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SALINE WATER INTRUSION INTO COASTAL NIGERIA

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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 seawater 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 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

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reversal of ground water gradients, which permits denser saline water to displace freshwater and vice-versa. This situation commonly occurs in 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 seawater displaces or mixes with freshwater. This situation usually occurs in coastal regions having hydraulic continuity with sea when the pumping rate in the wells disturbs the natural hydrodynamic balance. Intrusion of seawater into freshwater coastal aquifer is likely to cause problem when such aquifer is tapped for domestic water supply or for irrigation.

The coast of Nigeria is located in West Africa. The coastline of Nigeria stretches for about 1000km, from Republic of Benin in the west to Cameroon in the east. It forms part of the West African groundwater region. River Niger discharged into the Gulf of Guinea via a delta, as the major river thereby dividing the coastline into two parts. Other rivers discharges through estuaries either into lagoon of directly into the ocean. The surface strata of the coastline of Nigeria consists 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 ground water have led to increment of chloride content in groundwater. The chloride/bicarbonate ratio is a very good indicator of saline water contamination in ground water. 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 is this area is as a result of saline water intrusion. Upcoming occurs below wells as a result of continuous pumping of freshwater.

Saltwater intrusion is one of the most common forms of groundwater contamination in coastal areas (Bear, 1999). Saltwater 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 seawater/freshwater interface is disturbed, the hydraulic gradients so created induce sea water to encroach the freshwater aquifer (Domenico and Schwartz, 1998: Walton, 1970).

Saltwater 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 1000km long with the Atlantic Ocean bordering eight States. These are: Rivers, Bayelsa, Akwa Ibom, Cross Rivers State, Delta, Ondo, Ogun and 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 salt water 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 fresh water resources in coastal areas of the country.

The quality of water is the main constraint of ground water in the coastal aquifers in Nigeria. Like all coastal aquifers worldwide, saltwater 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.

Saltwater intrusion into unconfined and confined aquifers occur in Niger Delta. In Coastal beach ridges or sandy islands within the saline mangrove belt, fresh water lens floating above saltwater-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 Akpokodje (1998, in Frank Briggs 2003) "indiscriminate abstraction of ground water from the first aquifer has resulted in salt water intrusion in several coastal wells…". This limits the supply of potable drinking water in the area, which can have detrimental effects on human health, wild life habitat and increase the cost of water treatment (Domenico and Schwartz, 1998).

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 Cross River States. The States are contiguous and in direct contact with the sea. They are located between latitude 7^0 and 4^0 10' N and longitudes 2^0 30' and 8^0 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.

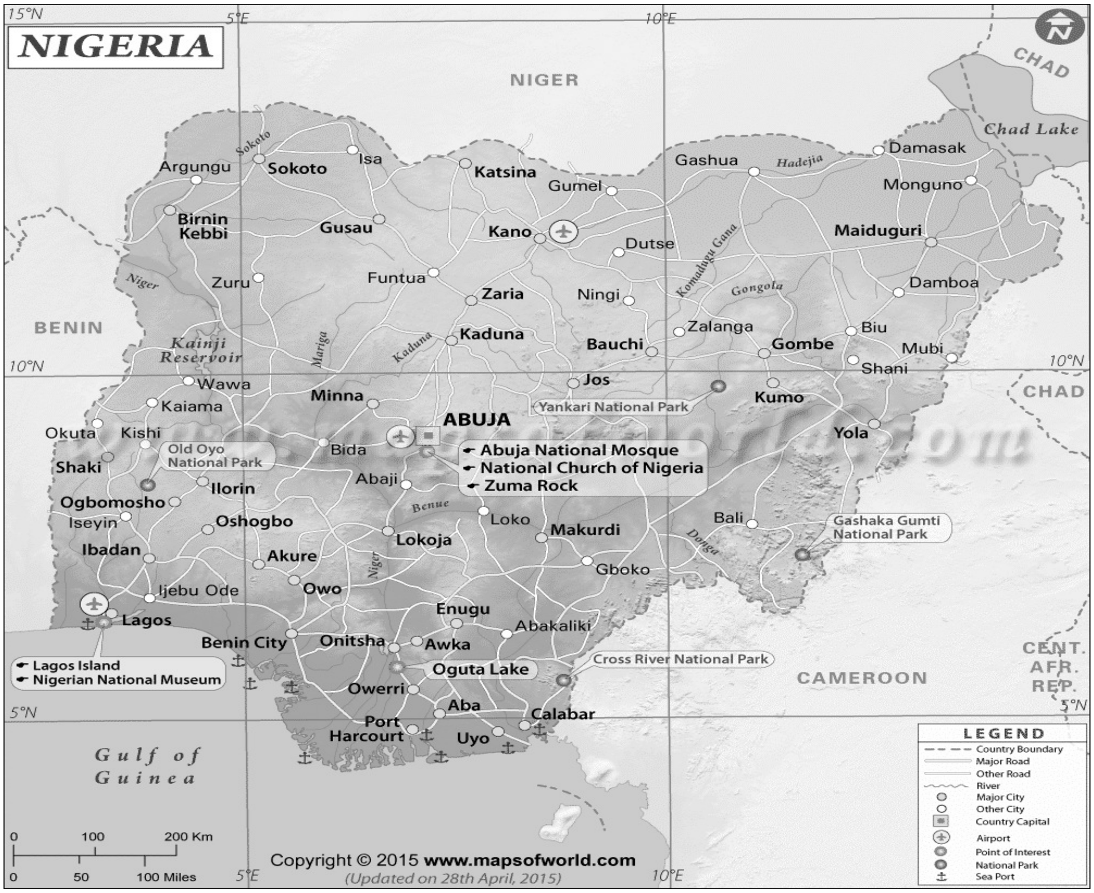

Fig. 1. Map of Nigeria

The coastal States of Nigeria fall within 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 mean annual value often exceeding 3000mm 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.

Fig. 2. Map of rivers in Nigeria

GEOLOGY OF THE AREA

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 Ondo States in Nigeria and stretches into the neighbouring countries of Benin, Togo, Ghana, and Ivory Coast.

This study is centered on the Niger Delta area of Nigeria.

Table 1: Stratigraphic succession of the niger delta

SUB SURFACE			**SURFACE OUTCROPS**		
Youngest Known Age		Oldest Known Age	Youngest known Age		Oldest known Age
Recent	Benin Formation	Oligocene	Plio/Pliestocene	Benin Formation	Miocene
Recent	Agbada Formation	Eocene	Miocene Eocene	Ogwashi-Asaba Ameki Formation	Oligocene Eocene
Recent	Akata Formation	Eocene	Lower Eocene Paleocene	Imo Shale Nsukka shale	Paleocene Maestrichtian
Equivalent not known			Maestrichtian Campanian Camp/Maest. Coniacian Santonian Turonian Albian	Ajali Fm Mamu Fm Nkporo Shale Agwu Shale Eze Aku Shale Asu River Group	Maestrichtian Campanian Santonian Turonian Albian

(Short and Stauble, 1967)

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 1,000m and it outcrops in a belt more than 100km 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).

Table 2: Tertiary correlation chart of the niger delta succession and outcrop equivalents

AGE	SURFACE FORMATIONS	SUB SURFACE EQUIVALENTS	BROAD DEPOSITIONAL ENVIRONMENTS
PLIOCENE - RECENT	COASTAL PLAIN SANDS	BENIN FORMATION AFAM & QUA IBOE CLAY MEMBERS	CONTINENTAL
MIOCENE - RECENT	OGWASHI - ASABA FM IJEBU FM		
EOCENE - RECENT	AMEKI FORMATION ILARO & OSHOSHON FM	AGBADA FM	PARALIC
PALEOCENE - RECENT	IMO SHALE FM	AKATA FM	MARINE

(Amajor and Agbaire, 1989)

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 1,900m (Short and Stauble, 1967). The formation is recognized throughout the delta due to its few shale streaks, absence of brackish water and 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, a massive porous fresh water-bearing sandstone with localized thin beds. The formation is, due its coarse texture and huge outcrop area, believed to constitute a very good groundwater aquifer. The aquifer in this basin has a south-west 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 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).

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 10,000ft and 12,000ft (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.

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 forminifera, which indicate deposition on a shallow marine shelf environment.

The formation occurs between depths of 0-6000m below the Abgada Formation and ranges in age from Paleocene to Recent. It represents the pro – delta mega facies (Tahal, 1998).

HYDROGEOLOGY AND AQUIFERS OF THE STUDY AREA

In the study area, groundwater is abstracted from the Benin Formation, mainly in its upper section. The groundwater potential of the Benin Formation is assumed to be 1mcm sq.km (Tahal, 1998).

Lenses of silty clay of some few metres 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. Table 3 shows the lithological variations of the Niger Delta. 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.

Table 3: Lithological variations of the niger delta

STRATIGRAPHICAL SEQENCE			LITHOLOGY	MAXIMUM THICKNESS (m)
Quaternary		Alluvium in general	Gravel, sand, silt, clay	100
		Meander belt	Gravel, sand, clay	
		Wooded back-swamps and fresh water swamps	Silt, clay	
		Mangrove swamps	Fine sand, silt, clay	
		Lagoonal marshes	Silt, clay	
		Abandoned beach ridges	Sand, silt, clay	
		Sombreiro – Warri deltaic plain	Sand, clay, silt	
Tertiary	Miocene	Benin Formation (coastal plain sand)	Sand, coarse sand with clay and shales	2,000
		Ameki Formation	Clay, Sand, Shale	1,700
	Eocene	Imo Shale Group	Clay, sand, shale, limestone	1,000

(Kampsax – Krüger, 1985)

Groundwater abstracted from the upper Benin Formation is characterized by low p^H (acidity), high carbondioxide (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:
-a northern zone consisting shallow aquifer of predominantly continental deposits;
-a transitional zone of marine and continental materials;
-a coastal zone of predominantly marine deposits.

Aquifer distributions in the Niger Delta are controlled by the geology. Table 4 is the summary of the properties and behaviour 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 3m – 5m below ground level (Offodile, 1984).
Ngah (1990) also identified three main aquifer zones in the Niger Delta. They are:
(i)an upper unconfined aquifer extending throughout the Benin Formation with its thickness ranging between 15m – 80m 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 30m – 60m

(iii)a lower aquifer system that extends from 220m – 300m 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 (<100m deep). The very few industrial and municipal ground water supply wells tap deeper aquifers.

Table 4: Summary of properties and behaviour of hydrostratigrapic units in the niger delta basin

Hydrogeol-ogical basin	**Hydrostratig-raphic 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, Sombreiro	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 salt water encroachment, Low Ph	
	Imo shales Deep oceanic Agbada – Akpata Shales	Shalestone, claystone lenses of sands	Aquitard Aquitard		

AQUIFER RECHARGE IN

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 of rainfall is much slower.

According to the lithologic profile of some boreholes, in some places there are few metres 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 100mcm to 150mcm (Tahal, 1998).

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 saltwater intrusion is both natural and man-made. For the natural saltwater intrusion, the problem is exacerbated by:

- The lack of willingness to carry out the necessary studies or utilize such studies when carried out.
- Lack of appreciation of the need for water resources assessment and management ground water resources of the coastal aquifers resulting in over-exploitation of the aquifers.

The activities of man have also led to increased saltwater 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 become salty a few months after especially in Ikoyi, Victoria Island and Apapa.
- Lack of proper sealing of disused boreholes or those abandoned due to salt water 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 determined the best material for casing and screens and also best completion techniques that will prevent saltwater ingress into fresh water yielding boreholes especially in situations where the fresh water aquifers underlie saline water bearing sands.

- Sea water level rise (as a result of global warming); 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
- Urbanisation – In the Lagos area for example. The rate of urbanisation is so high that recharge area have 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 saltwater 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 coastal aquifer ecosystem.

MANAGEMENT OF THE PROBLEM

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 behaviour of the saline water body under various conditions of recharge and discharge, such that efficient water resources management plan can be implemented. The optimum solution to the problem of saline water intrusion is prevention, by which the encroachment of seawater 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.

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