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*Full Length Research Paper*

# Sustainable Groundwater Development and Management in Nigeria: An Integrated Assessment Approach

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**Nigeria has greater challenges when it comes to groundwater development and management. The management of the resource is lagging behind the pace of development, and often, very little control is exercised in its exploitation. The current groundwater resources development and supply status is unacceptably low and needs a major transformation. With the rapid growth in population, urbanization, industrialization and competition for economic development, groundwater resource has become vulnerable to depletion and degradation. Management of this valuable resource is determined by its acceptability and utilizability in terms of quantity and quality. Due to imbalance between demand and availability, management approaches are facing various ethical dilemas. Against this context, relevant questions present themselves: What is the real extent of the problems? Why are the present efforts so limited?; and what can be done to change the situation, to start on a path to more sustainable and equitable development and management of groundwater resources? To be able to adequately address the questions and devise intelligent answers, an analysis of the present impediments deserves attention. Only by clarifying the constraints and addressing them, will any significant changes be possible, let alone occur. This paper therefore emphasizes that the machinery of groundwater resources development and management needs an urgent overhauling with the aim of streamlining the overlapping functions of the various agencies that have operated the system up till now. More importantly, the paper suggested integrated approaches/strategies for sustainable management as well as offers some relevant policy recommendations for groundwater management in Nigeria.**

**Key words:** Groundwater resources, groundwater management, groundwater policy, sustainability, groundwater utilization, Nigeria.

## INTRODUCTION

Nigeria (Figure 1) is located on the west coast of Africa, between latitudes 4°N and 14°N and between longitudes 2° E and 15°E. The land area is approximately 925,000 km$^2$, with abundant groundwater resources, enough to cater for the needs of her teeming population of about 140 million.

Despite the huge groundwater resources, water resources development has not been able to keep pace with the phenomenal population growth (Oteze, 2006). Water resources represent a major prerequisite and driver of socio-economic development. Economic sectors that water caters for include domestic, agriculture and fisheries, industry, recreation, municipality including waste/effluent disposal, and water transportation. It also plays a prominent role in power and energy generation: hydroelectric power generation's share of total power production has decreased from over 70% in 2004 to the present proportion of about 40% (Oyebande, 2004).

Groundwater is widely used because of its high quality. Groundwater development unfolds rapidly once a minimum level of technology and energy become widely available (Shah, 1993). Compared to surface water, groundwater use often brings large economic benefits per unit volume, because of ready local availability, drought reliability and good quality requiring minimal treatment (UN/WWAP, 2003).

The reliable supply of groundwater, uniform quality and temperature, relative turbidity and pollution free, minimal evaporation losses, and low cost of development are attributes making groundwater more attractive when compared to other sources (Menon, 1998). Yet, at the same time population and economic growth have led to

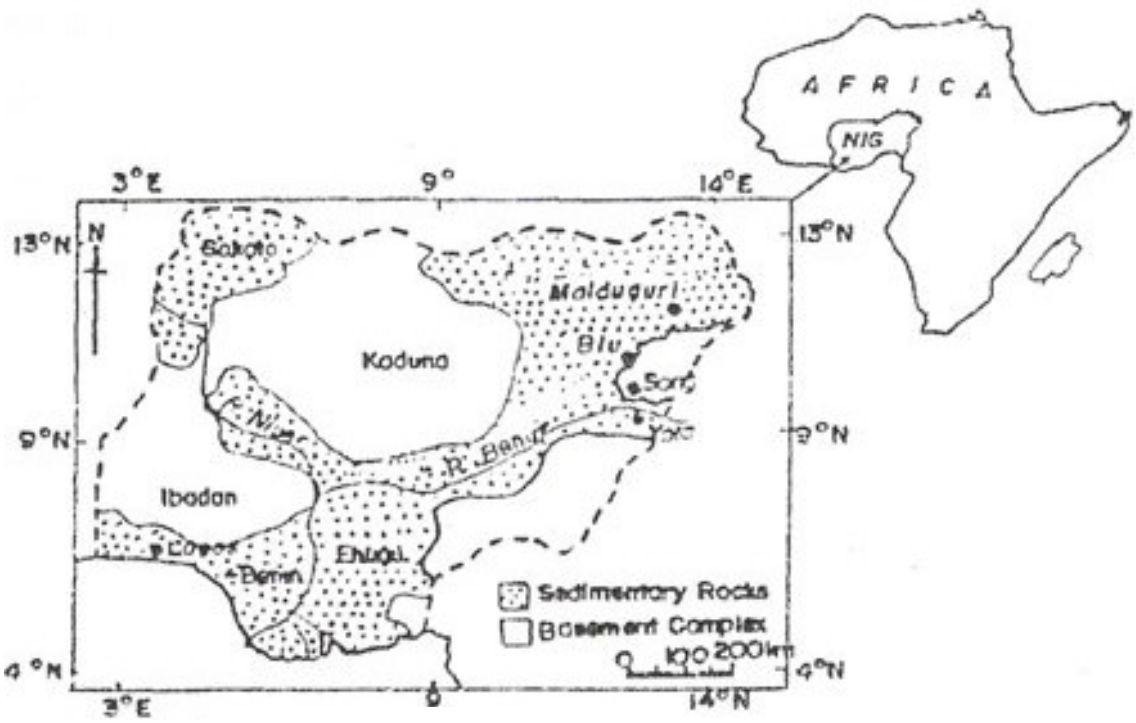


**Figure 1.** Geological Map of Nigeria. Source: Parker et al. (1964).

ever more demands on the resources. This paper therefore, attempts to identify the impediments and associated requirements for, and a path towards, long-term sustainable groundwater use and management in Nigeria.

## GROUNDWATER RESOURCES POTENTIALS OF NIGERIA

There is a very large groundwater potential in Nigeria, far greater than the surface water resources, estimated to be 224 trillion L/year (Hanidu, 1990). Rijswlk (1981) estimated groundwater resources at 0 to 50 m depth in Nigeria to be 6 × 10 km$^3$ (6 ×10$^{18}$ m$^3$). However, from the eight aquifers in Nigeria (Akujieze, et al., 2005), the Ajali Sandstone aquifer yields 7 to 10 L/s, the Benin formation (Coastal Plain Sands) aquifer yields 6 to 9 L/s, the Upper aquifer 2.5 to 30 L/s, the Middle aquifer 24 to 32 L/s, the Lower aquifer with yields of 10 to 35 L/s (of the Chad formation), the Gwandu formation aquifer with yields of 8 to 15 L/s, the Kerrikerri Sandstone aquifer with yields of 1.25 to 9.5 L/s and the crystalline fluvio-volcanic aquifer with a 15 L/s yield in the Jos Plateau region; groundwater occurrence is not limited to only 50 m b.g.l (below ground level). These eight mega regional aquifers have an effective average thickness range of 360 m, with a thickness range of 15 to 3,000 m at a depth range of 0 to 630 m b.g.l with an average depth of 220 m (Akujieze et al., 2003).

Reserves of groundwater are considerable in large sedimentary basins, which cover some 50% of the country. The potential annual groundwater resources are estimated at 51.93 ×10$^9$ m$^3$, out of which the sedimentary basins account for 67% (FMWRRD, 1995).

The occurrence of groundwater is greatly influenced by the local geological conditions which ultimately control yields. Recharge to aquifers, which influences the safe yields of wells, depends on rainfall over the area. Thus, rainfall ultimately controls the amount of groundwater recovered from wells in any given locality (Offodile, 1979). The amount of groundwater storage is not yet known, but available records indicate that major aquifers in Nigeria are located in the sedimentary deposit basins which cover about 50% of the nation's land area. The remaining 50% is underlain by crystalline rocks of the basement complex. Table 1 shows the static water resources of Nigeria while Table 2 shows the summary of the total static water resources in Nigeria

Aquifers within the basement are limited, their thickness ranges from 16 to 180 m, but depth of hand dug wells and boreholes are therefore seldom more than 60 m with a variable average of static water level between 1 to 45 m below the surface. This shallow depth coupled with the poor hydraulic conductivity, no doubt account for the general low yield of 1.0 m$^3$/h (Nwaogazie, 1995). On the sedimentary deposits, groundwater resources usually occur either as confined aquifers with

**Table 1.** Static Water Resources of Nigeria, groundwater and fresh meteoric water.

| Province | Structural unit | Area ($Km^2$) | TWRS M1 Million ($M^3$) |
|---|---|---|---|
| Crystalline hydrogeological province | N. Nigeria Shield | 234516 | 94979 |
| | W. Nigeria Shield | 115529 | 46789 |
| | Mandara Hills | 18460 | 2492 |
| | Biu Plateau | 4418 | 123.54 |
| | Adamawa Mountains | 60152 | 8121 |
| | Oban Hills | 4276 | 577 |
| | Total Cryst. | 437351 | 166212 |
| Sedimentary hydrogeological province | Sokoto Basin | 66424 | 3188352 |
| | Katsina Basin | 3564 | 28512 |
| | Nupe Basin | 36704 | 1468160 |
| | Coastal Monocl. | 12365 | 296760 |
| | Keri-Keri Basin | 22593 | 101669 |
| | Abakaliki + Mamfe | 24945 | 374175 |
| | Benue Synclinr | 96216 | 1443225 |
| | Niger Delta | 104234 | 2084660 |
| | Borno Basin | 119377 | 2148786 |
| | Total Sedim..W. | 486422 | 11134299 |
| | Total Fresh GWtr | 923773 | 11134299 |
| | Total Water Nig. | 923773 | 36201836 |

N/B: TWRS = Total static water resources. Source: Schoeneich (2003).

**Table 2.** Summary of the total static water resources in Nigeria.

| TWRS | | | Percentage | Cubic metres |
|---|---|---|---|---|
| Rain | | Atmospheric water | 3.08 | $1{,}117 \times 10^9$ |
| Surface | Fresh water | Fresh surface water | 0.03 | $12 \times 10^9$ |
| | | Fresh groundwater | 31.23 | $11{,}301 \times 10^9$ |
| Ground water | | | | |
| | Salty groundwater | | 65.66 | $23{,}772 \times 10^9$ |
| Total water Nigeria | | | 100.00 | $36.202 \times 10^9$ |

Source: Schoeneich (2003).

average piezometric level of 75 to 150 m or unconfined aquifers with thickness varying from 15 to 100 m (Nwaogazie, 1995).

## BRIEF HISTORICAL REVIEW OF WATER RESOURCES DEVELOPMENT IN NIGERIA

At the global scene, there has been continuing efforts in respect of sustainable management of water resources. The Earth Summit, the World Water Commission, the World Water Forum as well as other water related projects of Global Water Partnership, World Bank, WHO, UNESCO, FAO, UNICEF and UNDP etc have been at the forefront in the timely efforts of water resources management in Nigeria, especially in the provision of safe drinking water and basic sanitation which is within the frameworks of the United Nations Millennium Development Goals (MDGs).

In the early 1950s, government's attempt at groundwater development in Nigeria was through the Geological Survey of Nigeria. But concerted efforts have been made since independence towards the provision of potable water to the citizenry. The Nigerian government's major intervention in water resources development came during the first National Development Plan (1962 to 1968) which saw the establishment of the River Niger and Lake Chad Basin Commissions. In 1973 and 1974, the Sokoto-

Rima and Chad Basin Authorities were established. In 1976, the river basin authorities were increased to 11 to cover the whole country. But, before then in 1975, the Federal Ministry of Water Resources (FMWR) was created. Following the creation of the ministry, extensive water resources development (both surface and groundwater) was embarked upon to boost economic activities such as irrigation, fisheries as well as hydropower generation. More importantly, all these giant strides were aimed at improving water supply delivery in line with the United Nation's International Drinking Water Supply and Sanitation Decade (IDWSSD, 1981 to 1990). Aside from these noble efforts, the Federal Government embarked upon other numerous intervention programmes in the water sector, including the National Borehole Project (1980), Department of Food, Roads, and Rural Infrastructure (DFRRI)-(1986 to 1994), The Petroleum (Special) Trust Fund (PTF) Rural Water Supply Project (1995 to 1999), Improved National Access to Water Supply (1999) and lastly the Senate Constituency Water Projects (2001 till date).

## IMPEDIMENTS FOR SUSTAINABLE GROUNDWATER MANAGEMENT IN NIGERIA: MAJOR ISSUES AND TRENDS

In Nigeria, suitable machinery for the effective and sustainable management of groundwater resources has not yet evolved. This is because the authorities have put up institutions for this purpose, but at the same time set up rival agencies to carry out very overlapping functions. The overall implication is waste of available resources, leading to lack of progress in groundwater development and management. Generally, the Nigerian water problem revolves round two critical issues, namely:

(i) Inadequate access/poor distribution of water resources in time and space in relation to the needs of the people.
(ii) Inadequate planning and management of these resources.

The above mentioned problems have further manifested themselves in the form of incessant water shortages, poor access to public water supply and water-borne diseases, poor environmental quality causing groundwater pollution, improper or partial distribution of public wells due to lack of water well statistics and favouritism, poor maintenance and often sabotage in the development and operational process of public wells, and proliferation of shallow private/commercial wells of poor standard by individuals who are financially less capable of standard wells drilled with adequate drilling tools.

According to Ajayi et al. (2003), Ajayi (2006), Ezeigbo (2003), Goni (2006), Hanidu (2003), Nwankwoala and Mmom (2008), Nwankwoala (2009), Offodile (2003, 2006), Oyebande (2006), Oteze (2006), Tijani (2006), the major obstacles for sound groundwater management include: absence of or ineffective legal/institutional and regulatory framework, poor maintenance culture, poor technical and institutional capacity, lack of coordination, multiple programmes, lack of data and information for planning, shortage of well trained/committed manpower with appropriate local technology, irregular recruitment and limited manpower occasioned by the civil- service structure and the over-bearing bureaucratic control by supervising ministries, lack of professional input on water programmes and projects, absence of professionalism due to politicization, career stagnation and the lure of private practice, lack of community participation and inadequate revenue generation by water agencies, inadequate funding as shown by poor budget allocations, irregular disbursements of subventions, limited sources of aids and grants (particularly from foreign sources), inappropriate infrastructures as well as lack of adequate quality monitoring and evaluation.

In Nigeria, data on groundwater levels are not widely published or made available outside government organizations. Extraction and recharge estimates are also unreliable. As a result, discussions on groundwater over-exploitation and depletion are always based on unrealistic data. However, it is a fact that falling water tables and depletion of economically accessible groundwater reserves will have serious socio-economic consequences in a country like Nigeria. Therefore, it is needless to point out that there is an urgent need for conservation of this vital resource for sustainable groundwater development and management.

In the light of the foregoing, it is highly likely that the future expansion in groundwater will continue to take place in Nigeria. This is primarily due to the relatively high population growth rate, combined with the unprecedented rise in industrialization and welfare, which tends to increase the average per capita water use. The largest single consumer of water is, and will continue to be agriculture with urban and industrial uses on the rise. Though the generalizations made here may not be totally justified, as differences exist in different parts of the country.

Current groundwater use is characterized, as earlier noted, by uncoordinated development and supply to all sectors: rural and urban users, small and large scale users, industrial and agricultural users. This, in part, is attributable to the intrinsic properties of the resource. The general prevalence and stability in time and space of groundwater makes it a reliable and widely-accessible resource, easily amenable to private, local, and on – demand exploitation. However, this "common pool" property of groundwater also complicates a more formalized and coordinated control (Custodio, 2002). Therefore, options/strategies for significant improvements in groundwater supply are in the areas of formulation of adequate, efficient and effective water policies, funding/ appropriate infrastructures as well as monitoring and

evaluation.

## APPROACHES TO SUSTAINABLE GROUNDWATER MANAGEMENT IN NIGERIA

Groundwater management may be defined as the ongoing performance of coordinated actions related to groundwater withdrawal and replenishment to achieve long-term sustainability of the resource without detrimental effects on other resources (Kretsinger and Narasimhan, 2005). Importantly and preferably, such management programmes are a local responsibility, conducted in coordination with other entities (including cooperative monitoring programmes), and regularly evaluated to ensure consistency with basin-wide management objectives.

Globally, the issue of sustainability is on the front burner and has many different meanings; but the most widely espoused view is the continued productivity of commodities to maintain economic growth. The scientific community, however, has defined groundwater resources sustainability in prior publications (Sophocleous, 1997; Alley et al., 1999; Kretsinger and Narasiham, 2005; Alley and Leake, 2004). In White paper on groundwater management, sustainability was approached based on the physical laws that govern the behaviour of earth systems and was defined by Kretsinger and Narsimhan (2005):

"*Sustainability encompasses the beneficial use of groundwater to support present and future generations, while simultaneously ensuring that unacceptable consequences do not result from such use".*

This view of sustainability entails four premises (Kretsinger and Narasimhan, 2005):

(I) Surface water and groundwater constitute a single resource.
(ii) Groundwater is a finite resource and a component of a larger natural resources system. Actions on one or more system components generally affect the long-term balance of the whole system
(iii) Groundwater replenishment is strongly influenced by climate variability, as well as natural and enhanced recharge processes. Consequently, groundwater resources development must adapt to the system's varying capacity for renewal.
(iv) Communities need to share and manage groundwater resources so that the natural resources system retains its integrity for the future.

The overall sustainable concept varies primarily in that the overarching sustainability objectives connote greater consideration for balancing the beneficial use of components of the whole systems while avoiding long-term detriment to any part. In fact, rather than sustainability, "sufficiency" is the term presently used in many developed countries. Recent actions now move governments and local entities closer to "full" groundwater management where water agencies bring water supply and use into long-term balance (Peters, 1982). However, much remains to be done.

The issue of groundwater management is multi-dimensional, related to reliable assessment of available water, its supply and scope for augmentation, distribution, pollution and its protection from overexploitation, depletion and degradation. However, like surface water resource management, not much concerted efforts have been made for management of the hidden complex underground water resources.

Understanding the importance of groundwater resources and the growing demand for it makes it pertinent to search for effective strategies for managing the resource. For an effective supply side management, it is very essential to have full knowledge of hydrogeological controls that govern the yield and behaviour of groundwater levels under abstraction stress, the interaction of surface and groundwater in respect of river base flow and changes in flow and recharge rates due to their exploitation (Villholth, 2006). Because water supply is on the concurrent legislative list in the constitution and that means all tiers of government have responsibilities for the provision of water supply to the people.

Realizing the significant role played by potable water supply and clean environment in ensuring good and healthy individual, family and communal lives, government has embarked on certain policies and strategies to improve the coverage level of rural water supply and sanitation facilities. The water supply is to ensure that all Nigerians have access to clean water and sanitation at an affordable price. The viable options/solution to the Nigerian water problem is a unified and integrated approach to water resources planning and the provision of reliable information on the following:

( i) The nature and magnitude of available groundwater resources.
(ii) The future demand for water for domestic, agricultural and industrial purposes.
(iii) How these demands can be faithfully met within the ambit of available resources.

The issues raised above can be adequately addressed through groundwater resources mapping. Not only can the information be obtained at regular intervals but their accurate state, can also be updated. In this context, efficient groundwater policy is imperative if sustainable groundwater utilization is to be realized. Groundwater management policies therefore, will need to address a multitude of issues including, but not restricted to the following:

(i) Management of supplies to improve water availability in time and space
(ii) Management of demands including efficiency of water use, sectoral interaction with economic activities etc.
(iii) Balancing competing demands and preservation of the integrity of water dependent ecosystem.

Aside from the above mentioned groundwater management options, there is need for the following:

(i) Encourage user participation in the water resources administration.
(ii) Propose and coordinate actions geared towards the protection, defense and knowledge on groundwater use.
(iii) Proper coordination between the different tiers of government and the public, realistic tariff structure to cover cost of services, research into local production of materials required in the water sector, training of professionals and education of the public about water conservation.
(iv) Promote, organize, participate and undertake all kinds of activities, courses and seminars, outreach programmes, training, and specialization on groundwater, and any other relevant collaboration with different public administrations.

For an effective management of groundwater resources, there is a need to create awareness among the different user groups and workout area specific plans for sustainable development. Thus, groundwater management not only requires proper assessment of available resources and understanding of the interconnection between surface and groundwater system, but also actions required for proper resource management and prevention of the adverse effects of uncontrolled development of groundwater resources (Velayutham,1999).

Generally, according to Nwankwoala and Mmom (2008), the key steps necessary to move towards sustainable use of groundwater include:

(I) Improvement of the knowledge of groundwater resource.
(ii) Improvement in reporting and access to groundwater information.
(iii) Improvement in public education and better understanding of the public's attitudinal motivations.
(iv) Use of ecosystem approach to manage groundwater.
(v) Embracing adaptive management.
(vi) Adoption of a goal of sustainable use.

More importantly, one of the important strategies for sustainable management of groundwater is regulation in critical areas. This is because over exploitation / development of groundwater resources is increasingly being recognized as a major problem, especially in the Niger Delta region (Nwankwoala and Mmom, 2006). The tendency towards over exploitation of groundwater resources is rooted in the rapid spread of energized pumping technologies, resource characteristics, demographic shifts and incoherent / inconsistent government policies. There are very little efforts to check over exploitation and regulation of groundwater resource.

More specifically, there is an urgent need to check the contamination level of groundwater. The groundwater protection from contamination/ pollution can be ensured by several ways, as enumerated by Menon (1998) and Nwankwoala and Udom (2008) and summarized as follows:
(i) Restricting the disposal of industrial discharges to the ground in vulnerable areas through introduction of discharge permits and appropriate charges to encourage recycling and reduction.
(ii) Inventory of aquifers, their characteristics and classification.
(iii) Preparation of vulnerability maps, based on distribution of travel times, chemical parameters, types of topsoil, subsoil and landuse.
(iv) Control of groundwater withdrawals.
(v) Delineating and prioritizing areas of high groundwater vulnerability for main sewerage extension.
(vi) Effective enforcement provisions for groundwater protection regulations.

If the Millennium Development Goals (MDGs) formulated by the United Nations, designed to halve the number of people without access to safe drinking water by the year 2015, is to be attained, then all stakeholders – government, scientists, water managers, community leaders, Corporate Organizations, NGOs, CBOs, and others should begin to recognize that there is a distinct need for better data and better utilization of that data. These needs, though, generally exceed, most times the financial capacity to effectively address them, efforts must be intensified for improvement. Additionally, federal, states and local governments support must be garnered to address wide – reaching technological and research needs vital to developing the best possible science and groundwater management strategies that keep pace with the resource. This is very imperative because, with business as usual, Millennium Development Goals will not be met.

Therefore, the challenge is to communicate to decision makers and legislators that presently available information must be significantly enhanced to accomplish sustainability goals. Particularly, fundamental data, on-going programmes, data standards, data coordination and sharing and regional aquifer characterization are core requirements for more effective management.

## CONCLUSIONS

In this paper, serious attempts has been made to show that successful management of groundwater needs an interdisciplinary and holistic approach incorporating all

stakeholders, technocrats, hydrogeological conditions, local specific environmental issues, indigenous methods of water conservation and usage etc.

For a sustainable groundwater management, there should be effective policy framework. For any groundwater scheme to succeed, the stakeholders must be involved, motivated and trained. Thus, taking into account all the constraints related to proper management and protection of groundwater source vis-a vis action needed to be taken at different levels, a multi-pronged integrated approach with a well conceived mix of professional, technical, administrative and legal steps and community participation would pave the way for achieving the need for laying a proper/strong ecological foundation for ensuring sustainable management of groundwater resources in Nigeria.

Following the outcome of the present constraints for sustainable groundwater utilization and management in Nigeria, as outlined in this paper, can be inverted to summarize three essential prerequisites for reversing the despondent situation:

(i) Knowledge and adequate information concerning groundwater resources, and of options and tools for proper management.
(ii) A significant, detrimental groundwater-related event with large-scale effects (hitting across sectors and various users groups) to fuel a consensus and more unified goal of groundwater protection and balanced groundwater development.
(iii) Political will, commitment, and tenacity at national level to confront the problems squarely.

To this effect, the future of understanding and taking appropriate actions on groundwater resources management, in line with emerging international water policies (UN-Agenda 21, 1992), should involve integrated and coordinated efforts of all stakeholders. There is a need to build up a momentum with significant impact and credibility, and to avoid repetition and duplication of efforts. Hence, it is essential that data collection, monitoring and any dynamic modeling takes place continuously and on longer time scale to be able to detect and document effects of groundwater degradation and conversely show the effects of remedial activities, despite the superimposition on natural climatic variability.

Documentation, storage and dissemination of knowledge are important. Through the development of awareness, knowledge and capacity at the national and local level, it is envisioned that the overall knowledge gap will diminish- a step towards sustainable development and management of groundwater resources.

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