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Review Article

A Framework for Hydrogeological Data Acquisition and Monitoring In the Niger Delta

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ABSTRACT

Groundwater deserves serious attention in the Niger Delta. This is because there are no alternative sources of water supply in many parts of the region. Sadly enough, groundwater development in the Niger Delta region has been carried out with little hydrogeological considerations. This is probably, due to strong political and other extraneous pressures. Consequently, borehole drilling has been indiscriminately and randomly sited and located, resulting to a myriad of problems. As a result, boreholes have failed where there are abundant groundwater storage, and many a time, have been drilled in, obviously, most unpromising locations. Efforts to solve the problems have been unsuccessful and supply of potable water remains grossly inadequate. Whether for domestic, industrial or irrigational purposes, it is evident that groundwater constitutes the most economical, practical and sensible source of water supply in the Niger Delta. It would have to be harnessed in order to meet the water needs of the several development projects now planned for the region. Important data acquisition and monitoring steps need to be taken in order to utilize fully the groundwater resources of the region more efficiently and usefully in future. Recent development plans proposed for the Niger Delta would call for high water demand. There is therefore an urgent need for a sustainable hydrogeological data acquisition and monitoring approach in the Niger Delta region. It is therefore hoped that many of the expert suggestions made in this paper will not only form a guideline for meaningful collection of data for quantitative analysis in future, but will also help in the understanding of the hydrogeology of the region.

Keywords*:* Groundwater quality monitoring, hydrogeology, aquifers, Niger Delta.

INTRODUCTION

The Niger Delta is the second largest delta in the world with a coastline spanning about 450km terminating at the Imo River entrance (Awosika, 1995). The Niger Delta has an areal extent of 75, 000km^2 and is located between latitude $4^0 30^{'}$ and 5^0 $20^{'}$N and longitude 3^o and 9^oE. The region spans over 20,000km^2 and it has been described as the largest wetland in Africa and consists mainly of freshwater swamps, mangrove swamps, beaches, bars and estuaries. This difficult terrain made it a region mostly forgotten by the rest of Nigeria, until the advent of petroleum in the area in the late fifties.

The pressure on water supplies and precious ecosystems in the coastal areas of the Niger Delta is very high and can increase in the future if urgent management measures are not put in place (Nwankwoala, 2011). Groundwater is the only source of water for water supply for both domestic and industrial uses in the Niger Delta and its demand will increase astronomically within the foreseeable future with increase in population, improved standard of living and more expansion and growth of the oil and gas industry (Oteri, 1983; Akpokodje, 2005; Nwankwoala and Udom, 2011).

Though the Niger Delta produces over 80% of Nigeria's petroleum, it is still very much a neglected part of the country. Beside efforts made by oil prospecting companies in the process of oil exploration and production, the region has not been studied in many areas and respects. Groundwater resources development of the Niger Delta is one such area where no serious effort has been made to investigate its nature, distribution and occurrence. Geologic considerations are rarely or inadequately incorporated into the design of boreholes (Amajor, 1989). Generally, groundwater has not attained a high level of development in the Niger Delta partly as a result of difficult environmental condition, low level of general underdevelopment of the region, inadequate finance; and partly perhaps as a result of deliberate neglect of the area by successive governments.

The Niger Delta is a large and ecologically sensitive region in which various water species (including surface and groundwater, saline and freshwaters) are in dynamic equilibrium (Abam, 1999). Because of the very nature of the region, groundwater constitutes the predominant, if not the only source of water supply in the area and unless a determined effort is made to understand the nature of the groundwater in the region, serious problems would be encountered in the area of water needs of the region, in future. Reliable groundwater data is necessary for planning and for modeling studies. This paper, therefore not only presents a framework/ guideline for meaningful collection of data for quantitative analysis, but also highlights approaches for meaningful data acquisition and monitoring for better understanding of the hydrogeology of the Niger Delta region.

Geomorphologic/Geologic Setting

The geomorphology of the Niger Delta has been described by many researchers (NEDECO, 1954, 1959, 1961; Allen, 1965; Weber, 1971). The topography of the area is essentially flat, sloping very gently seawards. The area is low lying (usually does not exceed 20m above sea-level) and is drained and criss-crossed by network of distributaries. The Niger Delta constitutes an extensive plain exposed to periodical inundation by flooding when the rivers and creeks overflow their banks. A prominent feature of the rivers and creeks is the occurrence of natural levees on both banks, behind which occur vast areas of back swamps and lagoons/lakes where surface flow is negligible.

Although various types of morphological units and depositional environments have been recognized in the area (coastal flats, ancient/modern sea, river and lagoonal beaches, sand bars, flood plains, seasonally flooded depressions, swamps, ancient creeks and river channels), the area can be sub-divided into five major geomorphological units (Fig. 1) namely:

(a) Active/abandoned coastal beaches
(b) Saltwater, mangrove swamps
(c) Freshwater swamps, back-swamps, deltaic plain alluvium and meander belt
(d) Dry deltaic plain with abundant freshwater swamps (Sombreiro-Warri deltaic plain)
(e) Dry flat land and plain.

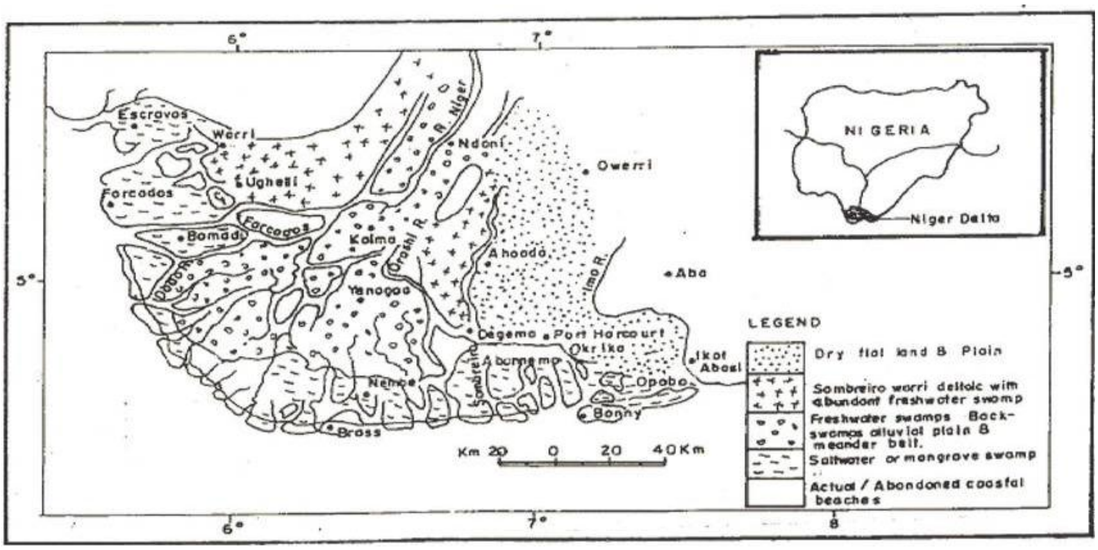

Fig.1: Major morphological Units of the Niger Delta (modified after Akpokodje, 1987)

Along the coastline lies a long coastal saline belt of active and abandoned beaches built by ocean currents and tides. This area is comparatively higher than the adjacent areas and its width varies from 1 to 10 km. Parallel to, and north of the coastal saline belt of the beaches, is a stretch of mangrove swamp with an approximate width of 10 – 25 km. North of the mangrove swamp is the freshwater swamp which is in turn succeeded inland by dry areas that are not prone to periodical flood inundation.

Consequently, the present knowledge of the geology of the Niger Delta was derived from the works of the following researchers (Reyment, 1965; Short & Stauble, 1967; Murat, 1970; Merki, 1970) as well as the exploration activities of the oil and gas companies in Nigeria. The formation of the so called proto-Niger Delta occurred during the second depositional cycle (Campanian Maastrichtian) of the southern Nigerian basin. However, the modern Niger Delta was formed during the third and last depositional cycle of the southern Nigerian basin which started in the Paleocene.

The geologic sequence of the Niger Delta consists of three main Tertiary subsurface lithostratigraphic units (Short & Stauble, 1967) which are overlain by various types of Quaternary deposits. From bottom to top, the Tertiary units are the Akata, the Agbada and the Benin Formations (Table 1).

Table 1: Geological units of the Niger Delta (after Short and Stauble, 1967)

Age	Geological Unit	Lithology
Quaternary	Alluvium (general) fresh water back swamp meander belt. Mangrove and salt water. Back Swamps Active/Abandoned Beach ridges Sombreiro Warri Delataic plain.	Gravel, sand, clay, silt, sand, clay, some silt, gravel. Medium-fine sands, Clay and some silt.
Miocene	Benin Formation (coastal plain sand)	Coarse to medium grain sand with subordinate silt and clay lenses. Fluviatile marine
Eocene	Agbada Formation	Mixture of sand, clay and silt, fluviatile marine

Groundwater Occurrence in the Niger Delta

The main body of groundwater in the Niger Delta is contained in mainly very thick and extensive sand and gravel aquifers. Three main zones have been differentiated. These are: a northern bordering zone consisting of shallow aquifers of predominantly continental deposit, a transition zone of intermixing marine and continental materials and a coastal zone of predominantly marine deposits (Etu- Efeotor, and Odigi, 1983; Amajor, 1989; Etu-Efeotor and Akpokodje, 1990). A distinct trend in aquifer properties have been observed following this division. Akpokodje *et al* (1996) have summarized the hydrostratigraphic units of the Benin Formation as four well defined aquifers in the upper 305m that vary in thickness to over 120m. The aquifers vary from unconfined conditions at the surface through semi-confined to confined conditions at depth. The aquifers are separated by highly discontinuous layers of shales, giving a picture of an interval that consists of a complex, non-uniform, discontinuous and heterogeneous aquifer system. Although, majority of groundwater supply wells abstract water from these aquifers, there is evidence that industrial and municipal groundwater supply wells produce water from deeper aquifers in the Benin Formation.

Aquifers at the northern border of the Niger Delta are more continental in character, being composed of river loads coming from the hinter land. They are also encountered at shallower depths, so that in most cases, an average depth of 60m had been all that was required to be drilled, to obtain very pure freshwater and in huge quantity. Clay materials, except a few metres found within the top soil, do not occur at depth. The sand is coarse to very coarse generally, and gravel layers are commonly encountered. The borehole performance in this section has generally been so good and the water quality so excellent, that sinking of wells at the northern borders of the Niger Delta has always been taken for granted. Very good examples of such regions are Port Harcourt, Ogoni, and Elele areas of Rivers State, eastern Niger Delta (Ngah, 2009).

Moving coastwards from the northern borders of the Niger Delta, one comes across a transitionary zone of swamp lands. Two types of swamp lands are observed – the mangrove swamp lands and the freshwater swamp lands. The mangrove swamp lands are associated with tidal inlets and they are therefore more prominent in those areas where estuaries penetrated farther inland, such as the western and eastern zones flanking the prodelta. On the other hand, fresh swamp land persists more within the front of the delta where the dense network of streams and rivers combine to empty into the sea.

A common feature of the transition zone is the presence of clay embodiments within the aquifers. These clay lenses are erratically distributed laterally and vertically within the region. In several cases, strata logs of wells drilled less than 200m apart, have been known to vary, and under such prevailing circumstance, prediction of aquifer performance in the region is difficult. However, the freshwater swamp lands which constitute the front of the delta continue to indicate many features of continental environments, until very close to the coast. The aquifers are still shallow, consisting of predominantly sand and gravel materials, but clay intercalations become more prominent, than within the northern zones. Lignitic materials are also present in the aquifer and the presence of vegetative matter strongly point to sedimentation under shallow water condition.

Within the mangrove swamp lands, very strong evidences of marine conditions are indicated. Thicker lenses of marine clay are encountered and saline conditions (Ngah & Nwankwoala, 2013a) are still well noticed. There is no doubt that these areas are protected from the dynamic zones of the deltaic front. This makes it possible for marine conditions to penetrate further inland, creating a more complex transition zone. This is the case in the freshwater swamp lands. There is an intermixing of continental and marine sediments resulting in a very complex aquifer system. Generally, it has been necessary to drill beyond the 200m depth before a good water yielding aquifer could be obtained and saline water intrusion problem plague the region. It is here, however, that artisan conditions, due to the interbedment of sand aquifers within clay aquicludes occur. But such confined aquifers are generally too deep seated to result in flow wells (Ngah, 2009; Nwankwoala, 2011).

Within the sand bars and beaches of the coastal lands, boreholes still need to go deeper to reach quality good water aquifers. Beneath the coastal sands that form the surface deposits of this last zone, marine conditions predominate, until at depth where deep seated aquifers empty into the sea. Aquifers within the Niger Delta generally produce and perform better during the rainy season. They dwindle in yield during the dry season. At the coastal lands, rains feed and maintain phreatic aquifers during the rainy season. But with the incoming of the dry season, such aquifers dry up, and wells sunk into them commonly go without water at that season.

Data Requirements for Groundwater Studies in the Niger Delta

Reliable groundwater data is necessary for planning and for modeling studies. The first phase of a groundwater model study consists of collecting all existing geological and hydrological data on the groundwater basin in question. This will include information on surface and subsurface geology, water tables, precipitation, evapotranspiration, pumped abstractions, stream flows, soils, land use, vegetation, irrigation, aquifer characteristics and boundaries, and groundwater quality. If such data do not exist or are very scanty, a program of field work must first be undertaken, for no model whatsoever makes any hydrological sense if it is not based on a rational hydrogeological conception of the basin. All the old and newly-found information is then used to develop a conceptual model of the basin, with its various inflow and outflow components.

A conceptual model is based on a number of assumptions that must be verified in a later phase of the study. In an early phase, however, it should provide an answer to the important question: does the groundwater basin consist of one single aquifer (or any lateral combination of aquifers) bounded below by an impermeable base? If the answer is yes, one can then proceed to the next phase: developing the numerical model. This model is first used to synthesize the various data and then to test the assumptions made in the conceptual model. Developing and testing the numerical model requires a set of quantitative hydrogeological data that fall into two categories:

i. Data that define the physical framework of the groundwater basin
ii. Data that describe its hydrological stress

These two sets of data are then used to assess a groundwater balance of the basin. The separate items of each set are listed below:

(a) Physical framework

1. Topography
2. Geology
3. Types of aquifers
4. Aquifer thickness and lateral extent
5. Aquifer boundaries
6. Lithological variations within the aquifer
7. Aquifer characteristics

(b) Hydrological stress

1. Water table elevation
2. Type and extent of recharge areas
3. Rate of recharge
4. Type and extent of discharge areas
5. Rate of discharge

It is common practice to present the results of hydrogeological investigations in the form of maps, geological sections and tables - a procedure that is also followed when developing the numerical model. The only difference is that for the model, a specific set of maps must be prepared. These are:

i) Maps of the aquifer's upper and lower boundaries
ii) Maps of the aquifer characteristics
iii) Maps of the aquifer's s net recharge
iv) Water table contour maps

Some of these maps cannot be prepared without first making a number of auxiliary maps. A map of the net recharge, for instance, can only be made after topographical, geological, soil, land use, cropping pattern, rainfall, and evaporation maps have been made.

The data needed in general for a groundwater flow modeling study can be grouped into two categories: (a) Physical framework and (b) Hydrogeologic framework (Moore, 1979). The data required under physical framework are:

1. Geologic map and cross section or fence diagram showing the areal and vertical extent and boundaries of the system.
2. Topographic map at a suitable scale showing all surface water bodies and divides. Details of surface drainage system, springs, wetlands and swamps should also be available on map.
3. Land use maps showing agricultural areas, recreational areas etc.
4. Contour maps showing the elevation of the base of the aquifers and confining beds.
5. Isopach maps showing the thickness of aquifers and confining beds.
6. Maps showing the extent and thickness of stream and lake sediments.

These data are used for defining the geometry of the groundwater domain under investigation, including the thickness and areal extent of each hydrostratigraphic unit.

Under the hydrogeologic framework, the data requirements are:

1. Water table and potentiometric maps for all aquifers.
2. Hydrographs of groundwater head and surface water levels and discharge rates.
3. Maps and cross sections showing the hydraulic conductivity and/or transmissivity distribution,
4. Maps and cross sections showing the storage properties of the aquifers and confining beds.
5. Hydraulic conductivity values and their distribution for stream and lake sediments.
6. Spatial and temporal distribution of rates of evaporation, groundwater recharge, surface water-groundwater interaction, groundwater pumping, and natural groundwater discharge.

Groundwater Data Acquisition and Monitoring

Modeling is one of the many tools that can be used to help determine remedial options. The use of groundwater modeling for contaminant fate and transport predictions is common in risk-based decision making process. Models range from simple mathematical equations to complex computer generated models. Models are generally used to support remedial decisions where groundwater contamination exists above a prescribed action level. While models can be used to develop and support remedial options, they should not be expected to substitute for real world data. Obtaining all the information necessary for modeling is not an easy task. In fact, a modeler may have to devote considerable effort and time in data acquisition, especially when the database for the study area is non-existent. Some data may be obtained from existing reports of various agencies/departments, but in most cases additional field work is required. Moreover, the data is not readily available in the format required by the model, and requires additional work to process it. The observed raw data obtained from the field may also contain inconsistencies and errors. Before proceeding with data processing, it is essential to carry out data validation in order to correct errors in recorded data and assess the reliability of a record. In addition, as the modeling exercise progresses, certain gaps in the database get identified. In such cases, the field monitoring program may undergo some revision including installation of new piezometers/monitoring wells.

Amongst the hydrologic stresses including groundwater pumping, evapotranspiration and recharge, groundwater pumpage is the easiest to estimate. Field information for estimating evapotranspiration is likely to be sparse and can be estimated from information about the land use and potential evapotranspiration values. Recharge is one of the most difficult parameters to estimate. Recharge refers to the volume of infiltrated water that crosses the water table and becomes part of the groundwater flow system. This infiltrated water may be a certain percentage of rainfall, irrigation return flow, seepage from surface water bodies etc., depending upon topography, soil characteristics, depth to groundwater level and other factors.

Values of transmissivity and storage coefficient are usually obtained from data generated during pumping tests and subsequent data processing. For modeling at a local scale, values of hydraulic conductivity may be determined by pumping tests if volume-averaged values are required or by slug-tests if point values are desired. For unconsolidated sand-size sediment, hydraulic conductivity may be obtained from laboratory permeability tests using permeameters. However, due to rearrangement of grains during repacking of the sample into permeameter, the obtained hydraulic conductivity values are typically several orders of magnitude smaller than values measured in *situ*. Furthermore, in a laboratory column sample, large-scale features such as fractures and gravel lenses that may impart transmission characteristics to the hydrogeologic unit as a whole are not captured. Due to this reason, laboratory analyses of core samples tend to give lower values of hydraulic conductivity than are measured in the field. In the absence of site-specific field or laboratory measurements, initial estimates for aquifer properties may be taken from standard tables.

When simulating anisotropic media, information is required on principal components of hydraulic conductivity tensor K_x, K_y, and K_z. Vertical anisotropy is defined by the anisotropy ratio between K_x, and K_z. For most groundwater problems, it is impossible to model geologic units at the isotropic scale. When the thickness of the model layer (B_{ij}) is much larger than the thickness of isotropic layer (b_{ijk}) (assuming this thickness can be identified from bedding information), the hydrologically equivalent horizontal and vertical hydraulic conductivities for the model layer may be calculated as:

$$\left(K_x\right)_{ij} = \sum_{k=1}^{m} \frac{K_{ijk}\, b_{ijk}}{B_{ij}} \quad \left(K_z\right)_{ij} = \frac{B_{ij}}{\sum_{k=1}^{m} \frac{b_{ijk}}{K_{ijk}}} \quad B_{ij} = \sum_{k=1}^{m} b_{ijk} \tag{1}$$

Where i represents column, j represents row and k represents layer number. Vertical anisotropy for each hydrogeologic unit or model layer may be computed using above equations, if sufficient stratigraphic information is available. The anisotropy ratio may also be estimated during model calibration. The thickness and vertical hydraulic conductivity of stream and lake sediments are required for estimating seepage. These values may be obtained from field measurements or during model calibration.

Monitoring of Groundwater Levels

To obtain data on the depth and configuration of the water table, the direction of groundwater movement, and the location of recharge and discharge areas, a network of observation wells and/or piezometers has to be established. The objectives of the groundwater level monitoring are to:

- Detect impact of groundwater recharge and abstractions,
- Monitor the groundwater level changes,

- Assess depth to water level,
- Detect long term trends,
- Compute the groundwater resource availability,
- Assess the stage of development,
- Design management strategies at regional level.

The water table reacts to the various recharge and discharge components that characterize a groundwater system and is therefore constantly changing. Important in any drainage investigation are the (mean) highest and the (mean) lowest water table positions, as well as the mean water table of a hydrological year. For this reason, water level measurements should be made at frequent intervals for at least a year (Ngah & Nwankwoala, 2013b). The intervals between readings should not exceed one month, but a fortnight may be better. All measurements should, as far as possible, be made on the same day because this gives a complete picture of the water table.

Monitoring of Groundwater Quality

For various reasons, knowledge of the groundwater quality is required. These are:

- Any lowering of the water table may provoke the intrusion of salty groundwater from adjacent areas, or from the deep underground, or from the sea. The drained area and its surface water system will then be charged daily with considerable amounts of dissolved salts;
- The disposal of the salty drainage water into fresh-water streams may create environmental and other problems, especially if the water is used for irrigation and/or drinking;
- In arid and semi-arid regions, soil salinization is directly related to the depth of the groundwater and to its salinity;
- Groundwater quality dictates the type of cement to be used for hydraulic structures, especially when the groundwater is rich in sulphates.

Groundwater is sampled to assess its quality for a variety of purposes. Whatever the purpose, it can only be achieved if results are representative of actual site conditions and are interpreted in the context of those conditions. Substantial costs are incurred to obtain and analyze samples, especially in the Niger Delta. Field costs for drilling, installing, and sampling monitoring wells and laboratory costs for analyzing samples are not trivial. The utility of such expenditures can be jeopardized by the manner in which reported results are interpreted as well as by problems in how samples were obtained and analyzed. Considerable attention has been given to standardizing procedures for sampling and analyzing groundwater. Although following such standard procedures is important and provides a necessary foundation for understanding results, it neither guarantees that reported results will be representative nor necessarily have any real relationship to actual site conditions.

Comprehensive data analysis and evaluation by a knowledgeable professional should be the final quality assurance step, it may indeed help to find errors in field or laboratory work that went otherwise unnoticed, and provides the best chance for real understanding of the meaning of reported results. To facilitate interpretation, the following steps should be included:

1. Collection, analysis, and evaluation of background data on regional and site-specific geology, hydrology, and potential anthropogenic factors that could influence ground water quality and collection of background information on the environmental chemistry of the analysis of concern.
2. Planning and carrying out of field activities using accepted standard procedures capable of producing data of known quality.
3. Selection of a laboratory to analyze ground water samples based on careful evaluation of laboratory qualifications.

4. The use of appropriate quality control/quality assurance (QC/QA) checks of field and laboratory work (including field blank, duplicate, and performance evaluation samples).
5. Comprehensive interpretation of reported analytical data by a knowledgeable professional. The analytical data must be accompanied by appropriate QC/QA data, be cross-checked using standard water quality checks and relationships where possible, and be correlated with information on regional and site-specific geology and hydrology, environmental chemistry, and potential anthropogenic influences.

The objectives of the water quality monitoring network are to:

- establish the bench mark for different water quality parameters, and compare the different parameters against the national standards,
- detect water quality changes with time,
- identify potential areas that show rising trend
- detect potential pollution sources
- Study the impact of land use and industrialization on groundwater quality
- Data collection for the reporting year

The frequency of sampling required in a groundwater quality monitoring program is dictated by the expected rate of change in the concentrations of chemical constituents in and the physico-chemical properties of the water being measured. Groundwater moves slowly, perhaps only a few centimeters to a few decimeters per day, so that day-to-day fluctuations in concentrations of constituents and in properties at a point (or well) commonly are too small to be detected. For monitoring concentrations of major ions and nutrients, and values of physical properties of groundwater, twice yearly sampling should be sufficient, and by varying the season selected for sampling, conditions during all the seasons could be documented over a 2-year cycle. A second group of constituents, trace inorganic and organic compounds, could be adequately monitored by collecting samples once every 2 years from wells in background areas (those areas unaffected by human activities), but more frequent sampling should be considered if the types and conditions of any up-gradient sources of these compounds are changing.

CONCLUSION

Consideration of several factors, as highlighted in this paper suggests that monitoring of ground-water quality should be a long-term activity. Not only does the structure of the program described herein mandate long-term monitoring, but the scales over which groundwater quality is likely to fluctuate also are long. Because of the slow rate of ground-water movement, any changes in factors that affect the quality of the water in recharge areas can take a long time to be reflected in surface-water bodies that are discharge areas for the groundwater. The duration of a groundwater quality monitoring program also is affected by the time scale of changes in the source area for the chemical constituents of interest. Important steps need to be taken in order to utilize the groundwater resources of the region more efficiently. In this regard, there should be a deliberate effort to promote more understanding in the profession of hydrogeology. Several practicing Engineers today in Nigeria's water industry dismiss hydrogeology as irrelevant in the process of supplying the nation with more water. Consequently, wells are drilled haphazardly and are pumped without regard to the characteristics of the producing aquifer. While such a state of affair may constitute no problem under our present level of development, there is no doubt however that things might not continue in a similar way for long. More importantly, there is a need for accurate data collection, monitoring and on longer time scale to be able to detect and document effects of water degradation and conversely show the effects of remedial activities, despite the superimposition on natural climatic variability. Therefore, documentation, storage and dissemination of knowledge are important. Through the development of awareness, knowledge and capacity at different levels, it is envisioned that the overall knowledge gap will diminish - a step towards sustainable development and management of water resources in the Niger Delta.

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