. The geological formations of primary interest for the evaluation of the groundwater resources potential of the study area are the sedimentary formations deposited in the Niger Delta during the Eocene-Quaternary periods. The stratigraphic sequence under consideration comprises, from oldest to youngest formations, the Imo Shale Group, the Ameki Formation, the Benin Formation, and the Quaternary deposits as described by Amajor and Agbaire (1989).

The Imo Shale Group is made up of marine clay, shale, and limestone. The formation is estimated to have a thickness of up to 1,000 m, and it outcrops in a belt more than 100 km north of the study area. The formation, due to its impermeable texture, is believed to constitute the base of the groundwater aquifers under consideration in the study area. The Ameki Formation overlies the Imo Shale Group. It comprises numerous alternations

of marine shales and fine to coarse, very heterogeneous, coastal – deltaic sands and sandstones. The formation is estimated to have a thickness of up to 1,700m and is out-cropping in an east-west and north-west – south-east oriented belt, approximately 100km north of the study area. The groundwater resources potential of the formation is believed to be good (Tahal, 1998). The present-day Niger Delta is defined geologically by three subsurface sedimentary sequences consisting of Benin, Agbada, and Akata Formations (Short and Stauble, 1967).

24.2 BENIN FORMATION

The Benin Formation overlies the Ameki Formation. The formation is an extensive stratigraphic unit in the Southern Sedimentary Basin, with an average thickness of about 1,900 m (Short and Stauble, 1967). The formation is recognized throughout the delta due to its few shale streaks, the absence of brackish water and a high percentage of sand. The Benin Formation, which consists mainly of coastal plain sands, extends from the west across the whole Niger Delta area and southward beyond the present coastline. The sediments comprise yellow and white sands with pebbly gravels. The clays and sandy clays occur in lenses of 3m to as much as 10m, and they make the groundwater formation a multi-aquifer system. The formation is massive porous fresh water-bearing sandstone with localized thin beds. The formation is, due to its coarse texture and huge outcrop area, believed to constitute a very good groundwater aquifer. The aquifer in this basin has a southwest gradient towards the Delta, and it thickens seawards in the same direction of groundwater movement. It is thus the most prolific aquifer in the region. It is overlain by the Quaternary deposits, which ranges in thickness in between 133 – 500ft (Etu – Efeotor and Akpokodje, 1990). The Quaternary deposit, which comprises recent deltaic sediments made up of sand, silt, and clay beds, overlies the Benin Formation in the swampy delta areas. The formations have a seaward dip resulting in confined aquifers.

The sandstones of the Benin Formation are coarse-grained, locally fine -grained, poorly sorted and sub angular to well rounded. The age of the Benin Formation lies between Oligocene and Recent. This formation constitutes the major aquifer in the Niger Delta area (Udom et al., 1999). Whiteman (1982) notes that a formation such as the Benin Formation, deposited in a continental fluviatile environment has a highly variable lithology, can be recognized because of its high sand percentage (70–100%), few minor shale intercalations and the absence of brackish water and marine faunas.

To date, very little oil has been found in the Benin Formation (mainly minor oil shows).

24.3 AGBADA FORMATION

The Agbada Formation underlies the Benin Formation and forms the second of the three strongly diachronous Niger Delta complex formations. It comprises mainly of alterations of sands, silts, and shales in various thicknesses and proportions, indicative of cyclic sequences of off-lap cycles, better called off-lap rhythms (Weber, 1971). The characteristic features of the sandstones here are poor sorting, calcareous matrix and shell fragment occurrences. The grain size varies from fine to coarse. The approximate total thickness of the Agbada Formation lies between 10,000 ft and 12,000 ft (Kogbe, 1976). The top of the Agbada Formation is sandy whereas the bottom is shaley because it grades into the Akata shales gradually. The shales are denser at the base of the formation due to the compaction process. The sandy parts constitute the main hydrocarbon reservoirs in the delta oil fields. The shales constitute seals to the reservoirs and as such are very important because the formation is rich in hydrocarbon. Paralic clastics of the Agbada Formation represent the true deltaic portions of the delta top-set and fluvio-deltaic environment (Short and Stauble, 1967; Weber and Dakoru, 1975). However, Whiteman (1982) notes that the Agbada Formation, as defined by Short and Stauble (1967), contains beds laid down in a variety of sub-environments grouped together under the heading-paralic environment. The age of the Agbada Formation ranges from Eocene to Recent.

24.4 AKATA FORMATION

This formation is the basal major time-transgressive lithological unit of the Niger Delta Complex. It is composed mainly of marine shales, but contains sands and silty beds which are thought to have been laid down as turbidites, and continental slope channel fills. The shales are typically under-compacted and over-pressured, forming diapric structures. Whiteman (1982) contributes that the Akata Formation is rich in planktonic foraminifera, which indicates deposition on a shallow marine shelf environment. The formation occurs between depths of 0–6000 m below the Agbada Formation and ranges in age from Paleocene to recent. It represents the pro-delta mega facies (Tahal, 1998).

24.5 HYDROGEOLOGY AND AQUIFERS OF THE STUDY AREA

In the study area, groundwater is abstracted from the Benin Formation, mainly from its upper section. Lenses of silty clay of some few meters thickness have been recorded in the borehole penetrating the Benin Formation (Tahal, 1998). To the south of Port Harcourt, belts rich in shales lying at a depth of 10m to 200m have been observed. These lenses create several sub-aquifers in the Benin Formation, the upper sub-unconfined, while the deeper aquifers range from leaky to confined and are isolated from the ground surface. The natural recharge comes mainly from the northern high coastal plain. Generally, the sediments of the Benin Formation dip seawards at a low gradient. The upper section of these sediments is being utilized in the development of groundwater.

The sandy components, in most layers, are about 90% of the lithological sequences (Tahal, 1998). The size distribution of the sedimentary particulates does not vary significantly from place to place in the study area. There is a steady gradation in quantity between coarse sands and clay beds. Locally to some extent, the clay beds separate hydraulically between the sub-aquifers.

Groundwater abstracted from the upper Benin Formation is characterized by low p^H (acidity), high carbon dioxide (CO_2) content, and hence it is corrosive and soft. In addition, the groundwater contains high concentrations of iron and therefore requires treatment. The water tables of all sub-aquifers penetrated by boreholes are relatively shallow and range between 5m to 15m where hydrostatic water levels increase with the depth (Tahal, 1998). According to Etu – Efeotor, and Odigi (1983), three main zones have been differentiated as follows:

i) A northern zone is consisting shallow aquifer of predominantly continental deposits.
ii) A transitional zone of marine and continental materials.
iii) A coastal zone of predominantly marine deposits.

Aquifer distributions in the Niger Delta are controlled by the geology. Table 24.1 is the summary of the properties and behavior of hydrostratigraphic units in the Niger Delta Basin. In most parts of the Niger Delta, including the study area, a multi -aquifer system is encountered, and the aquifer lies within the arenaceous Benin Formation. The depth to water table of the Benin Formation ranges between 3–5 m below ground level (Offodile, 1984). Ngah (1990) also identified three main aquifer zones in the Niger Delta Viz:

i) An upper unconfined aquifer is extending throughout the Benin Formation with its thickness ranging between 15–80 m while the Static Water Level (SWL) varies between 4m and 21 m.
ii) A middle aquifer system, semi -confined and consisting of thick medium to coarse-grained, sometimes pebbly sands with thin clay lenses. Its thickness varies between 30–60m.
iii) A lower aquifer system that extends from 220–300 m and consists of coarse -grained sands and gravels with some interlayer clay. The majority of the groundwater wells abstract water from the first and second aquifers (<100 m deep). The very few industrial and municipal groundwater supply wells tap deeper aquifers.

24.5.1 AQUIFER RECHARGE IN THE STUDY AREA

Precipitation is the main source of recharge to aquifers. The rate of recharge depends to a large extent on the infiltration capacity of the soil, evaporation rate and the overland drainage characteristics. In places where sandy clay forms a part of soil layers, recharge usually occurs mainly through a distant outcrop of the porous formation and partially through the lateritic sand. The northern and the southern movement of air masses and pressure belts characterize the rainfall regime of the coastal plain. The amount of rainfall decreases inland from the coast. The isohyets run parallel to the coast up to a line through Ahoada-Degema-Port Harcourt. From this line inland, the decrease in rainfall is much slower. According to the lithologic profile of some boreholes, in some places, there are few meters of lateritic sandy clay under the soil. Tahal (1998) observed that about 30% to 40% of the yearly average of rainfall (2,280mm) could infiltrate and recharge the Benin Formation. To the north, sandy, and porous outcrops exist, where the replenishment can be 60% to 70% of rainfall. The estimated annual recharge to the aquifer in the study area from the Northern High Coastal Plain is about 100 mcm to 150 mcm (Tahal, 1998).

24.5.2 PROBLEMS AFFECTING THE COASTAL AQUIFER ECOSYSTEM IN NIGERIA

The major constraint to the water resource in the aquifers of the coastal Nigeria is quality. The saline water intrusion is both natural and man-made. For the natural saline water intrusion, the problem is exacerbated by:

TABLE 24.1 Summary of Properties and Behavior of Hydrostratigraphic Units in the Niger Delta Basin

Hydrogeological basin	Hydrostratigraphic units	Lithologic details	Aquifer type and characteristics	Water quality	Economic importance
Niger Delta Basin	Alluvial plains aquifer	Sands, clays, silt	Unconfined	Saline water	Domestic Municipal Industrial uses
	Meander Belt aquifer	Sands, gravel, clays		Corrosion	
	Mangrove swamp aquifer	Sands, clay, swamps	Good, water table is confined	Iron-rich saline water intrusion	
	Abandoned Ridges aquifer, Sombrero	Sands and pebbles, yellow sands, clays	Poor aquifer		
	Benin aquifer	Sand, clays	Prolific		
	Delta Ogwashi – Asaba Ameki aquifer	Clays, shale, lignite, silty sand, clay siltstone	Aquitard	Problematic with iron and saltwater encroachment, Low Ph	
	Imo shales Deep oceanic Agbada – Akpata Shales	Shalestone, claystone lenses of sands	Aquitard Aquitard		

- The lack of willingness to carry out necessary studies or utilize such studies when carried out.
- Lack of appreciation of the need for water resources assessment and management groundwater resources of the coastal aquifers resulting in over-exploitation of the aquifers.
- The activities of man have also led to increased saline water intrusion through.
- Uncontrolled development of both unconfined and confined aquifers especially in Port Harcourt Metropolis, Lagos, Warri, and Bonny. In Lagos which is the commercial capital of Nigeria, the problem is particularly acute as many boreholes which were producing fresh water after drilling becomes salty a few months after especially in Ikoyi, Victoria Island and Apapa.
- Lack of proper sealing of disused boreholes or those abandoned due to saltwater intrusion.
- The groundwater in most of the confined aquifers in coastal Nigeria is corrosive, and casing corrosion is a major source of borehole failures. There is a need to determine the best material for casing and screens and also best completion techniques that will prevent saline water ingress into fresh water yielding boreholes especially in situations where the freshwater aquifers underlie saline water-bearing sands.
- Sea water level rise (as a result of global warming); the building of dams in upstream areas of the rivers leading to low flows and decrease in river sediments to the coast by the rivers have all led to increased coastal erosion.
- Construction of drainage canals, transportation canals.
- Urbanization – In the Lagos area for example. The rate of Urbanization is so high that the recharge area has been converted to concrete zones, while swamps and streams are being reclaimed and turned into cities. This decreases the amount of recharge to the aquifers, thereby increasing saline water intrusion.
- Oil spillage from both upstream and downstream operations of the oil industry is the next major problem affecting both the aquifers and the environment of coastal areas in general.
- Finally, disposal of wastes from industries and municipal areas is a threat to the coastal aquifer ecosystem.

24.6 CONCLUSIONS

The control of saline water intrusion demands knowledge of the hydraulic conditions within aquifer; it also demands knowledge of the source of the saline water. It is, therefore, necessary to identify the extent of the problem and to assess the behavior of the saline water body under various conditions of recharge and discharge, such that efficient water resources management plans can be implemented. The optimum solution to the problem of saline water intrusion is prevention, by which the encroachment of saline water is controlled to an acceptable degree. But in many cases, the problem is a legacy of the past; therefore, management must concentrate on minimizing further intrusion, and/or reducing the extent of the existing saline water, it may be that the aquifer in question is too badly polluted so reclamation may be the only viable option. In extreme cases, if the resource for potable water supply, it may be abandoned, although the water may still be utilized for certain industrial or agricultural applications.

KEYWORDS

- **coastal regions**
- **Nigeria**
- **saline water intrusion**

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