

Threats to Water Resources Development in Nigeria

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Abstract

"Threats to Water Resources Development" is a broad topic having global and national dimensions. Even though these threats cut across international boundaries, this paper focuses on the Nigerian geographical boundaries. We start with the general understanding that our water resources are made up of surface and groundwater components which are hydraulically connected. Secondly, these threats arise from two causes; natural and anthropogenic. The natural causes include all those adverse fallouts from climate change and hydrological extremes: well failures in shallow aquifers due to imbalance in seasonal precipitation and abstraction in the Sahel; sea level rise with attendant salt water intrusion in the coastal aquifers, decreased discharge rate of surface waters due to soil moisture deficits. The man-made threats include industrial wastes, effluents and oil spillages. Salinization of surface and ground waters through irrigation and fertilizers. Issues of threats to water resources development in Nigeria therefore follows the trajectory of water habitats, agricultural and industrial practices. While the Sahel with less than 750 mm rainfall per annum grapples with shallow well failures, water stress due to soil moisture deficits and salinization of surface and ground waters, the tropical rainforest zone with rainfall of 1250 mm-2500 mm contends with oil spillages which endanger local sources of water supply, and sea water intrusion. The Savannah zone with 1000 mm-1250 mm rainfall is relatively immune from the above natural threats but the anthropogenic threats more than compensates for these gains due to regulation lapses.

Keywords: Water resources; Development; Threats; Nigeria

Introduction

Nigeria is located approximately between latitude 4° and 14° North of the Equator, and between longitudes 2° 2' and 14° 30' East of the Greenwich meridian (Figure 1). It is bordered to the north by the Republics of Niger and Chad, to the south by the Atlantic Ocean, to the east by the Republic of Cameroon and to the west by the Republic of Benin. The population is more than 140 million, spread unevenly over a national territory of 923,770 km². Nigeria has the eighth largest national population in the world and about a quarter of the total population of all the countries in Sub-Sahara Africa.

In Nigeria, Water is widely regarded as the most essential of natural resources, yet freshwater systems are directly threatened by human activities and stand to be further affected by anthropogenic climate change. Water systems are affected by intensive agricultural activities; urban development, industrialization and unplanned engineering infrastructures. Unplanned agricultural practices arising from lack of adequate extension workers and largely unmechanised procedures leave farmers with the option of bush burning as the only site clearing method. This practice results in deforestation which translate into land degradation and mass wasting events leading to soil water deficits and sediment loading of surface water. Irrigation practices often affect the wetland hydrology of downstream areas thereby impacting negatively on aquatic ecosystem. It has become common practice in most Nigerian cities to always resort to surface water bodies as a viable receptacle of solid and industrial wastes.

The quantity and quality of Nigeria's water resources are affected by the coupling of the human factors and climate change. The spatial distribution of rainfall, climate pattern and hydrogeological units from the coastal areas to the Sahel regions of Nigeria provide a framework for the identification of the threats in terms of quantity and quality.

Considering the importance of water to a developing nation like Nigeria, and in line with the MDGs number 7, the issues to be addressed are; the ever increasing water demand due to urban population increase vis-à-vis the impairment of the available water resources from both manmade and natural causes. Identification of these threats and their pathways are key to the formulation of mitigation or adaptation

measures. This research work therefore sets out to: (1) Identify the factors adverse to the water resources development initiatives in Nigeria. (2) Establish patterns in the causality of these factors within the geographical areas of Nigeria. (3) Highlight human factors and the desired change needed to curtail or contain the environmental effects. (4) Advise government on future actions to minimize all natural and eliminate all human environmental threats to water in Nigeria.

Water Resources of Nigeria - Spatial and Temporal Distribution

The water resources of Nigeria are enormous and unevenly distributed among the various hydrological areas. The Niger Delta and tropical rainforest areas have the highest precipitation of about 300 mm/year and longer duration of rainfall up to eight months. This is followed by the Savannah zone with 1000 mm-1250 mm/year rainfall, the amount of rainfall decreasing northwards. The Sahel has annual precipitation of less than 750 mm/year and may be as low as 500 mm/year in the northeastern region occasionally. Rainfall duration can span for 3-4 months in these northern zones and shallow wells normally dry up during the dry seasons due to insufficient recharge. The south witnesses massive flooding and inundation of coastal aquifers by saline water especially low lying areas and reclaimed wetlands.

Surface water resources

According to Spon [1], there are four major drainage systems in the country:

- The Niger River Basin Drainage System with its major tributaries

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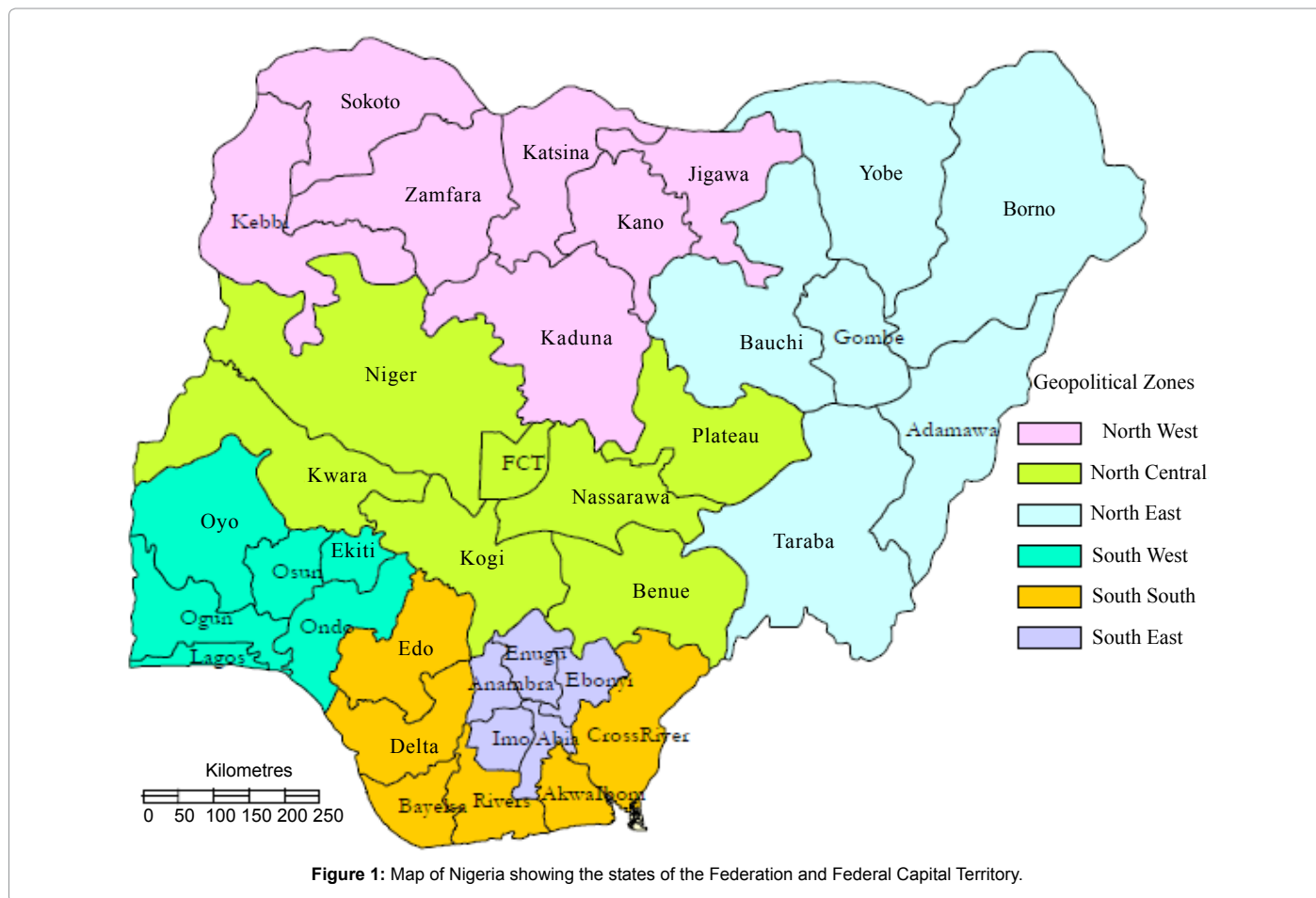


Figure 1: Map of Nigeria showing the states of the Federation and Federal Capital Territory.

of Benue, Sokoto-Rima, Kaduna, Gongola, Katsina-Ala, Donga, Tarabe, Hawal and Anambara Rivers.

- The Lake Chad Inland Drainage System comprising the Kano, Hadejia, Jama'are, Misau, Komadougou-Yobe, Yedoseram and Ebeji Rivers.
- The Atlantic Drainage System (east of the Niger) comprising the Cross River, Imo, Qua Iboe and Kwa Rivers.
- The Atlantic Drainage System (west of the Niger) made up of the Ogun, Oshun, Owena and Benin Rivers.

Apart from the Lake Chad Inland Drainage System, the remaining three drainage systems terminate in the Atlantic Ocean with an extensive network of delta channels (Figure 2).

From the annual total rainfall of 560 Km³, surface run-off is estimated at 215 Km³/yr, distributed among the major drainage systems as follows (Martins) [2]–

Niger- Benue Drainage System:	127 × 10 ⁹ m ³
Lake Chad drainage System:	0.63 × 10 ⁹ m ³
South-east (Cross R., Anambra R., etc.):	66 × 10 ⁹ m ³
-South-west (Ogun R., Oshun R., etc) :	22 × 10 ⁹ m ³

The Niger-Benue system alone accounts for over 50% of the total annual run-off.

Ground water resources

Groundwater resources are controlled by the hydrostratigraphy of the country and follow the pattern of occurrence of the aquifers, aquitards or aquicludes (Figure 3). More than half of the country is made up of igneous and metamorphic rocks which make up the basement complex. Even though these hard rocks are essentially non-waterbearing (aquiclude) there are areas of weathered basement rocks which have acquired secondary porosity due to weathering over geologic time. These areas furnish moderate to marginal water yields at depths of 20-100 m. normally, weathering and compaction processes are followed by fracturing which is a major factor of incompetent rocks at depths. These secondary aquifers are characterized by their non-extensive nature, susceptibility to anthropogenic pollution and climatic vagaries. As one proceeds towards the south, The prospects of good aquifers increase. Thus within the anambra basins and niger delta basins ground water yield becomes extensive to the extent that free flow conditions occur in confined areas.. Unlike surface water that cuts across geographical boundaries, the occurrence of groundwater in terms of quantity and quality displays spatial variability being driven by the geology and climate. On this premise, we can chronicle the availability based on three hydro-meteorological areas:

The Sahel region: Although the Sahel region comprises areas above latitude 11°, there is gradual southward advancement of the Sahara to now cover areas down to 10° latitude. As a result, three River basins are considered to lie within the Sahel; the Sokoto basin, the Hadejia-Yobe basin and the South-east Chad basin. The main characteristics of the

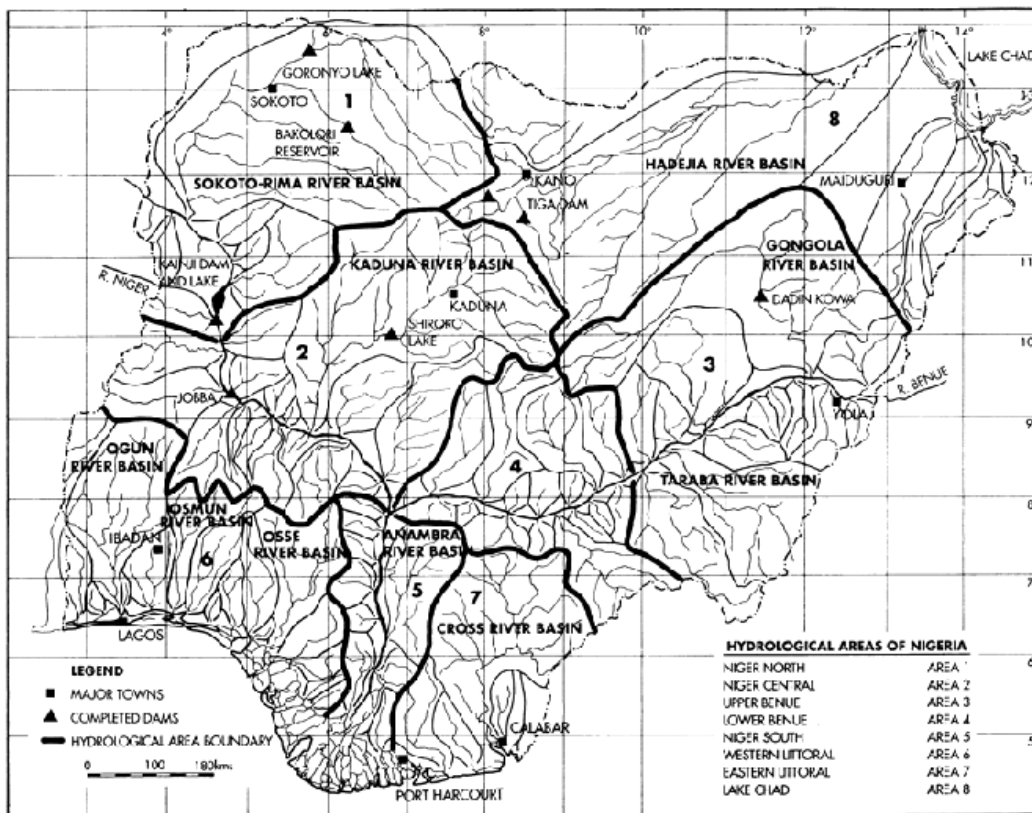


Figure 2: Map of Nigeria showing the Hydrological areas and Drainage network.

MAP OF NIGERIA SHOWING HYDROGEOLOGICAL SETTING



Figure 3: Hydrogeological Setting depicting Relative Permeability and Runoff Potentials.

area are low annual precipitation of 500-750 mm. The region is also associated with greater extremes of temperature as high as 44°C before the onset of the rains or drop to as low as 6°C during the cool harmattan air around December to February.

The Sokoto basin is drained by the River Sokoto with the Ka, Zamfara and Rima as tributaries. The groundwater resources are furnished by the fractured meta-sediments within the basement complex. Boreholes in these meta-sediments are shallow (30-40 m). Borehole yields are low (0.5-0.8 lit/sec), with steep drawdown. The Gundumi and Illo Formations are aquiferous but occasionally deeply confined. Yields of 8 lit/sec and transmissivity of up to 978 m²/day have been reported at Gusau-Sokoto road by Anderson et al. [3]. Another borehole in the same town (Bakura Farm) was 85 m deep and gave 3 lit/sec. The Rima group comprising the Taloka (poor aquifer) and Dukamaje (aquiclude) Formations are not impressive hydrogeologically. The Wurno Formation is a moderate water yielding aquifer in the Sokoto basin. The thickness varies from 5-30 m and the recharge is restricted to only 330 km² [4]. The Sokoto Group consists of the Dange (aquitard), the kalambiana (perched aquifer, furnishing water seasonally) and the Gwandu Formation (best known aquifer in the Sokoto basin). The Gwandu consists of two main aquifers—an upper sandy aquifer and a lower confined sandy aquifer. For the water table aquifer, water levels average 21 m, though in the uplands, near the Niger border, depths of 100 m can be recorded. Further west, and down dip, the aquifer is confined by 20 m of clay and lignite, giving rise to artesian conditions. The aquifer itself varies in thickness from 13-60 m.

The Hadejia-Yobe basin is drained by the Hadjia-Yobe River. The tributaries rise from Kano, Katsina and the Jos Plateau, with relatively higher rainfall than the rest of the region. The rivers flow from the area of high rainfall in the Southwest to the area of lesser rainfall towards the Lake Chad. The geology of the basin comprises (from the oldest to the youngest); the basement complex, the younger granite complex, the Gundumi Formation, the Kerrikerri Formation and the Chad Formation. Within the basement complex and younger granite complex areas, boreholes are shallow (20-35 m), Specific capacity of about 8-9 lit/m/min have been recorded [4]. In the overlying Gundumi Formation borehole depths average 45 m with maximum yield of 6.25 lit/sec and average of 3.2 lit/sec. The Kerrikerri Formation of thickness of up to 200 m is considered to be unpredictable and inadequately explored. It is however associated with deep water levels (165 m Southeast of Bauchi). It appears to belong to the same hydrostratigraphic unit with the Chad Formation which overlies it. The Chad basin sediments are reported to be 132 m at Gumel, 115 m at Nguru, and 132 m at Marguba. Yields of 3.3-5 lit/sec have been recorded. The separation of the Chad Formation into an upper, middle and lower aquifer cannot be defined in this part of the basin. The upper 20-30 m of the alluvial sands of the Hadejia-Yobe basin, holds a lot of water as bank storage, directly recharged from river flows.

The Chad basin is described as the largest area of inland drainage basin in Africa and occupies parts of Nigeria, Chad, Central Africa Republic and the Cameroon. Most of the rivers flowing into lake Chad rise from the watershed areas of the Jos plateau and the Adamawa highlands. The rivers include the Hadejia-Yobe, Alo and yedsaram from the southwest, and the Bambassa, Chari, Illi and lagone from the south east. The rivers Yedseram-Ngadda flow from the south to the northwest, and with all the minor tributaries and rivulets empty into Lake Chad. The Hadejia-Yobe, the Yedseram and all the other tributaries are seasonal. The yedseram with its smaller catchment area, starts to flow a little later, after the beginning of the rainy season, than the Hadejia-Yobe drainage system. There is practically no surface

flow from the more arid regions of the north [4]. Two Formations are important, hydraulically, in the Chad basin. These are the kerrikerri and the Chad Formations. While the kerrikerri is too deep to be of general hydrogeological interest, the Chad formation is well explored and demarcated into upper, middle and lower aquifers. In Maiduguri, the upper aquifer has a depth limit of 105 m. The aquifer consists of lenses of fine to very coarse, often, pebbly sands alternating with clays and sandy clays. The aquifer may be either water table or semi-confined. The water levels vary from 10 m to 15 m in wells tapping the aquifer with yields ranging from 2.5 lit/sec to 30 lit/sec. The middle zone aquifer is separated from the upper by about 150 m of plastic clays. It has a thickness of 300 m and is underlain by another 120 m of clay and shales. It is thus highly confined. The recharge areas of the middle confined aquifer all fall outside the geographical boundaries of Nigerai, making it a trans-boundary aquifer.

The Guinea savannah zone: This zone covers the area with mean annual precipitation of 1000-1250 mm and about 80 to 60 days of rainy days northwards. About five River basins fall within this zone, namely; the Kaduna River basin, the Benue River basins (upper and lower), the Upper and lower Niger Basins.

The kaduna River basin is drained by the River Kaduna and its tributaries. The River has its headwaters at the Jos Plateau. The climate is typical of most northern areas of Nigeria, except areas bordering the Jos Plateau which feature the orographic influence of highland areas of the Plateau. The temperature shows a mean annual of 24 °C to 30 °C. Precipitation shows a mean of 1120 mm but attain 1500 mm around the plateau area.

Over 80% of the kaduna basin is underlain by basement complex rock with shallow well yields of 0.2-1 lit/sec. The rest of the basin is underlain by the Nupe sandstone and alluvial deposits [4]. The Nupe sandstone underlies most of the southeast including Kotangora, Mokwa and Bida areas. It consists of slightly cemented fine to coarse sandstones and siltstones with interbedded thin beds of carbonaceous shale and clays. Yields of 1.8-4 lit/sec have been reported in the Nupe sandstone [5].

The Benue River is a continuous elongated geological structure, conveniently subdivided into Upper, Middle and lower basins. The upper Benue River basin occupies the upper reaches of the Benue valley. Its main drainage network comprises numerous streams and rivers flowing into the River benue from the north and South. The major river systems include the Gongola, Kilunga, and Pai to the north and the Faro and Tarabafrom the south of the River Benue. The temperature in the Benue valley is relatively high. It is typified by the recording from Yola where the mean daily maximum ranges from 29°C to 32°C in May to October, 32°C to 40°C in October to April. The highest mean maximum temperatures, of 38°C to 40°C, are recorded in February to April.

The mean minimum ranges from 18°C to 21°C from November to February. Rainfall is limited, with a mean annual of 750 mm to 1000 mm. The Upper Benue basin is underlain by patches of the basement complex rocks, including a number of volcanic plugs, basaltic flows, and sedimentary rocks of cretaceous age. The geological sequence comprises the basement overlain by the a thick sequence of shales of the Asu River group, continental sandstones of the Bima sandstone and shales, clays and limestones. The upper Benue is separated from the Chad basin by the Zambuk ridge. Of hydrogeological interest are the weathered basalts in Biu, Longuda and Sugu plateau areas. Of more hydrogeological interest is the Bima sandstone outcropping in Yola, Jimeta, Dabore areas. It is essentially feldspathic sandstone with grit,

pebbles and clay beds. It is highly cemented and behaves like crystalline rocks, hence its constraints hydrologically. Yields of 2 lit/sec to 8 lit/sec have been recorded. The Lower Benue River basin includes the lower reaches of the Benue valley, stretching from about river Wase down to the confluence of the Benue and Niger to the south. This part is drained by a number of River systems, including the River Wase, Shemankar, Dep and Mada, flowing northeast wards and the Donga, Bantaji and Katsina Ala drainage network flowing in the opposite direction, all the river systems emptying into the River Benue. The climate is characterized by high temperature regimes, like in the upper Benue, ranging from between 27°C as mean annual. The altitude influences the situation in Jos. Rainfall is moderate with a range of 1120-1500 mm on the Plateau. The geology of the Lower Benue is related to the Upper Benue with close similarity in lithology of the geological formations. These include the Interbedded Sandstones of the Awe Formation, the Sandstones of the Makurdi and Ezeakku Formation, sandstones of the Awgu Formation and the basal sandstones of the Lafia Formation. A number of boreholes have been drilled into the Makurdi Formation with varying degree of success. Yields of 2.5 lit/sec-8.7 lit/sec have been reported. A borehole of about 150 m drilled into the Awgu formation furnished artesian flow at Assakio, north of Lafia. The Lafia formation has a highly permeable sandstone of thickness 10-150 m and gives rise to various springs at the contact with underlying Awgu Formation.

The Niger Basin consists of the broad valley of the River Niger, from the confluence of the Rivers Niger and Benue to the northwestern border with Benin Republic. The Basin is sub-divided into Upper and Lower Niger Basins. The Upper Basin represents the upper arm of the drainage area of the River Niger covering an area of about 116,300 km². The River Niger, in the upper Niger Basin of Nigeria, is charged with water, from mainly, the Sokoto-Rima and Kaduna River systems.

The tropical rain forest zone: This zone comprises the Anambra basin, the Cross River Basin, the Kwa-Iboe River Basin, the Niger Delta and Southwestern Coastal basins. Here the dominant hydrometeorological features include heavy precipitation from 1250 mm-4000 mm from the Anambra to the Coastal basins. In the Anambra basin, the climate is hot and humid with mean annual rainfall of 1524 mm to 2032 mm in the Enugu area, to 1016 mm to 2286 mm in Idah area to the north. The dry season is relatively short from November to March. Maximum temperature is 34°C while towards the end of the rains it is 18°C - 21°C. In the Delta areas, rainfall can attain annual values of 4000 mm. The zone is drained by the Anambra, Cross River, River Niger and other tributaries. The Anambra Basin is noted for its groundwater reserves while the Cross River is more endowed with surface water resources, taking their sources from the uplands of the Anambra watershed. Borehole yields range from 10 lit/sec for shallow aquifers within the Cross River Basin to 5 m³/hr in some marginal aquifers like the Agbani Sandstone member to above 100 m³/hr within the Ajalli Sandstone aquifer in the Anambra Basin.

Water Resources Development, Policy and Regulations in Nigeria

Government and stakeholders' involvement

In Nigeria water supply development is a three tier responsibility between the Federal, State and Local Governments. Thus water supply is often a key campaign issue for politicians. The extent of water supply in Nigeria is clearly appreciable even though statistics are unreliable due to non-sustainability of previous interventions. The responsibility for sanitation is not always clear, but appears to fall into the purview of state governments.

The Federal Ministry of Water Resources, which had been part of the Ministry of Agriculture for a period until 2010, is responsible for large water resources development projects and water allocation between states. There are 12 River Basin Development Authorities under the Ministry, responsible for planning and developing water resources, irrigation work and the collection of hydrological, hydro-geological data. They also provide water in bulk to cities from dams. A Utilities Charges Commission was established in 1992 to monitor and regulate utility tariffs, including those of State Water Agencies. However, as of 2000, it was not functional. Presently water tariffs differ from state to state. The country's commitment to achieving MDGs goal 7 saw the collaboration of state and federal governments in the provision of water to rural communities.

Responsibility for potable water supply is entrusted to State Water Agencies (SWAs) or state water departments in the 36 Nigerian states. The SWAs are responsible to their state governments, generally through a State Ministry of Water Resources. SWAs are responsible for urban water supply, and in some states also for rural water supply. As of 2000, 22 states had separate state rural water and sanitation agencies (RUWASSA), mostly set up to implement a UNICEF program. In 2010, Lagos state set up a State Wastewater Management Office under the Lagos State Water Corporation. It took the responsibility for sanitation over from the State Ministry of Environment.

The Local Government Authorities (LGAs), of which there are 774, are responsible for the provision of rural water supplies and sanitation facilities in their areas although only a few have the resources and skills to address the problem. Only few LGAs have rural water supply divisions especially in Urban LGAs.

In some communities in rural areas, water and sanitation committees (WASCOS) have been formed to operate and maintain water facilities. These committees are supposed to collect their own water tariffs. Donors such as the African Development Bank have set a requirement that at least 30% of members of WASCOS must be women. In 1993 the Government committed itself to strengthen community participation in rural water supply in a policy document. As of 2000, the policy had not been disseminated or implemented in all government- or donor-financed programs.

Other stakeholders include civil societies and external partners. Nigeria's Water and Sanitation sector has a vibrant and dynamic civil society implementing several initiatives to address sectoral crisis. The Society for Water and Sanitation (NEWSAN) is the umbrella network of WASH NGOs, while the Water and Sanitation Media Network www.wash-jn.net comprises Journalists reporting the sector. A leading nongovernmental organization in the sector is Bread of Life Development Foundation which manages the eWASH weblog www.assemblyonline.info on water and sanitation news in Nigeria.

The most important external partners in the Nigerian water supply and sanitation sector are the African Development Bank, the European Union, Japanese JICA, UNICEF, USAID, the NGO WaterAid and the World Bank. The African Development Bank and the World Bank provide loans to the government; the European Union, JICA and USAID provide grants to the government; UNICEF and WaterAid receive grants from governments and donations from the public to implement their projects in cooperation with, but not through the government.

Water policy

Nigeria's National Water Supply and Sanitation Policy, approved

in 2000, encourages private-sector participation and envisages institutional and policy reforms at the state level. However, little has happened in both respects. As of 2007, only four of the 37 states - Lagos, Cross River, Kaduna and Ogun States - began to introduce public-private partnerships (PPP) in the form of service contracts, a form of PPP where the responsibility of the private sector is limited to operating infrastructure without performance incentives. While the government has a decentralization policy, little actual decentralization has happened. The capacity of local governments to plan and carry out investments, or to operate and maintain systems, remains low despite efforts at capacity development. Furthermore, the national policy focuses on water supply and neglects sanitation.

In 2003 a “Presidential Water Initiative (PWI): Water for People, Water for Life” was launched by then-President Olusegun Obasanjo. The initiative had ambitious targets to increase access, including a 100 percent water access target in state capitals, 75 percent access in other urban areas, and 66 percent access in rural areas. Little has been done to implement the initiative and targets have not been met

In 2011 the government voted in the United Nations in favor of a resolution making water and sanitation a human right. However, it has not passed legislation to enshrine the human right to water and sanitation in national law. With the above scenario, it is doubtful if the country will be able to attain the Millennium Development Goal for water and sanitation.

Threats to Water Resources Development in Context

Water resources development includes the Construction, harnessing, distribution and protection of both surface and groundwater infrastructures for the domestic, agricultural and industrial needs of the society. The exploitation of Nigeria’s water resources has progressively increased with the return to civil rule. Despite the progress that has been made in water supply development since the first waterworks in Nigeria was commissioned in Lagos in 1915, many Nigerians still have inadequate access to modern water supply. Water shortages exist periodically in almost every major town and are present in many rural areas of the country. Areas that are provided with water more often than not revert to water distress due to the unsustainable nature of the infrastructures, making statistics of access unreliable.

The turning point for water resources development and management in Nigeria occurred after the severe drought of the 1960s. The Government’s response to the catastrophe was the initiation of strategies for co-ordinated and effective water resources development, culminating in the mid-1970s in the creation of the Federal Ministry of Water Resources and the River Basin Development Authorities. The activities of these institutions were further strengthened in 1981 by the establishment of the National Committee on Water Resources, and by the Water Boards at the state level. Later the National Water Resources Institute (NWRI), the Nigerian Hydrological Services Agency (NIHSA), the Rural Water Supply and Sanitation Agencies (RUWASSA) were added. These bodies were charged with taking an inventory, and ensuring rational and systematic planned management and conservation, of the country’s water resources. This is further boosted by the various interventions by government, donor agencies and the setting up of many agencies at the national and sub-national levels.

In spite of the robust structure in place for the development of Nigeria’s Water Resources, there are numerous threats militating against the achievement of the MDGs Goal 7. Development is threatened when the quantity and quality of water available in an environment

is insufficient to meet the various needs of the population and future expansion is hampered by the depletion and or quality deterioration of the resources resulting in water poverty or distress (Figure 4).

Implications for surface water bodies

- Climate Change manifesting in increased evapo-transpiration and the attendant moisture deficit, decreasing precipitation with accompanying water level lowering in shallow aquifers and decreasing surface flows. These threats impact more on the sub-sahelian region.
- Climate change manifesting in increased coastal floods and saline water intrusion into upper coastal aquifers especially in the tropical rainforest zones.
- Oil spills that pollute the creeks and surface waters and groundwaters in the Niger Delta.
- Indiscriminate disposal of industrial effluents into surface water bodies due largely to regulation lapses nationwide.
- Impoundment of surface water for irrigation purposes and use of fertilizers for agriculture which result in decreased downstream flows and pollution of shallow aquifers by leachates.
- Poor management of water resources leading to infrastructural decay that result in unsustainable development and unsafe exploitation of ground water.

Concept of the hyporheic zone

This is a concept used to understand the interaction between surface and ground water. It is basic to the understanding of the pollution of aquifers through pollution of overflowing surface water and vice-versa. It is where surface and ground water mix and underscores the hydraulic connectivity between the two (Figure 5).

Threats to ground water Systems,

Groundwater degradation occurs where there is

- Excessive exploitation, for example where groundwater levels fall too fast or to unacceptable levels. This not only reduces available water resources and borehole yields but can result in other serious and potentially costly side effects including saline intrusion and subsidence.
- Inappropriate or uncontrolled activities at the land surface, including disposal of waste and spillage of chemicals, which contaminate the underlying aquifer. This can arise from diffuse sources, which

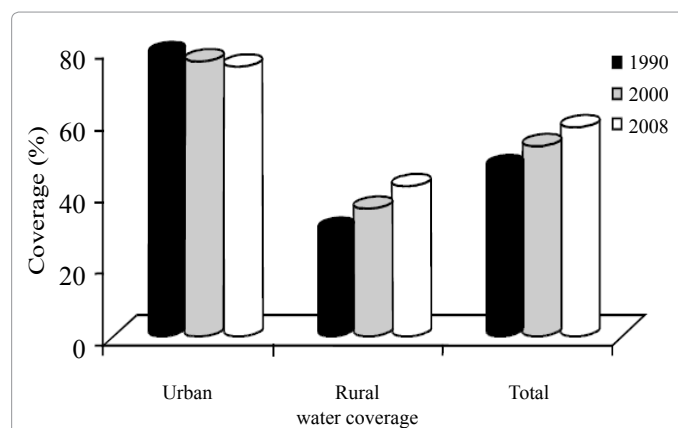


Figure 4: Improved Water supply coverage in Nigeria [Data Source for chart WHO/UNICEF] [6].

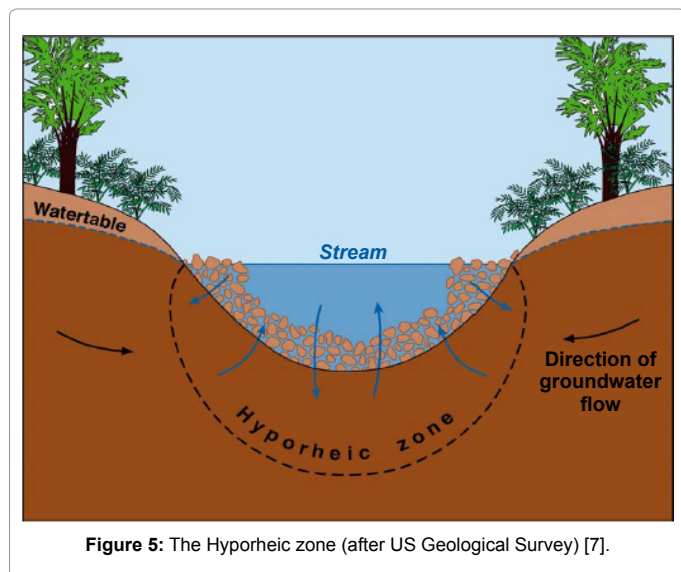


Figure 5: The Hyporheic zone (after US Geological Survey) [7].

	Consequences of excessive abstraction	Factors affecting susceptibility
Reversible interference	Pumping lifts/cost increase Borehole yield reduction Spring flow/river baseflow reduction	Aquifer diffusivity characteristic Drawdown below productive horizon Aquifer storage characteristic**
Reversible/irreversible***	Phreatophytic vegetation stress (both natural and agricultural). Aquifer compaction/transmissivity reduction	Depth to groundwater table Aquifer compressibility
Irreversible deterioration	Saline water intrusion Ingress of polluted water (from perched aquifer or river) Land subsidence and related impacts	Proximity of saline/polluted water. Vertical compressibility of overlying/interbedded aquitards

*Diffusivity (T/S). An aquifer response characteristic defined as transmissivity (T) divided by storativity (S)
 **Aquifer storage characteristic (S/R). Defined as storativity (S) divided by average annual recharge (R).
 ***Reversible/irreversible. These two effects depend on local conditions and the period during which excessive abstraction persists, the immediate response to abstraction is controlled by (T/S) and the longer term trend by (S/R).

Table 1: Impact of excessive groundwater abstraction (Modified from Foster et al.) [8].

results in widespread but generally less intense contamination, or from a point source, which causes more intense but localized problems.

- Major change of land use, for example in Sahel, the removal of natural vegetation through overgrazing led to water logging and salinization problems. The nature of the aquifer will also influence the scale of the contamination problem. Thus, in a highly fractured aquifer where groundwater flow is easy and relatively rapid, contamination may become more widely dispersed in a given time than where flow is intergranular, especially if the strata have only a modest permeability (Table 1).

- Salinization:** Salinity is the major threat to aquifer sustainability because it does not reduce naturally, and salinized groundwater can only be made fit for purpose by energy-intensive desalination or by dilution. Salinization can occur as a result of poor irrigation practice in agricultural areas, and as a result of over-abstraction inducing saline intrusion. The latter occurs usually, but not exclusively, in coastal aquifers. Mixing with just 3 to 4 per cent sea water (or groundwater of equivalent salinity) will render fresh groundwater unfit for many uses,

and once this rises to 6 per cent the water is unfit for any purpose other than cooling and flushing. Once salinized, aquifers are slow to recover. In intergranular-flow aquifers, the enormous volumes of water in storage have to be displaced, and in some fracture-flow systems where the matrix is also porous, it is difficult to drain relatively immobile water that has entered by diffusion from the fracture network.

Patterns of Occurrence of Water Resources Development Threats in Nigeria

Threats due to climate change in the sahelian zone

Part of northern Nigeria falls within the Sahel or sub-sahelian region characterized by scanty rainfall, vegetation and extreme temperatures. The groundwater systems in the area are such that the aquifers- basement or sedimentary, shallow or deep are all under one form of threat or the other. The sahel region is populated by farmers who depend on water supply for their livelihood. They need water for their crops and animals. Because of the scanty vegetation, overgrazing has further depleted the soil cover exposing the soil to denudation and moisture deficit. These farmers often resort to the digging of wells in the shallow basement aquifers to augment surface water resources furnished by various dams in the area. Due to dwindling precipitation, the water levels of these shallow wells are being lowered. The surface water quality is often impaired by excessive use of sulphate fertilizers and the authorities are not immediately sensitized to the present and future implication of the leachate into surface and ground water systems. The implication of the state of affairs is that both surface and ground water systems in the north are under threat of impairment and or depletion. A well-articulated Integrated Water Resources Management involving the Ministry of Agriculture, Ministry of Wtare Resources and the Ministry of Environment must be vigorously pursued to adapt to the natural threats and prevent the human threats. Figure 6 shows a typical shallow well designs in the basement based on water quality considerations. Ideally, these basement wells should have a bottom at an elevation that is above the surface of the stream (shallow, non-bedrock well) and fed supplied by many fractures that connect to the shallow ground water system at points "uphill" from the stream (bedrock well) [9].

Threats due to oil spillage, industrial effluents and marine incursion in the coastal areas

The effects of oil Spill on water quality was Investigated by Emadadja [10] by identifying a spill affected area (Emadadja) as the study area, while geographically similar but unaffected area (Egini) served as control. Water samples were collected from both surface (streams) and underground (hand- dug wells) sources. Some physico-chemical properties that reflect water quality such as pH value, total hydrocarbon, dissolved oxygen, turbidity, exchangeable cations (Ca⁺, Mg²⁺, Na⁺, K⁺) anions (NO³⁻, SO₄²⁻, PO₄²⁻, Cl⁻) Heavy metals (Fe, Cd, Pb, Cr) Biological Oxygen demand (BOD), Dissolved Oxygen (DO), Chemical Oxygen demand (COD), Dissolved Carbon dioxide (CO₂) were determined using standard methods and results from the two areas were compared. There was a significant increase in temperature average of (29.38 in surface, 27.62 in underground) decrease in pH average of (3.27 in surface samples, and 3.58 in underground), low dissolved oxygen of (1.63 mg/l in surface samples, 2.50 mg/l in underground). increased BOD of (14.69 mg/l in surface, 12.46 mg/l underground), increased CO₂ (17.86 mg/l in surface and 15.33 mg/l in underground) and increased THC content of (1.86 in surface and 1.57 in underground samples) of the oil spill affected study area of Emadadja when compared with the WHO standards and the non affected control area of Egini. Low nitrate

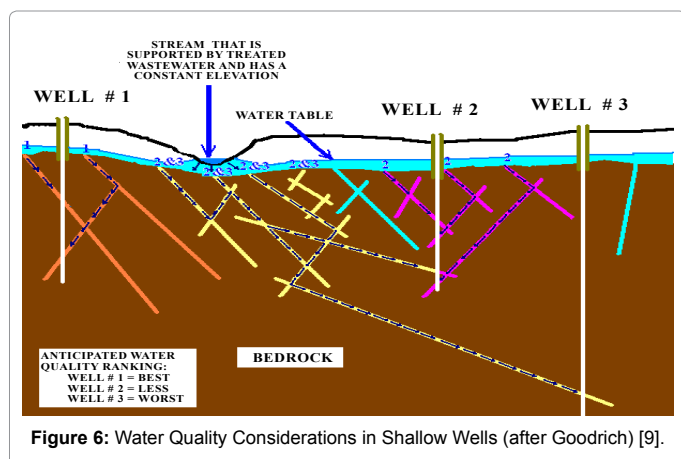


Figure 6: Water Quality Considerations in Shallow Wells (after Goodrich) [9].

values were observed at the study area. This may be due to utilization by the species in absence of sufficient oxygen. The presence of heavy metals and pollutants were lowest in the underground water samples than the surface water samples. Lead showed typical build up in the surface water samples from the study area. Test of the null hypothesis using ANOVA showed that there is significant difference in water quality between the study and control areas for both the surface and groundwater samples.

Studies carried out in most cities in Nigeria had shown that industrial effluent is one of the main sources of surface water pollution in Nigeria [11]. Industrial effluents when discharged directly into the rivers without prior treatment have capacity of Increasing water quality parameters. Dada [12] indicated that less than 10 % of industries in Nigeria treat their effluents before being discharged into the rivers. This has led to highload of inorganic metals such as Pb, Cr and Fe in most of water bodies [13,14]. Table 1 shows the results of physico-chemical parameters of effluents collected from some industries in Lagos, Kaduna and Port Harcourt.

Total effluent discharge from observed industries, TSS-total suspended solids, TDS-total dissolved solids, BOD-biochemical oxygen demand, COD-chemical oxygen demand, DO-dissolved oxygen (Data adapted from Ekiye and Zejiao [11]).

As can be observed from Table 2, most of the results were higher than the permissible limits set by FEPA [18]. The overall effects of these above normal concentrations will be that gaining streams and rivers will suffer quality impairment and disequilibrium in the aquatic ecosystem. Water-usage for recreation, industrial and domestic purposes will also be hampered due to non-potability. The incidence of high phosphate concentrations in these effluents could result into nutrient enrichment of the receiving water bodies thereby leading to ecological problems for both flora and fauna. Metal pollution of Warri River by industrial discharges was reported by Ayenimo et al., [20]. The River was monitored for heavy metals such as Fe, Cu, Ba, Pb, Cd, Cr, Ni and Co. Results showed elevated values of these metals at sampling point located near an industry. Correlation analysis of the metals also suggested common source. Other water quality parameters showed elevated values indicating pollution by the nearby industry. The activities of the oil industries in the Niger-Delta region of Nigeria have been widely reported and the negative impacts on the surface water quality around the area globally highlighted. This has led to water scarcity, disruption of socio-economic activities and poor aesthetic quality of most of the water bodies polluted by the oil spills [21]. Rivers as source of drinking water around the Niger-Delta region

of the country are generally cost-ineffective for treatment for drinking purpose because of heavy pollution by crude oil.

In Enugu State, industrial effluents into the Ajalli Owa surface water intake, the activities of sand miners and cattle rearers have become the main obstacle to public water supply (Figure 7). Mining activities initiate gully erosion and the sediment loading of the raw water while cattle rearers dislodge water pipelines to access water for their cattle. During rainfalls, domestic wastes are unleashed into the drainages for onward movement to the surface water that criss-cross the length and breadth of Enugu. These surface water bodies would have been sources of portable water to the ever increasing population. The state environmental agency still turn blind eyes to the heaps of refuse and human wastes dumped at stream courses.

The effect of coastal erosion with aggravated by land reclamation must also be highlighted. Education is necessary here. Wetlands occur due to a number of reasons, among which is the manifestation of local ground water discharge. These wetland generally lie in very low areas and reflect the hydraulic potential of the underlying water. Reclamation will result in temporal confinement of flow and since equilibrium must be maintained by the surface and groundwater regimes, fresh flow channels must be created while the intrusion of sea water must interact

Effluent Parameters	Lagos (Adebayo et al. [15])	Kaduna (Yusuf, Shonibare [16])	Port Harcourt (Ajao, Anurigwo [17])	FEPA [18] Standard
Temperature (°C)	27.6	30.3	30	< 40
Color (CTU)			2400	
pH	7.6	4.8		6-9
Conductivity				
Turbidity (NTU)	761	1156.6		
Salinity (%)	0.1	0.5		
Alkalinity (mg L-1)	766.6	445		
Free Chlorine (mg L-1)			0.5	
Nitrate (mg L-1)		4.0	362	20
Ammonia (mg L-1)		1.0		
Phosphate (mg L-1)		1.0	836	5
Total Hardness (mg L-1)	1233.3	4083.3		
TSS (mg L-1)	320	833.3	400	30
TDS (mg L-1)		1100		200
Oil and Grease (mg L-1)	0.0	7.0	2343	10
BOD (mg L-1)	534	300	4374	30
COD (mg L-1)	850	2253	1800	
H2S (mg L-1)	17.2	130	0.6	

Table 2: Effluent analysis of some industrial discharges in Nigeria (after Taiwo et al.,) [19].



Figure 7: Effluents from breweries at the 9th mile Industrial area, Enugu State. This retention pond is located upstream of Ajalli Raw water intake and overflows from the pond is the main source of pollution of Enugu Urban water supply. In the adjoining photo, Some of the effluents bypass the pond and go direct into the river.

with these fugitive flow component to degrade the quality of coastal aquifers. Fresh storm water must find ares of passage and inundation of these reclaimed areas occur.

Threats due to municipal and agricultural wastes

As noted by Taiwo [22] the management of solid waste is a major problem in most developing nations of the world including Nigeria. Indiscriminate disposal of municipal wastes remains a major threat to surface water pollution in Nigeria. During rainfall events, used polythene bags and water sachets are plus other domestic wastes are routed into the rivers and streams via the runoff water. Jaji et al., [23] found elevated water quality parameters in some sampling locations of Ogun River. These were partly attributed to the activities of abattoir located close to the River at a notable market in Abeokuta metropolis. The work of Arimoro et al., [24] on the impact of sawmill activities on the water quality of River Benin reported high BOD and low DO values at the discharge point of the wastes into the River. The impact of point source pollution from sewage treatment oxidation pond on a receiving stream was studied by Ogunfowokan et al., [25]. The researchers observed significant elevation of water indices such as pH, BOD, nitrate, phosphate and TSS. It is well known that oxygen depletion in water bodies could cause fish death while increase in BOD signifies high load of organic matter. Also, organic matter decomposition in surface water produced inorganic nutrients such as ammonia, nitrate and phosphorus with resultant effects of eutrophication and other serious ecological problems of such water body [25]. Taiwo [26] has also observed high water quality parameters of a stream in Abeokuta due to direct discharge of poultry wastes into the stream. The use of pesticide sand fertilizer for bumper food production is a well-known policy of several Governments all over the world. However, agriculture remains the major source of nitrate and phosphate pollution of surface water. Nitrate in drinking water is detrimental to infant health due to the disease known as methemoglobinemia [26].

Threats due to domestic and industrial leachate through storm water flow

Urban runoff poses very great threats to both surface and groundwater systems in most Nigerian cities. With the cities mostly unplanned, population explosion with the attendant competition for inadequate infrastructure has led to disposal of solid and liquid wastes without recourse to their environmental impacts. During rainfall, some of these wastes are washed into the poor drainage systems and subsequently, into nearby rivers. Lack of town planning principles and strategies in Nigeria's cities and towns had aggravated the risks of urban run-off with resultant effect on surface water. The poorly managed drainage system in the country had caused the surface water impairment due to erosions during rainfall. Rainfall runoff carries all sorts of pollutants from houses, industries, farmland and dumping sites. Industries are the major sources of pollution in all environments. Based on the type of industry, various levels of pollutants can be discharged into the environment directly or indirectly through public sewer lines. Wastewater from industries includes employees' sanitary waste, process wastes from manufacturing, wash waters and relatively uncontaminated water from heating and cooling operations. High levels of pollutants in river water systems causes an increase in biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), toxic metals such as Cd, Cr, Ni and Pb and fecal coliform and hence make such water unsuitable for drinking, irrigation and aquatic life. Industrial wastewaters range from high biochemical oxygen demand (BOD) from biodegradable wastes such as those from human sewage, pulp and paper

industries, slaughter houses, tanneries and chemical industry. Others include those from plating shops and textiles, which may be toxic and require on-site physiochemical pre-treatment before discharge into municipal sewage system. Research has shown that some of the water quality parameters of both ground and surface water often rise up during rainfall with high values of turbidity, solids and anionic species often been recorded [22,23,26,27]. The effect of urban run-off has been studied on the Epie Creek in the Niger Delta by Izonfuo and Bariweni [28]. The impact of human activities around the Creek was felt on the water body as low DO values were recorded during the wet season due to urban run-off.

Agricultural run-off of pesticides, plant and animals wastes is also a major contributing source of organic pollution to water bodies in Nigeria. The work of Mustapha [27] had Linked the periodic eutrophication of Oyun Reservoir in Offa, Kwara state to run-off of phosphate fertilizers from nearby farms in addition to cow dung washing from the watershed into the Reservoir. Water pollution through surface run-off has been reported in Literatures with subsequent effects on nutrient enrichment, water quality impairment, marine lives spawning ground destruction and fish kill [28,29].

Threats to existing water infrastructures from erosion and contamination of water pipelines

Due to regulation lapses, and mining is a common business in eastern Nigeria. These activities often lead to severe erosion of the pipelines leading to excavation and collapse of the pipelines (Figure 8). Effluents from industrial and domestic activities usually enter the network through the joints of the collapsed pipes. The situation is further aggravated by the activities of cattle men who take advantage of the leakages from the pipes to provide water for their herds. Unfortunately these activities take place in areas far from residential areas such that detection may take months to occur.

Recommendations and Conclusions

The only way forward to mitigate threats to our water resources is to step up Integrated Water Resources management where all sectors must synergize to achieve results.

Water quality degradation had been found most severe in Lagos, Rivers, Kano and Kaduna where most of the country's industries are located [11] with subsequent effects on public health and economic development [30,31]. There is need for protection of water bodies in Nigeria as millions of the populace rely on it for daily water supply. Exploitation of shallow aquifers in the Su-Sahel must take into cognizance, basic well hydraulics and its relation to water quality stability. In this unregulated development must be discouraged to afford informed professionals the latitude to track the threats posed



Figure 8: Destruction of Enugu Municipal mains pipes by erosion triggered by mining proximal to the pipelines.

by over-exploitation. The Federal Ministry of Environment must strengthen the present environmental laws such that the polluters of water bodies could be prosecuted. Industrial and agricultural sectors should also be compelled to treat their wastes before being discharged into the water bodies. Drastic measures must be taken by all authorities concerned to minimize children morbidity and mortality due to poor sanitation and water quality problems.

This paper has reviewed the various threats to water resources development in Nigeria. The threats are variable and many. The variation in water quality experienced in Nigeria reflects differences in land management and the physical environment. These differences occur both as a result of natural variability, societal development and pollutant inputs. In addition, water quality in the vicinity of urban areas is influenced by industrial and urban development. Understanding the condition of rivers and streams and their relation to ground water is critical to effective mitigation of threats to water development. The River basins and research institutes must evolve custom mitigation measures suitable for the hydrometeorological environment. Education of the benefitting masses is also likely to help in reducing anthropogenic threats to our water bodies. The Ministry of Environment should take up the challenge by stepping up regulations.

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