



UNICEF NIGERIA

WASH SECTION

# STUDY OF PUBLIC AND PRIVATE BOREHOLE DRILLING IN NIGERIA

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FINAL

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## List of Abbreviations

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ADP	Agricultural Development Programme
CEB	Cost Effective Boreholes
DFID	Department for International Development
DFRRI	Department for Food, Roads and Rural Infrastructure
GEP	Girls Education Project
EEC	European Economic Community
ESA	External Support Agencies
FMAWR	Federal Ministry of Agriculture and Water Resources
GSN	Geological Survey of Nigeria
JICA	Japan International Cooperation Agency
KNARDA	Kano Agricultural and Rural Development Authority
LGA	Local Government Authority
NEEDS	National Economic Empowerment Development Strategy
PTF	Petroleum Trust Fund
NA	Not available
NEEDS	National Economic Empowerment and Development Strategy
NWRI	National Water Resources Institute
NUC	National University Commission
O&M	Operation and Maintenance
OPEC	Organisation of Petroleum Exporting Countries
RBDA	River Basin Development Authority
RUWASSA	Rural Water Supply and Sanitation Agency
RWSN	Rural Water Supply Network
WSP	Water and Sanitation Program
UNICEF	United Nations Children’s Fund

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## Exchange rate

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At the time of the preparation of this report US\$1 exchanged for Nigerian Naira 118.

## Executive Summary

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UNICEF has been supporting the Federal Government of Nigeria in water supply and sanitation in the rural areas in all the 36 states of the country since 1999. Most of the water supply is through the provision of boreholes. UNICEF Nigeria commissioned the **Study of Public and Private Borehole Drilling in Nigeria** to evaluate the factors affecting the cost of drilling in the country and determine how to achieve more cost effective borehole provision. This report presents the study methodology, findings and recommendations for improving cost effective borehole provision in Nigeria. The study was carried out between April and September 2008 by a 2 man team. Due to the size of the country it was agreed that data should be collected in the four states of Kano, Lagos, Niger and Rivers.

Existing data and information on drilling practices in the country and elsewhere was reviewed and about 70 sector players were interviewed. Prices of boreholes were collected from several programmes and projects as well as state agencies and compared with a systematic framework for analysis of borehole costs.

The cost effectiveness of borehole drilling in the study states was analysed using the conceptual framework for cost effective borehole provision developed by the Rural Water Supply Network (RWSN). The framework recognises that the cost and quality of boreholes are influenced by six core factors and ten elements. The core factors are independent variables which cannot be easily changed from within the sector but have a bearing on the cost and quality of boreholes e.g. geology, climate, communication network, sector players, finance as well as the cost and availability of material. The ten elements can be influenced from within the sector and are:

- Borehole standards and design should fit the purpose
- Contracts should be packaged for multiple boreholes
- Smaller rigs should be used if possible
- Hydrogeology knowledge should be improved and appropriate siting practices utilised
- Pumping tests should be matched to borehole purpose
- Drilling should be properly supervised
- Groundwater resources should be evaluated and information made available
- Private contractors should be supported
- Communication networks should be improved for both public and private sector and management skills of public and private sectors enhanced.

In addition to the above elements, the study also considered the process of tendering and contract award.

Nigeria has a diverse terrain and geology. The geology incorporates several aquifers which provide borehole supplies. Governments, external support agencies and the private sector are making investments into water supply boreholes. The EU, DFID, JICA, UNICEF and WaterAid provide support to borehole provision in rural areas. World Bank is involved in urban water supplies. Attaining the MDGs for water and sanitation is a priority and recently the Federal Government set up a special office to address the Millennium Development Goals using funds from the debt relief granted the country by Paris Club creditors.

Borehole casing material is available, uPVC pipes are manufactured locally, but steel linings are imported. Light and medium duty drilling rigs are made locally and there are local agents of international rig manufacturing companies.

The National Water Resources Institute (NWRI) is responsible for conducting training courses for development for the water industry. These include courses on borehole drilling, siting, supervision and rehabilitation as well as groundwater exploration and exploitation. Over 1,000 people are trained annually.

The different geology underlying the four states covered by this study (Kano, Lagos, Niger and Rivers) means that borehole depths differ. Drilling techniques, expected borehole yield and borehole designs are therefore also different. The smaller population and the lower level of economic development in Niger State have led to a smaller number of drillers in the state than the other states. Despite the favourable geology and population the civil unrest in the Rivers State has discouraged some of the drillers and increased the cost of borehole provision. The difficult terrain of River State also makes it different from the other states.

**Kano State** is the most populous state in the country according to the 2006 census figures. The geology is almost entirely crystalline. Aquifer depth is an average of 40 m. The Hadejia River Basin Authority and the State RUWASSA are the major employers of drilling contractors. The RUWASSA is one of the few government agencies still involved in direct drilling. The drillers in the state have formed themselves into an association of about 100 members.

**Lagos State** is the second most populous state in the country. It is underlain by sedimentary rocks and aquifer depths vary between 40 m to 250 m and 800 m. The State Water Corporation and the Ministry of Rural Development and the private sector are the main employers of drillers. The number of drillers in Lagos city is estimated at about 150. Some of the conventional drillers also engage in manual drilling.

The population of **Niger State** is less than half that of Lagos or Kano. It is underlain partly by sediments and partly by crystalline rocks. There are only two conventional drillers resident in the state capital. There are no pipe manufacturers. The major employers are the Upper Niger Basin Development Authority and the State RUWASSA.

The population of **Rivers State** is about half that of Kano. It is underlain by sediments. The low lying coastal terrain and the creeks make communication difficult and drilling cost much higher than other places in Nigeria. The on-going Niger Delta unrest has worsened communication. As a result, the drilling sector is in a depression. Several of the drillers have closed down.

#### **Analysis of the cost effectiveness of current drilling practices**

**Tendering and contract award:** The contract award process in the country tends to follow the laid down procedure of advertising, prequalification, tendering, evaluation and award. However the process can up to a year and there are allegations that it is not always transparent, particularly on government projects. A major constraint mentioned by drillers is the inability to participate directly in government contracts.

**Borehole standards and designs:** FMWR use five borehole designs based on geology and aquifer depths in different parts of the country. All the agencies and programmes recognise the need to design boreholes to fit the purpose. Plastic lining is used in the shallow aquifers and steel in the deep aquifers. All the drilling contracts in the country specify that boreholes are lined the full depth despite the inherent strength of the underlying hard rock formation on the basement complex. Apart from increasing the cost of drilling it tends to block water from flowing freely into the hole. In other countries, the lower part of the borehole in the rock is left uncased and savings made on the unused lining material. The idea of an open hole was rejected by all the drillers interviewed because it is never certain that the material from the weathered mantle will not migrate down and block the hole. Better the extra cost of lining material than the loss of the entire hole. There has not been work undertaken in Nigeria using 75mm casing for handpumps.

**Smaller and less costly rigs:** Drillers have realised the benefits of small light duty rigs and are using them where appropriate. 50% of the rigs encountered in the course of the study can be classified as light to medium. 30% were made in Nigeria. Most of the heavy duty rigs are between 20-30 years old and are found mostly in the southern sedimentary terrain. Conventional drillers use manual drilling where found to be more cost effective than mechanised drilling.

Manual or hand drilling for both water supply and irrigation is widely practised in the country as there are aquifers within 100m depth that can be reached manually. This may be done by augering, percussion drilling or jetting. The most commonly used technique is jetting or wash boring. The ranks of the hand drillers include farmers, and artisans trained in washboring, university graduates and conventional drillers with rigs but who consider hand drilling cost effective where it is feasible.

An estimated 20,000 water supply boreholes have been drilled manually in the major cities of the country and 10,000 tubewells for irrigation. Hand drillers are patronised mostly by private householders. Rivers State RUWASSA is the only government agency recorded as being involved in hand drilling or engaging hand drillers for water supply. The Agricultural Development Programmes (ADPs) in the north train fadama farmers in washboring for irrigation tubewells.

**Contract packages** are small and do not allow for long term planning and investment in equipment by the contractors. Most drillers working on the shallow aquifers drill an average of 50 boreholes per annum which in essence means a 60% idle time.

**The knowledge of the hydrogeology** of the country has improved over the years. The Nigeria Hydrological Agency (formerly the Hydrology and Hydrogeological Department of FMWR) has for several years been collecting data for a hydrogeological map of the country and when it is eventually published should further increase information on the groundwater resources of the country.

**Siting practices:** The success rate of borehole siting by geophysics on the basement complex has also improved. There is a tendency on some of the projects to specify geophysics on all drilling sites even where it is not necessary. On some of the consolidated sediments a review of existing borehole data will be more applicable in determining depths to the aquifer than geophysics.

On most projects drillers are responsible for the geophysical survey and do not get paid when the borehole is dry. This is a contentious issue between drilling contractors and the employers. Although geophysics reduces the probability of drilling a dry hole, it is not fail proof. As such drillers feel that once their survey has been approved as properly carried out they should not be penalised for a dry hole. On the other hand, sponsors like UNICEF feel their interest is in the provision of water sources and until that is achieved there should be no payment.

**Test pumping:** Both the FMWR and the state projects design the pumping tests to fit the purpose of the borehole. Pumping tests are usually specified to last 2 to 6 hours for handpump boreholes and 8 to 24 hours for motorised schemes depending on the expected output and use of the borehole.

**Supervision:** Capacity for proper supervision in terms of experienced personnel and equipment is limited at state level. This to some extent is responsible for borehole failure. The Federal government and external support agencies engage consultants to carry out supervision.

**Operation and maintenance procedures:** 30% to 50% of the existing boreholes are broken down at any one time. Failure may be due to poor construction, or abstraction exceeding renewable resource or pump failure. This constitutes a major source of wastage and a drawback in meeting water supply targets. FMWR is currently carrying out an inventory of water and sanitation facilities in the country. The data will give an estimate of non functional schemes.

**Evaluation of groundwater resources:** Post construction monitoring is hardly ever carried out. Water quality tests do not conform to the National Drinking Water Quality Standards. Arsenic has been reported in the groundwater in some parts of the country but none of the projects specify testing for arsenic. Intensive drilling in the urban areas of Lagos and Kano State poses risks of water level decline and groundwater mortgaging.

**Private contractors:** Borehole drilling by the private sector has been going on since 1951. Most of the drilling in the country is presently carried out by the private sector. There may be up to 1,000 drilling contractors in the country. Some are conventional drilling contractors with equipment and a management structure; others are artisan drillers engaged in manual drilling or using locally fabricated rigs and there are also contractors with some interest in drilling but no equipment whatsoever. FMWR has 230 pre-qualified contractors on its list and the recently established Water Well Drilling Association of Nigeria has a directory of 350 drilling contractors.

### **Pricing and Costing**

The price of the borehole is what the customer be it government, project or the householder pays for it. The cost is what the driller pays to deliver the product. The difference between the cost and tender price is due to the need to allow for profit, overheads, taxes, risk, contingencies and competition.

The costs incurred in producing a borehole can be broken into mobilisation; drilling; casing and completion; and development and pumping test. Each component contributes significantly to total cost therefore cost saving on one particular item will not necessarily have a major impact on the overall cost. The **geology** has a bearing on the occurrence and depth of the aquifers and therefore on the drilling depth and the type of rig that can be used in a particular terrain and the lining material.

Modelling of three scenarios found that prices (including only mobilisation; drilling; casing and completion; and development and pumping test) would be expected to be as follows:

- (i) 110mm diameter uPVC lined borehole 50m deep (basement complex) ~ US\$ 4,708 (US\$ 94 per m)
- (ii) 110mm diameter uPVC lined borehole 80m deep (sedimentary) ~ US\$ 8,500 (US\$ 105 per m)
- (iii) 150mm diameter steel lined borehole 150m deep (sedimentary) ~ US\$ 24,893 (US\$ 166 per m)

These prices are in a similar range to the prices quoted in bills of quantities collected for the study; ie:

- (i) Basement complex (ave 35m, maximum 60m) 110mm uPVC casing US\$ 3,400 to US\$ 6,100.
- (ii) Hand drilled borehole with a 110 mm uPVC lining ~US\$2,100
- (iii) Shallow sediments (80 m) 150 mm diameter UPVC casing US\$6,300 to US\$ 7,600
- (iv) Deep sediments (150 m) 150 mm diameter steel casing US\$18,500 to US\$ 26,400
- (v) Very deep sediments (250 m) 150 mm diameter steel casing US\$50,800 to US\$ 55,100

However, additional costs incurred, such as for waiting time can cause the actual price paid to be higher. Systematic costing procedures are not always reflected in the priced bill of quantities.

On the basement complex that underlies about 55% of the country, aquifer depths are on average 35 m and maximum depth is 60 m. For this depth, a light rig can be used. If the overburden is thick enough the depth can be reached by manual drilling. The lower price end is represented by drillers using locally manufactured rig and drilling to 35 m depth and the upper end is government contracts specifying drilling to 50 m. On most drilling projects the price is of the order of US\$ 5,100. The cost of a hand drilled borehole is about a third to quarter of a machine drilled hole of the same depth and casing material.

Boreholes are often drilled deeper than they need to be due to contract practices and lack of a proper survey. Most of the coastal areas of Nigeria and other sedimentary areas have several aquifer horizons (40 m to 250 m and 800m). Different drilling techniques are required for the different aquifers and so the prices vary. The shallow aquifers may be accessed by hand drilling or a light rig whilst the others need medium to heavy duty rigs. uPVC lining could be used on the shallow aquifers but steel lining are required for the deeper aquifers. The deep boreholes take longer to drill and so labour, drilling fluid and fuel costs are higher. Hence a much higher borehole cost.

Apart from the drilling depth, movement of equipment may be hampered by the terrain. In the creeks of the Niger Delta barges are required to move drilling rigs to some of the sites which results in additional costs. Different demands from the boreholes require different lining diameters which affects price. Varying distances to the site means differences in mobilisation costs. uPVC pipes are produced in Kano and Kaduna and Lagos and are thus cheaper to supply by drillers close by. Steel casings are imported to Port Harcourt and Warri. Where these are required for water wells in Lagos or Maiduguri they are hauled over distances of up 800 km.

Some drillers in Lagos have to engage a police escort to get their equipment to site to protect them from theft and for ease of passage through police check points. The unrest in the Niger Delta has led several drilling contractors to give up the business and those left have increased their prices.

## Recommended Strategic Actions for Cost Effective Boreholes

### Federal level

1. The Federal Government and its agencies should concentrate on **policy formulation and coordination** whilst providing financial support to the states and local governments to implement borehole drilling projects.
2. FMWR/UNICEF should develop an **action plan for cost effective borehole drilling** which takes the following recommendations into consideration:
  - i. Increase the transparency of the award process
  - ii. Reduce payment delays
  - iii. Accelerate the production of hydrogeological maps for the country
  - iv. Improve the sustainability and maintenance of existing handpumps
  - v. Ascertain capacity development requirements of Government staff and improve it as necessary
  - vi. Improve groundwater resources monitoring (quality and quantity)
  - vii. Base drilling depths in the basement complex on realistic figures from the geophysical survey rather than a standard assumed depth of 50m or 60m
  - viii. Cluster boreholes together in terms of location to reduce mobilisation costs
  - ix. Develop the capacity of drillers and supervisors in construction
  - x. Identify the areas in Nigeria where hand drilling is feasible and promote this technology
  - xi. Set up a system to ensure the quality of hand drilled wells

The action plan should be presented as a memorandum to the National Council for Water Resources for adoption by all stakeholders. It should also set standards of materials and practices in the drilling industry and ensure compliance.

3. The Federal Government should spearhead a **national water supply programme** involving all stakeholders and determine the number of water supply sources, including boreholes required in each state to meet the MDGs. The programme needs to be in harmony with the National Water Resources Policy. This requires more participation at the lower levels of Government. The budget and the financing options to meet the targets have to be worked out and the roles and responsibilities of every stakeholder identified.
4. The **investments required** to meet the water supply targets, available financing options and the responsibility of each stakeholder should be identified. Government should ensure timely provision of its share of the cost.
5. The Federal Government should instigate actions to **determine the available capacity in the country** i.e. the number of drilling contractors, the number of rigs and their location so that if there is a shortfall in meeting the targets, options to bridge the gap can be identified and mobilised.
6. The Federal Government should provide **support to the drillers association** as a forum for discussion with the drillers, professionalizing borehole drilling and increasing the capacity of the drillers for cost effective drilling.

### State level

7. The State Governments should **identify the manpower and capacity development requirements** of their staff for effective supervision of borehole drilling and provide the training, tools and enabling environment.
8. The National Water Resources Institute in Kaduna should better market itself, in order to fulfil the large demand for water well drilling and supervision expertise.
9. The State Governments and the RUWASSAs should ensure that borehole contracts follow the principles of cost effective borehole drilling as enunciated in the study report, reflecting transparency, and equity. Also ensuring where possible that
  - larger contract packages are awarded with boreholes in close proximity and similar geology

- drilling depths are based on reality
- contracts are supervised by experienced personnel
- water quality tests reflect the National Drinking Water Standards

The State Governments should work with local governments and develop guidelines for **continuous monitoring** of water sources, both quality and output, and operation and maintenance. Groundwater resources monitoring, both the quantity and quality, needs to be stepped up to check the trends and prevent deleterious effects of over pumping and contamination.

10. They should also provide **training and technical** support for LGA staff to be able to continue the training of community members in operation and maintenance of their facilities.
11. State Governments should **identify** those areas in their states where **hand drilling is feasible** and hand drilling operators with entrepreneurial skills who can be engaged in hand drilling. This technology should be promoted as a cost effective means of meeting the demands for community and household domestic water supply. However, there is need to set up a quality assurance system to ensure the quality of the drilling process and the product.

#### **Local Government level**

12. Local governments should keep an **inventory of the boreholes** within their area and monitor their functionality and support the communities in the maintenance of the facilities
13. LGAs should **identify and train handpump mechanics** in their areas and promote the setting up of sources of spare parts for handpumps within the locality.

#### **External Support Agencies**

External Support Agencies are to support governments in sector and institutional reforms including the development of policy, strategy and regulatory frameworks, and build capacity of government institutions at all levels to monitor and drive progress. They should support other processes that promote equity, transparency and good governance such as fiscal discipline, free and dynamic political processes, and civil society participation.

# 1 Introduction

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UNICEF has been supporting the Federal Government in the provision of rural water supply and sanitation in all the 36 states from 1999. Some concerns have been expressed about the cost and quality of drilling in Nigeria. In response to this, UNICEF Nigeria commissioned a study of public and private borehole drilling in Nigeria in April 2008.

The aim of the study was to evaluate the factors affecting the cost of drilling in the country and how they could be addressed to achieve cost effectiveness in borehole provision and thereby increasing access to water supply in the country.

The outputs of the study were:

- an assessment of drilling prices and costs, cost factors for selected programmes/ institutions in four states
- a comparison of cost effective borehole drilling between the four states and other programmes
- identification of strategic actions for cost effective boreholes for actors at federal, state and local governments
- a field note for hand drilling practices in Nigeria
- a short summary report.

This report synthesises the above outputs into one document.

The study approach was agreed at a two-day stakeholders' workshop in May 2008. It was agreed to focus on information and data from Kano, Lagos, Niger and Rivers states. These were selected based on differences in geological terrain, population size and level of drilling activity. The study was carried out by Dotun Adekile, an independent consultant and Olusola Olabode, staff of the National Water Resources Institute (NWRI) between April and September 2008.

Although concern has been raised about the cost of drilling in the country the study adopted a neutral stand to this issue from the outset. The study was carried out by reviewing existing data and reports as well as interviewing personnel of key institutions involved in borehole drilling in the four states. Checklists and questionnaires were used to collect the information to ensure consistency in data collection. Field visits were made to 18 institutions involved in drilling and 41 drilling contractors were interviewed as listed in Appendix 1.

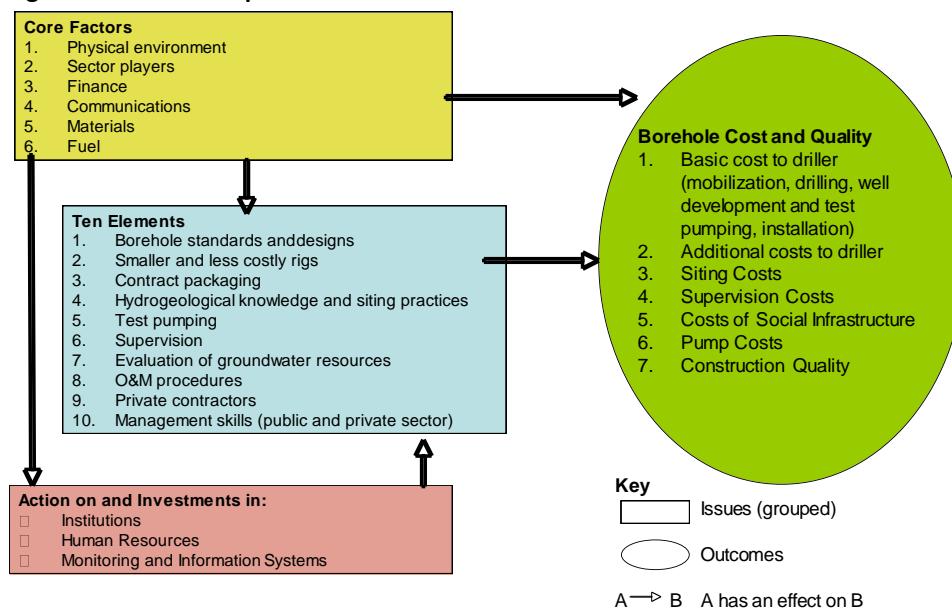
The cost effectiveness of the projects in the Federal Ministry of the Water Resources and the four states was subsequently analyzed using the conceptual framework for cost effective borehole provision developed by the Rural Water Supply Network (RWSN)<sup>1</sup> as given in Figure 1.

The framework recognizes that borehole costs and quality are influenced by six core factors and ten elements which need to be analysed to determine the most effective ways to bring about improvements in a particular context. Borehole costs are borne by the drilling contractor but sometimes they are also borne by the project, consultants and government.

The core factors comprise six independent variables which cannot be easily influenced from within the sector but have a bearing on the cost and quality of boreholes. The ten elements are policies and practices which can be influenced and changed more easily than the core factors. To address them actions and investments are required with respect to human resources, the institutional framework and monitoring and information systems are required.

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<sup>1</sup> RWSN is a global network promoting sound practices in rural water supply and is committed to the development of cost effective boreholes in Sub Saharan Africa.

**Figure 1 RWSN Conceptual Framework for Cost-Effective Boreholes**

In this report the core factors and the elements of cost effectiveness for the different projects are analysed and comparisons made. In addition to the ten elements in Figure 1 above, the tendering procedures are also examined. Borehole prices and factors affecting them are presented, as well as recommendations for strategies and actions to be taken to improve drilling in the country. As part of the study, a field note on hand drilling in Nigeria was prepared (Adekile and Olabode, 2008). Strategic actions for actors at federal, state, local government and the role of the external support agencies (ESAs) were developed in a participatory manner by participants at the final stakeholders' workshop at which the findings of the study were presented.

The report is structured as follows:

- Chapter 1 provides the background and context of the study.
- Chapter 2 gives a review of the literature on drilling in Nigeria and cost effective borehole practices in general.
- Chapter 3 provides a description of the political and physical terrain of Nigeria.
- Chapter 4 gives an overview of the Nigerian drilling environment as part of the evaluation of the core factors affecting drilling in the country.
- Chapter 5 looks at the interplay of the core factors in the study states and how they may affect the cost effectiveness of borehole drilling.
- Chapter 6 looks at drilling practices at FMWR and in the states in view of the 10 elements of cost effectiveness.
- Chapter 7 provides an overview of hand drilling in Nigeria.
- Chapter 8 looks at borehole costs and prices and factors affecting them in the four states.
- Chapter 9 gives the conclusions of the study.
- Chapter 10 sets out recommendation for strategic actions by actors at the three levels of government.

## 2 Literature review

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Some of the books, reports and papers on drilling in Nigeria and cost effective borehole which were consulted are reviewed in this section.

### 2.1 Groundwater resources

Nigeria has a long history of groundwater studies. Raeburn and Jones (1934) published the results of the first regional hydrogeological studies in the country in their account of *The Geology and Water Supply of the Chad Basin* (Geological Surveys of Nigeria, Bulletin 15). Some of the earlier works include:

- *Geology and Hydrology of Gombe* by J.H. Thompson (1956). Records of the Geological Survey of Nigeria
- *Pressure water in Chad Formation of Borno and Dikwa Emirates* by W. Barber (1965). Geological Survey of Nigeria Bulletin No. 35
- *Groundwater in the Eastern Region of Nigeria* by J.R.T. Hazell (1960). Geological Survey Report 5198
- *Groundwater Resources of Western Nigeria* by J.D. Carter (Undated). Geological Report 1185
- *Aquifers in the Sokoto Basin, North Western Nigeria with a Description of the General Hydrogeology of the Region* by Henry R. Anderson and William Ogilbee (1973). Geological Survey Water Supply Paper 1757

Recent accounts are mainly consultant's reports reviewing State or local hydrogeology for various projects. The reports of the drilling accounts of several World Bank funded Agricultural Development Programme (ADP) rural water supply projects provide a lot of information on the groundwater resources of the project areas. The ADP projects which were carried out in present day Bauchi, Gombe, Jigawa, Kaduna, Kano, Katsina, Kebbi, Kwara, Sokoto and Zamfara probably generated logs of about 8000 boreholes. Also the consultants' reports of the investigation of the irrigation potential of shallow alluvial aquifers in most of the northern states for the ADPs provide excellent information on the groundwater resources of the floodplains.

Offodile (2002) attempts a synthesis of existing knowledge on the groundwater resources of the country. He recognises the interplay between rainfall, climate and geology and described the groundwater resources of the country according to the river basins. He attributes the droughts that occur almost on a ten yearly cycle, and the southward movement of the Sahel and its effects on groundwater recharge to global climate change. He also discusses the issues of poor quality groundwater, contamination and over abstraction in some parts of the country.

Eduvie (2008) identifies the areas of difficult groundwater terrain in the country as those relating to

- geological environments e.g. the compacted sediments of the Benue trough and lack of fractures and regolith in the basement complex of the Katsina/Zamfara area
- deep water levels and aquifer zones being over 300 m e.g. parts of Enugu, Borno and Yobe States
- poor water quality e.g. salinity in most of the shallow coastal aquifers and some sediments of the Benue trough
- poor access to drilling sites especially in the Niger Delta area.

### 2.2 Establishing the drillers association and the Nigerian drilling environment

As one of the steps in achieving cost effective borehole provision, RWSN is facilitating the setting up of a drillers association in the country. To understand the drilling environment in the country, the network commissioned the *Nigeria Drilling Study Background Report* (Adekile, 2007). The report describes the physical terrain of the country, gives a brief history of drilling in the country and the emergence of the indigenous drilling contractors and their challenges. It evaluates drilling practices and knowledge in the country and concludes that the principles of cost effective borehole provision are not completely new to

practitioners in Nigeria but a lot of work is still required to get the principles into the mainstream. It includes a directory of 300 drilling contractors, with their telephone numbers and email addresses.

### **2.3 Who drills in Nigeria**

Most of the drilling in the country is presently carried out by the private sector. In the past, some public sector agencies were involved in drilling but they were unable to overcome the restrictions imposed by having to conform to civil service conditions and were inefficient (Adenle and Beale, 1989). Apart from a few agencies like the Kano State Rural Water and Sanitation Agency, most government agencies have disengaged from borehole drilling.

There may be up to 1000 drilling contractors in the country (Adekile, 2007). However some of the drilling companies in the country have no equipment. Adenle and Beale (1989) identified only 25 competent and committed local drilling contractors out of the estimated 400 drilling companies operating in the country at the time. Of the estimated 1000 drilling companies currently operating in Nigeria, FMWR has 230 pre-qualified contractors on its list (Adekile, 2007). As stated above, the Water Well Drillers Association of Nigeria currently has a directory of 300 drilling contractors.

### **2.4 The constraints of the Nigerian Drilling Contractor**

Adekile (2007) identified the following as the challenges facing the Nigerian driller

- Third party involvement in drilling contracts
- Small Contract Packages
- Long distances between contract locations
- Lack of credit facility
- Difficulty in obtaining spares and consumables
- Clients not following contract procedure
- High turnover of personnel
- Poor access
- Responsibility for geophysical survey

Most of these constraints were identified by Adenle and Beale (1989) and they concluded that the best way to professionalize and improve the drilling industry was the formation of a drillers association. But there was no response to the call until recently.

### **2.5 Borehole costing and pricing**

Wurzel (2001) points out that the cost of construction of boreholes is several times more expensive than the combined cost of handpump, sanitation facilities, and health education. Therefore for more people to have water and sanitation facilities the focus should be on reducing the cost of borehole construction.

Borehole price is the amount paid by government or a project for the successful boreholes whereas cost is borne by the contractor, consultant, and in some cases by government (Danert et al, 2009). The differences between the cost and the priced bill of quantities are accounted for by the need to allow a percentage for overheads and profit, taxes, and risks. In some cases the tendered price may be lower than the cost price where the contractor is particularly keen to win the business or undercut competition (Carter et al, 2006).

Borehole cost comprises four major components – mobilisation/demobilisation, drilling, casing and completion, and development and test pumping. Rowles (1995) presents a systematic cost calculation for the drilling component, taking account of fixed and running costs, equipment lifetime and drilling performance. Carter et al (2006) adopt this method in calculating the percentage cost of the drilling component in the overall borehole cost but use actual cost from a drilling enterprise to calculate the other components.

Current prices of different boreholes in the different terrains by the FMWR are given by Adekile (2007) as shown in table 1. It should be noted that the prices are inclusive of pump and in some cases overhead tank and generator.

**Table 1 Federal Ministry of Agriculture and Water Resources Borehole Prices**

Type of Borehole	Cost per hole
PVC lined, 60 m deep, fitted with a handpump	\$11,700
Steel lined, 75 m deep, fitted with a submersible pump	\$61,560
Steel lined, 150 m deep, fitted with a submersible pump	\$83,280
Steel lined, 300 m deep, fitted with a submersible pump	\$112,421
Steel lined, 600 m deep, fitted with a submersible pump	\$197,656

Eduvie (2008) gives the average of borehole prices in different geological environments as shown in table 2.

**Table 2 Borehole Prices in Different Geological Environments in Nigeria**

Geological Environment	Cost per hole
Basement Complex	\$3,500 - \$6,200
Sedimentary area	\$7,000 - \$58,000
Deep sedimentary area (500 -1000 m)	\$200,000 - \$375,000

Danert et al (2009) give a comparison of prices in several countries as shown in table 3.

**Table 3 Examples of Estimated and Actual Drilling Prices**

Country, year	Price per well	Price per meter	Comments
Kenya 1996	\$8,400	\$120	Price estimated for 70 m well in specific programme (includes drilling, testing but not siting, supervision or failure)
Nigeria 2006 (Adekile, 2007)	\$11,700	\$195	Federal Ministry of Water Resources 2006 borehole price. PVC lined 60 m depth fitted with handpump inclusive of services to the engineer
Tanzania 2004 (Baumann)	\$6000		Budget for borehole with a handpump as in the National Rural Water Supply and Sanitation Programme (2004). Main Report V 1
Uganda, 2007 (MWE, 2007)	\$8,700		Average price of private sector drilled deep boreholes (with handpumps) paid for by the district local governments in financial year 2006/7
Malawi 2001 (Mthunzi, 2004)	\$2,730		Estimated average well cost including capital, recurrent, personnel & material; assuming 45 wells drilled per year with small NGO rig
Burkina Faso 06 (Antea 2007)		\$152	Average cost of drilling and installation of casing and screen (PVC) but not the pump, as established by study of drilling costs
Senegal, 2006 (Antea 2007)		\$500	Average cost of drilling and installation of casing and screen (stainless steel) but not the pump as established by study.

Eduvie (2008) quoting Sehmi (2004) also presents a comparison of drilling prices in some developing countries as shown in table 4.

**Table 4 Borehole Prices in some Developing Countries**

Country	No. of boreholes/rig/annum	Drilling Costs/m	Year
India	150	\$10	1989
Sudan	150	\$60	1989
Nigeria	150	\$160	1989
Ethiopia	6	\$400	Before 1989
Ethiopia	50	\$106	1989

However Carter et al (2006) in the Ethiopia drilling study rejected the simplistic comparison of borehole costs between countries, particularly the often cited comparison between drilling costs in Africa and India. They pointed out that India is a subcontinent with huge markets, developed infrastructure,

widespread competition, and relatively easy drilling. Whilst Africa is a continent of 52 nations, relatively small markets, vast distances and poor roads, and relatively little drilling activity. The study therefore did not start from the premise that drilling costs in Ethiopia were unnecessarily high but rather attempted to understand the factors that influence the cost of boreholes before attempting to proffer the means by which they could be reduced. This neutral approach was considered essential for an objective appraisal of the drilling economy and was also followed for the study presented in this report.

Previous studies on cost effective boreholes put emphasis on cost reduction by focusing on technical issues such as appropriate drilling equipment and efficient borehole siting and designs. Carter et al (2006) agree that these issues are important but the key issues affecting many of the individual cost often originate elsewhere e.g. cost of transaction, condition of equipment, high prices related to perceived level of risk.

The outcomes of the Ethiopia study have been adopted as the ten principles for cost effective boreholes provision by the *RWSN* which is part of the evaluation framework for cost effectiveness. See table 5.

**Table 5 Ten Elements For Cost effective Borehole Provision**

<b>1. Boreholes should be designed and constructed to fit their purpose in terms of diameter, depth, casing and screen.</b>
<b>2. Smaller and less costly rigs should be utilised to provide boreholes that are fit for their designed purpose.</b>
<b>3. Contracts should be packaged for multiple boreholes in close proximity and for boreholes with similar geology.</b>
<b>4. Knowledge of hydrogeology should be improved and appropriate siting practices utilised.</b>
<b>5. Test pumping requirements should be matched to borehole purpose while taking into account the importance of data to improve the understanding of hydrogeology and water resources.</b>
<b>6. High quality, timely construction supervision should be emphasised.</b>
<b>7. Rigorous evaluation of ground water resources should be undertaken and information made available.</b>
<b>8. O&amp;M procedures to ensure the sustainability of pumped water groundwater sources should be established.</b>
<b>9. Private contractors should be supported regarding importation, local manufacture, taxation, work flow and to professionalize.</b>
<b>10. Communications network should be improved and the management skills of public and private sectors enhanced</b>

Danert (2009) has proposed using the ten principles as the basis for developing proxy indicators for cost effective boreholes. This would enable realistic comparisons to be made between countries and programmes and even allow bench marks to be set.

## **2.6 An early call for cost effective boreholes**

Water Surveys Nigeria Limited (1986) in the Bauchi State Shallow Aquifer Study argues that rural boreholes do not need a big rig and if urgency is not paramount such boreholes do not need high tech rigs. Smaller rigs are very much cheaper and simple rigs need less expert operation – so boreholes produced are much cheaper.

In the same vein Ball (2004) calls for a change in the practice of groundwater development in developing countries being the preserve of imported experts to the training of local people and more appropriate equipment so that the ability to extract water from boreholes becomes permanently available in rural areas. In this way communities in the developing world will be able to meet their own demand at a cost they can afford.

Wurzel (2001) proposes that cost reduction in borehole construction can be achieved by

- matching borehole depth and other parameters to the borehole yield which for a handpump is a maximum of 1m<sup>3</sup>/hour
- using low cost drilling technique

He queries the use of expensive geophysics for low yielding boreholes, suggesting that an experienced eye may just be able to site a borehole without geophysics. This is debatable as in most of the crystalline areas of Nigeria and Africa in general geophysics is required to find the pockets of groundwater.

Ball (2004) shows that cost reduction can be achieved by reducing drilling diameter for handpump boreholes from 110 mm to 75 mm. He reminds us that the convention of 110 mm diameter cased hole arose from the need to accommodate the cylinder of the India Mark II pump and that the new modifications Afridev can fit into a 76 mm hole. He shows that a 3 inch hole requires 25% of the inputs of a 6" hole and all the savings. He also asserts that 90% of the boreholes in Africa do not need lining to depth.

## **2.7 Hand drilling**

Danert (2006) documents the history of hand drilling in Niger republic. Since the introduction of hand drilling in the country in the early 60s, the number of boreholes drilled manually had gone up to 3,500 by 1996 with some support and promotion by an NGO.

### 3 Political and Physical Terrain of Nigeria

This chapter gives an overview of the political and physical terrain of the country. Some of it appeared in the RWSN Nigerian Drilling Study Background Report (Adekile, 2007).

#### 3.1 Political and administrative structure

Nigeria occupies an area of 924,000 km<sup>2</sup> between latitudes 4°1' N and 13°9' N and longitudes 2° 2' E and 14° 30' E. It shares borders with 4 countries: the Republic of Niger to the north, the Republics of Chad and Cameroon to the east and Benin Republic to the west. The country is bounded to the south by the Atlantic Ocean and a coastline of approximately 800 km.

**Figure 2 Map of Nigeria showing the 36 states and Abuja (Federal Capital Territory)**



The country operates a federal constitution and a 3-tier government structure i.e. Federal, State and Local Government. There are presently 36 States and 774 Local Governments constituting the federation. Figure 2 shows the 36 states of the country. Out of its 48 years as an independent nation, the country was ruled by military governments for 30 years. The country returned to full democratic government in 1999. According to the 2006 census figures the population of the country is 140 million. Approximately half of the population live in rural areas (FMWR, 2004).

Crude oil accounts for 95% of the foreign exchange earnings of the country. Nigeria has an estimated proven reserve of 32 billion barrels of crude oil and is the 6<sup>th</sup> largest producer in OPEC. In spite of the huge earnings from the sale of crude oil the country remains essentially poor with inadequate infrastructure. According to the UNDP Human Development Report 2006 the country is rated 159<sup>th</sup> out of 177 countries on the human development index. The Gross Domestic Product per capita is \$1,154 whilst life expectancy is put at 43.4 years and adult literacy is 67%.

The main economic activities in the rural areas are agriculture and livestock rearing with about two thirds of the population engaged in small holdings.

## 3.2 Physical terrain

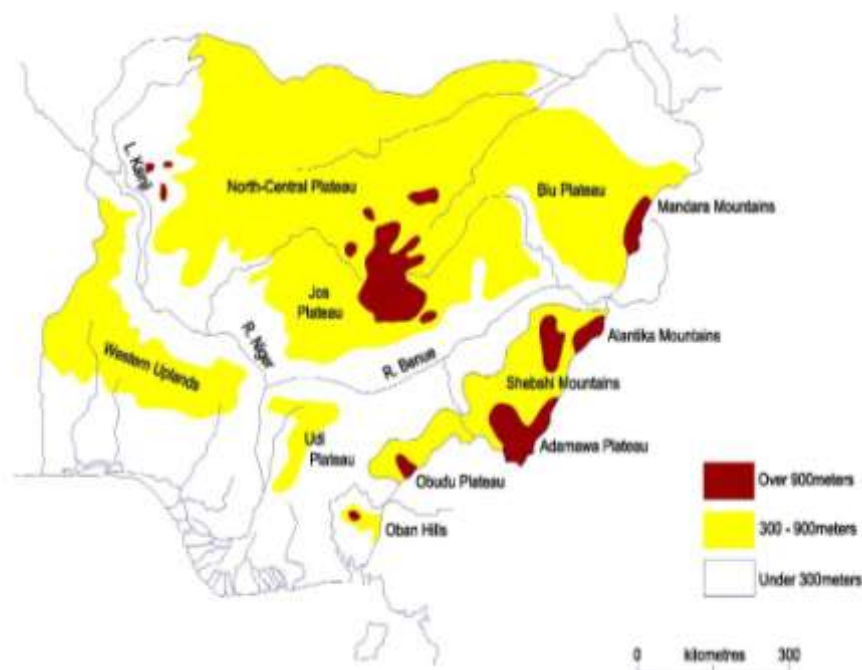
### 3.2.1 Relief

The relief of the country consists of the high plateaux where the land is generally over 300 m above sea level, and the lowlands which can be less than 5 m above sea level in the coastal areas (figure 3). The highlands are dissected into three blocks by the three trunks of the Niger-Benue river system:

- the Central Plateaux in the north
- the Eastern and North eastern highland in the east
- the Western uplands in the west

The lowlands lie in the basins of the major rivers and along the Atlantic Coast.

Figure 3 Relief Map of Nigeria (Iloeje, 1996)



### 3.2.2 Climate

The climate is tropical with two distinct seasons – the rainy season from around April to October and the dry season from November to March.

The country is divided into three climatic zones

- the Sahel region in the north (on the southern fringes of the Sahara Desert)
- the Savannah in the middle belt
- the Tropical rain forest in the south.

The zone of convergence of the southwest and northwest trade winds marks the approximate boundary of the Tropical rain forest and the Sahel region and the Savannah represents the transition zone between the two extremes.

The Sahel is characterised by a mean annual rainfall of 75 mm and rainy days of 60-40 northwards. The Savannah has a mean annual rainfall of 1000-1250 mm with rainy days of 80-60 days northwards. In the Tropical rain forest the mean annual rainfall is 1250 mm to over 4000 mm and the number of rainy days is 80-120 southwards (Offodile, 2002).

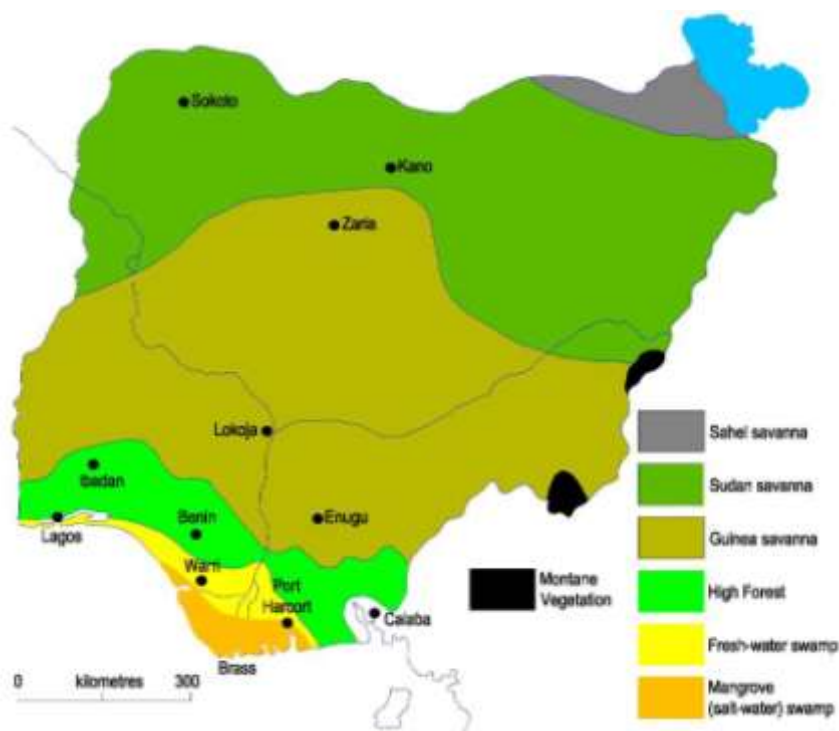
A rainfall deficit occurs approximately every 10 years in the West African sub region and resulted in the drought of 1973 which devastated most of northern Nigeria. It re-occurred to some extent between 1983 and 1985 (Hazell and Barker, 1995).

### 3.2.3 Vegetation

The vegetation follows the rainfall pattern. It consists of the Sahel savannah grassland in the arid north which consists of short grass, 0.5 - 1.0m high, interspersed with sand dunes.

The Sudan Savannah occupies most of northern Nigeria in places where the rainfall is between 65 mm and 1000 mm and consists of grassland, 1.5 to 2 m high, interspersed with some stunted trees. (See figure 4).

**Figure 4 Vegetation Map of Nigeria (Iloeje 1996)**



The Guinea savanna is the broadest vegetation zone in Nigeria and occupies half of its area. It occupies the areas where the rainfall is between 1000 and 1500 mm per annum. It consists of tall grasses and some trees which gives it the appearance of a park and for this reason is some times referred to as parkland savanna.

The Tropical rain forest comprises the swamps of the coastal strip where the soil is permanently water logged and the vegetation consists of a tangled mass of mangrove plants and the high forest area where the top canopy can be as high as 60 m.

### 3.2.4 Drainage

The drainage pattern is influenced by the relief. The rivers in southern Nigeria are arranged in almost parallel north-south direction because the land slopes to the south whilst the rivers in the north radiate from the Central Plateau and flow in all directions. There are five major hydrological basins – the Niger, Benue, Chad, Cross River and South Atlantic drainage basins.

The Niger rises on the Futa Jalon Plateau in Guinea, and traces its course at first northwards to Mali before turning southwards into Niger and Nigeria and emptying into the Atlantic Ocean.

The Benue is a tributary of the Niger and like the latter rises outside the country in the Cameroon highlands and flows southwest to empty into the Niger at Lokoja. It is navigable almost through out its entire course in the country.

Five rivers flow into Lake Chad, three of which are in Nigeria – the Yedseram, Yobe and Hadejia. Lake Chad occupies an area of about 10,000 square kilometres but is rather shallow, usually not more than 1.2 m in the dry season. This is because the rivers that feed it are also shallow and flow sluggishly in arid, sandy country and thus lose much of their water by percolation and evaporation. The lake itself is on the fringe of the Sahara Desert and much of its surface is exposed to the sun so that water is lost from it by evaporation, percolation and sand encroachment. It is feared that the lake will eventually dry up.

The rivers of the Southern Atlantic drainage basin rise from the edge of the plateau and flow southwards in the direction of the slope of the sea. In western Nigeria this plateau edge is represented by the southern margin of the basement complex rocks which outcrop at the Western Uplands. In the east it is the crest of the Udi Plateau.

The Cross river also rises outside the country in Cameroon descending 1200 m over a stretch of 30 to 60 km to enter Nigeria at Ikom from where it flows in a low gradient into the Atlantic. It is separated from the South Atlantic Drainage Basin by the crest of the Udi Plateau.

### **3.2.5 Geology**

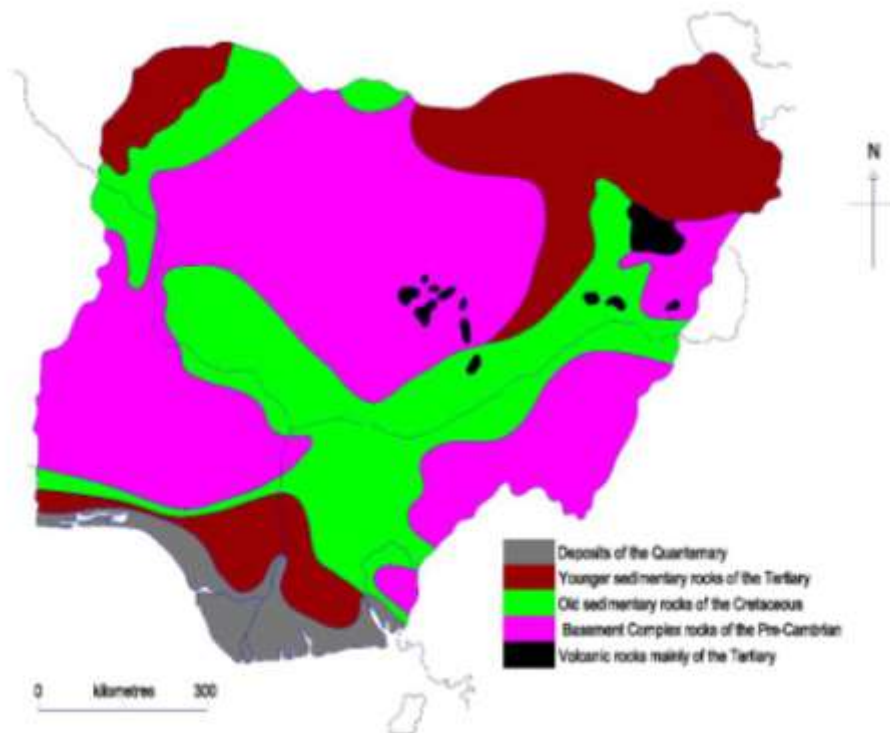
The geology of the country spans the Precambrian, Palaeozoic, Mesozoic, Tertiary and Quaternary times. See figure 5. The rock types can be divided into three broad groups.

The **Basement Complex rocks** are mainly granitic in composition and in different stages of metamorphism. They are found in the higher parts of Nigeria. They comprise Precambrian gneisses, migmatites, schists, phyllites and quartzites. There are also Older and Younger Granites. The Younger Granites are intrusive masses, confined mainly to the Jos Plateau area whilst the older granites are batholithic and are disperse.

The Basement Complex also includes metasediments and volcanic rocks of different ages. About 55% of the country is underlain by the Basement Complex. This includes the entire area of Kaduna, Kano, Katsina, Bauchi, Plateau, Oyo, Oshun and Ekiti States and parts of Zamfara, Adamawa and Kwara and Taraba States.

The **consolidated sediments** were laid down in Cretaceous seas. They comprise limestones, shales, sandstones and mudstones. They are usually gently inclined, locally fractured and gently folded. They cover about 20% of the country. This includes most of Sokoto State, the northern parts of Katsina State, the Niger-Benue trough and the south eastern parts of the country.

**Unconsolidated sediments:** These are mainly loose sands and clays deposited in the Tertiary. They occupy about 25% of the country and are to be found in Sokoto, Borno, Yobe, Jigawa States and most of southern Nigeria. The unconsolidated sediments also include the Quaternary deposits laid down along the floodplains and deltas of rivers and the wind-blown sediments of northern Nigeria.

**Figure 5 Geology of Nigeria (Iloje, 1996)**

### 3.2.6 Groundwater occurrence

**The crystalline basement complex** rocks in the fresh state possess no primary porosity and therefore do not hold water but where weathered or fractured they incorporate many isolated minor aquifers. Much of the weathered mantle which developed in the Tertiary has survived to present times, and in areas of fracturing where the mantle is thicker than average there is sufficient storage for domestic and rural community requirements. The aquifers are very often the only source of water close to rural settlements but have to be located using a combination of remote sensing, geological analysis and geophysical survey.

In most cases during exploration, sites for successful boreholes are located within reach of the nominated villages. Depth of drilling hardly exceeds 60 m. Borehole yield is of the order of 1 m<sup>3</sup>/hour and a handpump will provide a basic supply for about 300 people. Thousands of boreholes have been drilled in the country to provide rural water supply from these aquifers.

**The consolidated sediments** contain only minor aquifers. As a result of repeated episodes of folding the rocks have been compacted and cemented and all primary porosity lost. Groundwater is stored in fractures and in the weathered mantle overlying the rocks. Due to the small particle size of the weathering product the permeability is limited. Borehole yields are in the range 0.5 to 1.2 m<sup>3</sup>/hour and borehole depth of about 10 - 60 m. Exploration of the aquifers is similar to that on the basement complex. On some of the consolidated sediments a review of existing borehole data will be more applicable in determining depths to the aquifer than geophysics.

**The unconsolidated sediments** incorporate sandy horizons which constitute viable aquifers, usually confined. They have been exploited by borehole sources for industrial, municipal and private water supply for more than half a century in the major population centres of Lagos, Benin, Port Harcourt, Maiduguri and Sokoto. Where the water level and the sands occur at reasonable depths they have been utilised for handpump supplies.

In the Lagos area there are two major aquifers systems, the Tertiary Coastal Plains Sands aquifers and the Cretaceous Abeokuta Formation aquifers. The former is encountered at about 60-100 m depth and

the yield is of the order of 50-100 m<sup>3</sup>/hr. The Coastal Plains Sands Formation stretches across the southern part of the country from the west to the east. The Abeokuta Formation is encountered at a depth of about 800 m in the Lagos area. It constitutes a prolific aquifer and yield of the order 300 m<sup>3</sup>/hour are possible but the great depth at which it occurs, means it is only utilised by the big industries. The water also tends to be hot, between 60 and 80°C.

### 3.2.7 Groundwater quality

The quality of the groundwater in the country is generally good. Only in some areas are iron, nitrate and fluoride concentration above WHO standards. In about 20% of the country the groundwater has low pH (<6.5) and the water is very corrosive which affects the choice of borehole lining material. In about 40% of the country the water is moderately corrosive with pH of 6.5-6.8 and in the remaining 40% of Nigeria the pH is higher and the water is not corrosive (FMWR, 2004).

The groundwater in some areas underlain by the consolidated sediments of the Benue trough tends to be high in dissolved solids. Around Awe and Keana in Nassarawa State and in Abakaliki in Ebonyi State the groundwater is saline rendering it unusable. Also most of the shallow aquifers of the coastal belt are prone to saline invasion from sea water. The presence of arsenic has been reported in the groundwater in some parts of Benue State by WaterAid.

### 3.2.8 Groundwater mining

Cases of groundwater mining caused by over-abstraction have been reported in Lagos and Maiduguri. Table 6 shows the different rates of decline measured by several workers in the Lagos area. The water level decline has not resulted in the dewatering of the aquifer and it remains confined. It however created flow reversals leading to saline intrusion into boreholes at the coast (Parkman Consultants, 1996). Groundwater level measurements carried out by one of the authors in 2006 in the Ikeja area of Lagos indicated that the water level was the same as recorded in 1996.

In Maiduguri, several of the artesian boreholes in the Chad Formation aquifers have lost their head and are no more free-flowing. It has been suggested that the aquifers have no recharge routes and more exploitation will lead to further decline of the water level.

**Table 6 Estimated lowering of ground water levels**

Source	Estimated lowering of ground water level
Kampsax – Kruger	Between 1970 and 1975 decline = 1-1.5 m in Ilupeju and Ikeja predominantly from industrial abstraction. 230 boreholes in operation
Onwuka and Adekile	By 1986 annual decline of 2.2, 2.0 and 1.6 m in Ikeja, Agege and Iganmu
Scanwater	By 1978 reported annual decline of 2 m since 1967 in Agege
Blizzard et al	By 1996 GWL stabilisation in Ikeja and Isolo with <25% public supply boreholes functioning and most factories operating at <50% capacity

## 4 The Nigerian Drilling Environment

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This chapter provides an overview of the borehole drilling sector in Nigeria within the context of the national water supply framework.

### 4.1 National Water Supply Framework

The National Economic Empowerment and Development Strategy (NEEDS), Nigeria's poverty reduction strategy paper, recognises that water supply and sanitation are central to many aspects of human development – health, education, urban and rural development (National Planning Commission, 2005). The National Water Supply and Sanitation Programme proposes a strategy for the water supply and sanitation sector in four sub sectors; urban, small towns, rural areas, and water resources management. For rural areas government's focus is on increasing the water supply coverage to 60% by 2007 with a three pronged approach of rehabilitation, expansion and construction of low cost rural water schemes.

The National Water Supply and Sanitation Policy (FMWR, 2000) defines rural water supply scheme in Nigeria as a simple scheme serving a population of less than 5,000 people with a guaranteed minimum level of service of 30 litres per capita per day within 250 meters of the community and serving about 250-500 persons per water point. NEEDS is currently being revised to consolidate the gains of the past and continue the reform for the next 7 years i.e. 2015, the same target year as the MDGs.

The Federal Ministry of Water Resources (FMWR) has the responsibility to formulate policies, collect data and monitor and co-ordinate water resources development at the national level but it executes water supply projects. The state governments are more directly responsible for provision of water supply at state level. They usually operate through the state water board or corporation and the state rural water supply and sanitation agency (RUWASSA). The Water Boards are usually responsible for urban water supply and the latter for water supply and sanitation in rural areas. The RUWASSAs are supported by UNICEF and other external support agencies. The technology used is mainly boreholes fitted with handpumps. The Local Government Authorities are responsible for the provision of potable water to rural communities in their areas of jurisdiction.

Apart from UNICEF other external support agencies involved in rural water supply are the EU, DFID, JICA and WaterAid. The EU is collaborating with UNICEF on a \$45 million rural water and sanitation programme over a period of 5 years. DFID is also collaborating with UNICEF and WaterAid on a \$20 million dollar programme over a 6 year period. JICA is focused on Kano State with a support of \$3 million.

Both the National Water Supply and Sanitation Policy (FMWR, 2000) and the National Rural Water Supply Programme Strategic Framework (FMWR, 2004) stipulate that Government has the responsibility of capital investment for rural water supply, with token contribution from the community to foster a sense of ownership and promote sustainability. The communities take full ownership of water supply facilities provided by the Government while the State provides technical assistance to the Local Government rural water supply units. The Federal, State, Local Governments and beneficiary communities are required to share the cost of capital investment in water supply and wastewater projects as shown in Table 7. It has not been possible to ascertain how much investment has been made by the federal and state governments into rural water supply say in the last 10 years but Keast (2007) stated that projects funded by external support agencies make up only about 5 per cent of sector funding.

**Table 7 Cost sharing for capital investment**

Stakeholder	Rural WS	Small Towns WS	Urban WS
Federal Government	50%	50%	30%
State Government	25%	30%	60%
Local Government	20%	15%	10%
Community	5%	5%	Nil

## 4.2 Borehole drilling in Nigeria – the Beginnings

Prior to colonisation and up to independence most of the groundwater abstraction was from unlined hand dug wells. Between 1930 and 1933 the Geological Survey of Nigeria experimented and perfected the 1.2 m diameter lined dug well which became the standard for anglophone and francophone West Africa.

In 1947 the Public Works Department took over the construction of rural water supplies. A cable tool rig was purchased and the first rural boreholes were constructed. Rotary water drilling by a contractor, Balakhany Chad, a British company began in 1951 mainly for townships. The first major water supply drilling programme was between 1956 and 1962 when 280 boreholes were drilled in the north eastern part of the country to explore the artesian aquifers of the Chad basin. The drilling was carried out by government drillers and Balakhany Chad.

Balakhany Chad dominated the sector for several years with some competition from another British company (George Stow) and an Israeli Company (Nigeria Water Resources and Engineering Company). Between independence and the beginning of the Water and Sanitation Decade in 1980 several other operators came into the country from Italy, Germany, Britain and Greece.

In the 1980s others came in from China, Japan and Canada through the international competitive bidding of the World Bank supported ADPs. Through the ADPs about 8000 boreholes fitted with handpumps were drilled in the northern parts of the country. All the companies employed and trained Nigerians as rig operators, mechanics, welders and drivers. The FGN/UNICEF Water and Environmental Sanitation Programme also assisted some state governments with geophysical and drilling equipment. Thus in the mid 1980s when the Nigerian economy went into a recession and the expatriate drilling firms found it difficult to operate and had to close down, there was already a crop of trained Nigerian drillers. Some of the companies left their equipment on lease to their local employees. Some of the employees who were laid off set up their own companies such that by 1996 when the government embarked on another large scale borehole drilling programme under the Petroleum Trust Fund, 800 prequalification applications were received from which 167 contractors were appointed. Only three were foreign companies.

## 4.3 Borehole drilling in Nigeria since the Water and Sanitation Decade

Several rural water supply interventions involving borehole drilling have been embarked upon by the Federal Government or its agencies. Some of these are:

- National Borehole Programme (1981-1985)
- Department of Food, Roads and Rural Infrastructure (DFRRI) RUWATSAN Programme (1986-1992)
- Petroleum Trust Fund (PTF) Water Supply Project (1996-1999)
- Improved National Access to Water Supply and Sanitation (2000-2001)
- The Presidential Water Initiative (2003 – to the present)
- Millennium Development Goals Water and Sanitation Projects (On going)

Apart from the interventions listed above, there are others sponsored by external support agencies. Also the various State and Local Governments have also been carrying out borehole drilling programs.

At present the following public institutions are actively involved in the award of borehole contracts

- Federal Ministry of Agriculture and Water Resources
- The River Basin Development Authorities
- Niger Delta Development Commission
- The State Water Boards
- State Ministries of Water Resources
- The Office of the Senior Special Assistant to the President on Millennium Development Goals OSSAP-MDGs
- The LGAs
- UNICEF
- DFID
- EU
- WaterAid
- World Bank
- Other NGOs and Faith Based Organisations such as the Roman Catholic Church and the Evangelical Church of West Africa
- The oil companies – Chevron, Shell

A major problem of the rural water supply sector is that there is hardly any coordination between the different levels and organs of Government carrying out drilling in Nigeria and there is no focused national rural water supply programme. This creates duplication and in spite of all the previous efforts, the country still records less than 50% access to safe water. According to JMP (2008) the water supply coverage reduced from 50% in 1990 to 47% in 2006 overall and for rural coverage it declined from 33% to 30% in the same period. This is probably due to two factors, population increase and installed facilities not working. To meet the MDGs and national goals it is estimated that 15,000 boreholes need to be drilled annually. This poses a challenge to all in the industry.

#### 4.4 Drilling companies in Nigeria

There may be up to 1000 drilling contractors in the country but not all of them are of equal capacity. They can be classified into three categories:

- conventional drilling contractors with equipment and a management structure
- artisan drillers engaged in manual drilling or using locally fabricated rigs
- contractors with some interest in drilling but no equipment whatsoever

Several of the new drilling companies are headed by hydrogeologists and engineers who started the companies with personal savings. They operate under difficult conditions. Credit is hardly available from the banks, some projects do not provide advance payment, some suffer as much as 40% down time because of lack of work. Most of the drillers do not drill more than 50 boreholes a year which does not give them room for expansion. Table 8 provides a summary of data on a cross section of drilling contractors in the 4 states.

The equipment used by the organised drilling sector is of several makes and comes from all over the world e.g. China, England, Germany, Nigeria, USA and Thailand.

uPVC casing and screen used in handpump fitted boreholes are manufactured locally. Steel casings and screens and drilling chemicals are imported and stocked by local dealers.

Light and medium duty rigs using reconditioned engines are fabricated locally in Kano, Lagos and Ibadan. The profile of one of the local rig manufacturers is shown in box 1.

Manual drilling is widely practised for both water supply and irrigation boreholes. The manual drillers are patronised mostly by the private sector. Their cost is only a fraction of a conventional borehole. Only one government agency is known to have engaged them on a project.

**Table 8 Drilling Contractors Summary Profile**

Company	Year established	Background of CEO	No of technical staff	No. of rigs	No. of geophysical equipment	No of holes drilled	
						2006	2007
Agro-fountain Lagos	2001	Hydrogeology	8	2	None	20	26
Bee Drilling, Lagos	1978	Petroleum Engineering	16	3	None	12	6
Bi Star, Port Harcourt	1990	Ph.D Civil Engineering	21	5	None	NA	NA
Deepwells Lagos	1985	B.Sc Chemistry	18	2	None	NA	NA
Dumson, Lagos	1992	MSc. Hydrogeology	11	2	None	47	53
Fatigen, Jos	1996	Drilling Engineering	16	2	1	74	80
Finning Port Harcourt	1999	M.Sc Hydrogeology	22	2	None	12 Deep holes	11 Deep holes
Fortia Water Kano	1989	Hydrogeology	8	4	3	400	400
Geological drilling Investment, Kano	2000	B.Sc Geology M.Sc Geophysiscs		2	2	50	50
Global Earth Solve, Kano	2006	Hydrogeology		1	2	30	35
Hydro construction Lagos	1980	Civil Engineering		4	None	30	40
Kayfem consult, Lagos	1982	M.Sc Chemical Engineering	10	2	None	22	26
Male Integrated Science, Ibadan	1999	M.Sc Hydrogeology	5		2	32	50
Mongo Hydro-Geo Consult	1990	B.Sc Geology	6	1	2	NA	NA
Rich drill Port Harcourt	1986	Drilling Engineer with Shell	18		None	56	30
Shamadek, Lagos	1987	B.Eng (Civil)	9	1	None	6	8
Water Team Solutions Minna	2005	B.Sc Geology	9	2	1	35	36

### Box 1 Profile of a local rig manufacturer

A.U. Drilling Ltd in Kaduna started as mechanics repairing drilling rigs and trucks. About 5 years ago they started to fabricate drilling rigs. At the time of the visit to their yard there were 8 rigs under construction. The company currently constructs three types of rigs:

- small trailer rigs capable of drilling up to 30 m,
- light duty trailer rigs cable of drilling up to 80 m and
- medium duty rigs capable of drilling up to 150 m.

All the components of the rigs are procured locally. They are fitted with refurbished second hand engines. All the three types can be fitted with a hammer and compressor to drill through hard crystalline or compacted sedimentary rocks. The price ranges between \$15,000 and \$20,000 for the truck mounted rigs excluding the cost of the truck. Customers buy their trucks and the rigs are then mounted on them.

WED Limited, a drilling contractor, bought one of the rigs in 2004. According to their records they have drilled 200 boreholes with the rig by mid 2008. In 2006 they bought a truck mounted rig from the same outfit. The author witnessed the rig drilling a borehole at the British High Commission residential village in Abuja. The 35 m hole was completed in 2 days

Drilling contractors using the rigs complain that the power head and swivel head break down quite often. The rigs have no name, no standards and part specification but spares are readily available.



Locally fabricated rig

## 4.5 The Water Well Drilling Association of Nigeria

Some of the constraints facing the indigenous drillers are mentioned in section 2.4. Most of the constraints were also identified by Adenle and Beale (1989). They concluded that *“the most sensible approach to strengthen the drilling industry is the formation of a National Drillers Association.”*

For several years there was no response to the call for the formation of the drillers association in Nigeria. Although there were relevant organisations such as the Nigeria Water and Sanitation Association and the Nigeria Water Supply Association, their objectives were not specific to drilling. With support from WSP and RWSN the process of establishing the drillers association has reached an advanced stage. The objectives are geared towards professionalizing the industry and tackling the identified constraints.

#### 4.6 Training Institutions

The drought of the early seventies prompted the Federal Government to set up several institutions to manage the water resources of the country. These institutions include the Federal Ministry of Water Resources 1976, the River Basin Development Authorities (RBDA) 1976, and the National Water Resources Institute (NWRI) 1977.

NWRI is responsible for conducting training courses for all cadres of man power development for the water industry. There is a component of groundwater development in all the programmes. Apart from the regular programmes leading to a diploma or certificate there are also short courses of 1 or 2 week duration. The courses are:

- Borehole siting
- Borehole drilling and design
- Borehole drilling technology for drillers
- Borehole drilling technology for supervisors
- Borehole rehabilitation and development
- Hand dug well digging and completion
- Handpump installation and maintenance
- Spring water construction and development
- Groundwater exploration and exploitation

The Institute also runs outreach training courses which provide on-the-job training for staff of particular agencies at their location.

Every year the institute trains an average of 1,280 persons (58 in regular courses, 137 in short courses and 1,085 outreach training). However the institute is not well known amongst the drilling contractors. Several of the drilling contractors interviewed were not aware of the facilities available at the Institute. The Institute needs to market itself to make a greater impact in the sector.

The Institute in collaboration with the Standards Organisation of Nigeria is currently developing a Code of Practice for Borehole Drilling in Nigeria.

Apart from the National Water Resources Institute there are 64 approved universities in the country, 14 of which offer degree courses in geology (NUC, 2007). There are universities also providing courses in engineering and administration. There are also several polytechnics and technical schools training technologists and technicians who are later employed in the drilling industry.

**Figure 6 A heavy duty rig imported from the US capable of drilling to 1500 m depth**



## 5 Core factors of Cost Effective Borehole Provision in Project States

This chapter discusses the relative importance of the core factors of the cost effective borehole evaluation framework and their influence on the drilling industry in each of the states.

### 5.1 Kano State

With 44 local governments and a population of 9.4 million Kano State has the largest number of LGAs in the country and is the most populous state. It is also one of the major centres of trade and commerce in the country. Communication within the state and with other state capitals is quite good either by road or by air. Telecommunication has improved with the advent of the internet and mobile phones.

The vegetation of the state is Sudan Savannah and it lies in the Sahel climatic zone (annual rainfall is 75mm). The geology comprises almost entirely crystalline rocks of the Basement Complex except for a small portion in the north eastern parts of the state underlain by sedimentary rocks of the Chad Basin. As stated earlier, on the Basement Complex, groundwater is only available in fractures in the rocks or in the weathered zone overlying the fresh rocks. The average drilling depth is 35 m. The borehole yield is of the order of 1l/s; adequate for domestic boreholes and rural water supply. Geophysical surveys are required to locate the aquifers and hammer drilling is needed to get into them. Some water is also obtainable from the alluvial aquifers along the major river floodplains.

The climate, the vegetation and the geology are not limiting for the movement of drilling equipment. The geology is also favourable for groundwater development. As a result of its size, population and commercial activity there is considerable demand for water supply boreholes. The government, external support agencies and the private sector patronise the drilling industry. Drill casings and screens are manufactured locally and there are small enterprises manufacturing drilling rigs.

The key players in the drilling sector are the

- Hadejia-Jamaare River Basin Development Authority
- Kano State Ministry of Water Resources/the State RUWASSA
- UNICEF, EU and JICA
- Kano State Agricultural and Rural Development Authority
- Kano State Water Board
- private sector drillers
- pipe manufacturers
- rig manufacturers

#### 5.1.1 *Hadejia –Jamaare River Basin Development Authority,*

The authority, a federal government agency is involved in the drilling of boreholes for rural communities. The boreholes are fitted with both handpumps and motorized schemes. All the drilling projects are contracted out.

Apart from its own main projects which are budgeted for, the authority is also involved in carrying out the MDGs Water and Sanitation projects of the Presidency and the Constituency projects of the National Assembly. Under the main projects in 2006, it achieved 87 handpumps and 9 motorised schemes. In 2007, only 6 motorised borehole schemes were constructed. None has been carried out in the current year.

#### 5.1.2 *Kano State Rural Water Supply and Sanitation Agency (RUWASSA)*

Kano State RUWASSA is responsible for rural water supply and sanitation provision in the state. It receives funding from the state government's budget but it also receives financial support and grants from UNICEF, JICA and the EU. The agency is one of the few government agencies in the country still involved in direct drilling. It maintains a complement of 4 drilling rigs.

In 2006, JICA provided a grant to drill 240 boreholes in 37 LGAs in the state. The grant consisted of a drilling rig, 2 truck mounted cranes, 1 water tanker, 1 flat lorry, 2 pick up vehicles, 1 compressor and workshop tools and equipment. After completion of the drilling the equipment will remain with the agency.

In 2007 a joint EU/UNICEF/FGN project supported the drilling of 50 boreholes in the state. Apart from the EU/UNICEF/FGN project, UNICEF is also supporting the construction of 10 solar powered borehole schemes.

The agency also carries out drilling for private individuals and private householders at what was described as a lower rate.

### **5.1.3 Kano State Agricultural and Rural Development Authority (KNARDA)**

KNARDA is involved mainly in tubewell drilling for irrigation and training of farmers in tubewell construction by jetting (washboring). They have two light rigs which were bought in 2008. There are 1500 Fadama Farmers Associations in the state and in every association KNARDA has trained at least 3 farmers to carry out washboring. Some of the trainees have extended the technique to providing water supply holes.

### **5.1.4 Drilling Contractors**

The private drillers in the state number about 100 and they have organised themselves into an association. Some of the drilling companies are well organised and run by experienced professionals, mostly hydrogeologists.

### **5.1.5 Equipment Manufacturing and Supplies**

Panar Nigeria Limited produces borehole casings and screens. The company presently operates at 50% of its installed capacity because of the constraints of irregular power supply and delays in clearing of goods due to port congestion.

Unisteel Construction and Furniture Company, Kano started as a mechanic workshop repairing trucks and drilling rigs and later ventured into building rigs from local materials, mostly scraps and reconditioned engines. The rigs are made to order.

In the neighbouring towns of Kaduna and Jos there are also local rig manufacturers as well as agents of international manufacturers. Shebag Holdings in Kaduna are agents of Boart Longyear of Germany and PAT-Drill Nigeria in Jos represent PAT-Drill UK. Apart from rigs they also stock spare parts and other drilling tools such as bits and hammers.

## **5.2 Lagos State**

Lagos state is situated in the coastal belt. The relief is below 30 m. It lies in the Tropical rain forest and no month has less than 25 mm of rainfall. It is the most economically important state in the country. According to the 2006 census figures it has a population of 9.013 million, the second largest after Kano state although this is disputed by the state authorities who feel the population is closer to 15 million. With the smallest land area, it is the most densely populated state in the country. Telecommunication is good but the heavy road traffic within the metropolis is a perennial problem.

Unlike Kano, Lagos state is underlain by sedimentary rocks, mainly clays, sands, shales, limestones and sandstones. The stratigraphy is summarised in table 9 below.

**The Littoral and Lagoonal deposits** occur in the southern parts of the state (Victoria Island and Ikoyi) and have sandy aquifers within 60 m depth which are utilised for domestic boreholes and can be reached by manual drilling.

**Table 9 Stratigraphy of Lagos State**

Age	Formation	Rock type
Recent	Littoral and lagoonal deposits	Sands, clays, mangrove relics
Tertiary Oligocene-Pliocene	Coastal Plains Sands	Clays, silts, silty clays, sands
Tertiary Eocene	Ilaro	Clays, silts, shales
Tertiary Palaeocene	Ewekoro	Shales and limestones
Cretaceous Maestrichtian and older	Abeokuta	Shales and sandstones

The sandy horizons of the **Coastal Plains Sands** also constitute viable confined aquifers and have been exploited for industrial, municipal and private water supply for over 60 years. Coode Blizard Consultants (1996) compiled an inventory of 680 industrial and municipal boreholes in the Lagos area. 95% derive their water from the Coastal Plains Sands, although thousands of domestic boreholes were not inventoried.

Three sandy horizons are usually present in the Coastal Plains Sands. The lowest is generally the best developed which is encountered at a depth of 110 – 130 m below ground level in the Ikeja area but as the beds dip to the south the same aquifer will be encountered at 250 m depth in the southern parts of Lagos metropolis. The sand bands are in lenses and tend to be rather thin. The average thickness is about 30 m. Borehole yield is of the order of 20 to 30 l/s depending on the design. As mentioned in section 4.7 groundwater level decline was observed in the Coastal Plains Sands aquifer in the past but it has recovered over the years.

**The Abeokuta Formation** consists mainly of sandstones with some mudstones and shales which form recognisable horizons, with a linear trend dipping north-south. By 1996, 12 boreholes had been drilled into the Abeokuta Formation aquifer in the factories at Ikeja. The aquifers are intercepted at an average depth of 750 m.

Rapid development of the aquifer has been precluded by the high cost of drilling into them. The sandstones are very coarse, of good permeability and thickness and are recharged from the outcrop and are of good chemical composition. The specific capacities indicate that discharges greater than 50 l/s can be obtained from a borehole.

Like Kano, the large population, commercial activity and groundwater availability means there is great demand for the services of the drilling industry in the state. The drilling contractors operating in the state are estimated to number about 150, a third of which engage in hand drilling. The drillers are employed both by government agencies, industries and householders. The key players in the state are the

- Lagos State Water Corporation
- Lagos State Ministry of Rural Development
- Private Sector Drillers
- Manufacturers and suppliers

### **5.2.1 Lagos State Water Corporation**

The corporation is responsible for providing water supply in the urban areas of the state. In a bid to attract private investors and to privatize some of the schemes, the World Bank is assisting the State in the rehabilitation and expansion of the Ikoyi, Broad Street, Dolphin and Onikan plants by replacing the old boreholes.

### **5.2.2 Lagos State Ministry of Rural Development**

The Rural Water Supply and Sanitation Department of the ministry is responsible for the provision of water and sanitation in the rural areas. The targets are guided by the State Economic Empowerment Development Strategy (SEEDS) and the MDGs (Ayeni, per.comm.). The ministry has a 4 year (2007-2011)

rolling plan for water and sanitation. In the 2008, budget N500 million (\$42 million) was voted for capital development for water and sanitation.

### **5.2.3 Equipment Manufacturers and Suppliers**

As in Kano and Kaduna there are also local rig manufacturers in Lagos and neighbouring Ibadan. Probably the best organised of them is Deep Well Hydraulics in Lagos. They have been building rigs since 1985. The company has now standardized on four types of rigs as follows:

- DW 1000, trailer mounted capable of drilling 100 m, 40 hp engine, with no mud pump
- DW 2000, trailer mounted also capable of drilling 100 m, 40 hp engine but with a mud pump
- DW 3000, trailer mounted capable of drilling 150 m, 60 hp engine with a mud pump
- DW 4000, truck mounted capable of drilling 220 m, 80 hp engine with a mud pump

The mud pumps are 5 hp petrol driven pumps. The engines are reconditioned air-cooled Deutz engines. All the rigs are hydraulic. The trailer-mounted rigs have manual jerks and the truck mounted ones have 4 hydraulic jerks. They give a one year warranty on their products.

Friluckson in Ibadan are also reputable for the quality of their rigs. The managing director said that in 1993 he copied the design of the rig imported by his company and built 2 more rigs for the company. Heaton is another Ibadan based rig manufacturer.

There are several pipe manufacturers in Lagos and surrounding towns of Ibadan and Osogbo producing borehole casings and screens. O&M Pipes in Lagos and Lopin in Osogbo are the more reputable ones.

Eauxwell Nigeria Limited import and stock stainless steel screens and Dodomeh stock steel casings.

## **5.3 Niger State**

Niger State lies in the Guinea savannah. Total rainfall is 1200mm per annum. It has a population of 4 million. The Niger River forms the southern boundary of the state. The Niger/Benue trough which lies in the southern part of the state represents a previous arm of the Atlantic ocean into which sediments were deposited. The land surface in the Niger/Benue trough lies below 300 m above sea level and it has been deeply dissected by erosion into tabular hills. The northern part of the state lies at the edge of the North-Central Plateau.

The geology comprises the Nupe Sandstones in the Niger/Benue valley and the Basement Complex on the North-Central plateau. Drilling depths on the Nupe Sandstones varies between 30 m and 100 m but is usually about 40 m. Borehole yield is of the order of 4 l/s. On the Basement Complex comprising mainly granites and gneisses the aquifers are the fractures and the weathered rocks. Drilling depth as on the basement in Kano is of the order of 30 -40 m and borehole yield of the order of 1l/s.

Commercial activity in the state is on a much smaller scale than Lagos and Kano. The population is also less than half of the other two states and mostly rural. Thus the drilling industry has not developed as in the other two states. There are only two resident conventional drillers in Minna, the state capital. Most of the drilling contracts are carried out by drillers from outside of the state. There are about 10 manual drillers in Bida. Bida is underlain by the Nupe Sandstones, and suitable for hand drilling. The general geology of the state is however favourable for groundwater development. The major players in the drilling sector are:

- The Upper Niger River Basin Development Authority
- Niger State Ministry of Water Resources/ Rural Water supply and Sanitation Agency
- Niger State Water Board
- Niger State Agricultural Development Programme
- Private sector drillers

The officers of the Upper Niger River Basin Development Authority were away at a conference at the time of the consultants' visit to the state and it was not possible to interview them.

### **5.3.1 Niger State Water Board**

The board is involved in the maintenance of 190 rural boreholes drilled in the 1980s. The boreholes are all fitted with motorized submersible pumps, run on electricity from the national grid and 2 standby generators. The LGAs pay the Water Board for the maintenance of the schemes. The EU-supported Small Towns Water and Sanitation Project took over two of the schemes in 2007.

### **5.3.2 Niger State RUWASSA**

The agency is responsible for the provision of rural water supply and sanitation in the state. It receives assistance from UNICEF.

The agency has 4 rigs, 2 of which were provided by UNICEF in 1982 and 2 by JICA in 1991. They are all out of operation. All the borehole projects are presently contracted out.

In 2006, UNICEF supported the construction of 47 boreholes in Girls Education Project (GEP) schools and 5 in guinea worm affected communities. In 2007 UNICEF also supported the construction of 97 boreholes, 37 in GEP schools and 60 in guinea worm affected communities. In the state government's 2008 budget there is a provision for the drilling of 125 new boreholes and rehabilitation of 250 existing boreholes but the funds had not been released at the time of the visit.

### **5.3.3 The Niger State ADP**

The ADP is involved in the drilling of tubewells and washbores for irrigation. The focus of the ADP as in Kano is the training of Fadama Farmers Association members in the construction of washbores. It has 5 drilling rigs, two of which are functioning. Since 1997 the agency has constructed 360 washbores. Several of the trained washbore drillers have become hand drillers who operate around Bida.

## **5.4 Rivers State**

Rivers State is in the lowlands of the Niger Delta. It gets over 3000 mm of rainfall per annum and there is no month with less than 25 mm of rainfall. Half of the state lies in the creeks of the Niger Delta and road communication is very poor. The population of the state is 5.6 million. The capital, Port Harcourt is an important commercial centre as the base of several operators in the oil fields.

The geology consists mainly of sediments – sands and clays. Like Lagos there are several aquifer horizons. Abstraction for domestic water supply is from the shallow aquifer at about 60 m depth. A deeper aquifer lies at about 250 m depth which is used for municipal and industrial water supply. Borehole yield varies between 20 and 30 l/s depending on the design.

The state has a well developed drilling sector however there is a discernable feeling of uncertainty and loss of interest amongst the drilling contractors because of the on-going unrest in the Niger Delta. The enthusiasm and hopeful outlook of the Kano and Lagos drillers is completely absent in the state. Several of the well established drilling contractors such as Waterpit, Fomoyi and Reo Brothers have closed down their drilling activity and there are no new incomers. For 20 years, Bee Drilling had a rolling contract with Shell to drill and maintain boreholes but this has stopped as Shell reduced their activity in the state. The managing director is thinking of selling off his equipment.

The major players are:

- The Niger Delta Basin Development Authority
- The Rivers State Rural Water Supply and Sanitation Agency
- Rivers State Water Board
- Private Sector Drillers
- Pipe Manufacturers

### **5.4.1 The Rivers State Rural Water Supply and Sanitation Agency**

The agency was established in 2001 and started operation in 2002 but the bill for its establishment has not been passed and therefore has no legal backing and therefore has no budgetary allocation. UNICEF

has been supporting the agency by releasing cash assistance to the agency which is meant for the allowance and transportation of the staff to project sites. This has been used to carry out some projects.

Although presently with no legal standing the agency is the only government agency known to have directly employed hand drillers. This was found more cost effective as the access is very poor for mechanised rigs and the agency is constrained by funds.

Three boreholes have been drilled in each of the UNICEF/FGN focal communities of Khana and Omuma LGAs and one in Andoni LGA.

Monitoring and repairs are constrained by lack of funds, the terrain and the Niger Delta insurgency.

#### **5.4.2 The Rivers State Water Board**

The board operates 9 pumping stations with a total of 28 boreholes under its jurisdiction. The board is responsible for the maintenance of the boreholes which are flushed twice a year. The most recent borehole was drilled 4 years ago. Boreholes have to be very deep, 200- 250 m because of salinity of the shallow aquifers.

There are several hand drillers in Port Harcourt, probably as many as the conventional drillers. Machine drilling is hardly ever required in Port Harcourt city itself as the terrain is sandy and the aquifer is within 50 m. Every middle income household has its own private borehole. As in Lagos several of the conventional drillers also engage in hand drilling.

The conventional drillers operate with many constraints. For example barges are required to move equipment in the creeks, thus mobilising depends on the availability of a barge but barge movement in turn depends on the tide. And then the community may demand illegal landing fees of as much as N1,000,000 (US\$ 8,500). A drilling contractor mobilising from Port Harcourt to Escravos to drill a 200 m deep borehole charged N60 million (US\$ 500,000) because of the uncertainty of the safety of his equipment and men. On two occasions he has had to pay ransoms of N1,500,000 (US\$12,700) and N600,000 (US\$ 5,000) for his staff. Another driller narrated how he lost his rig when it fell off a barge into the river.

#### **5.5 Comments on the core factors in the four states**

The different geology underlying the four states means that borehole depths differ. Drilling techniques, expected borehole yield and borehole designs are therefore also different. The smaller population and the lower level of economic development in Niger State have led to a smaller number of drillers in the state than the other states. Despite the favourable geology and population the civil unrest in the Rivers State has discouraged some of the drillers and increased the cost of borehole provision. The difficult terrain of River State also makes it different from the other states.

## 6 Elements of Cost Effective Borehole Provision

Current practices in the drilling sector on the Federal Ministry of Water Resources Project and other projects in the four states of Kano, Lagos, Niger and Rivers are reviewed in this section in line with the RWSN elements of cost effective boreholes.

### 6.1 Tendering Procedures

Most of the public institutions i.e. FMWR, RBDAs, State Governments, and ESAs involved in the award of borehole drilling contracts tend to follow the same award procedure i.e.

- Advertising of projects and expression of interest
- prequalification of contractors
- verification of prequalification submission
- short-listing of contractors
- submission and evaluation of tenders
- contract award

Contracts in the Federal and State Ministries and RBDAs also undergo “due process” verification by the Ministry of Finance to ensure that the contracts are within budgetary provisions and are appropriately priced.

FMWR in November 2005 asked for prequalification application from interested contractors under the Federal Rural Water Supply Programme spread across the country. The prequalification document was very detailed asking for amongst others:

- evidence of past contracts of similar nature
- cost and complexity
- personnel capabilities
- equipment capabilities
- financial capability
- litigation history

To qualify the applicant must have an average annual turnover of N 150,000,000 (US\$ 1.27 million) over the previous 5 years and must also have

- 2 no drilling rigs
- 2 no compressors
- 1 no geophysical equipment
- 2 truck mounted cranes

Verification of the prequalification document was carried out and successful applicants put in their bids. The bids were opened at a public function and prices announced. The contracts were eventually awarded in August 2006, not at the tendered price but at a uniform price for the different categories of drilling. Contractors were allowed 50% mobilisation payment on presentation of a bank guarantee and one of the contractors informed the consultants that he got his mobilisation payment in March 2008 and commenced work. Some of the contractors alleged that the process was not as transparent as it looked on paper and that some of those who got the job were not qualified.

In the case of the Kano State RUWASSA EU/FGN/UNICEF 50 borehole project, the process from request for prequalification to award of contract took 5 months. In contrast, Niger State RUWASSA stated that from submission of tender to award usually takes about two weeks. Niger Delta Basin Development Authority said it takes about 3 months.

Several contractors complained that the delays and lack of transparency have made them to lose interest in government contracts. This complaint is not limited to FMWR projects but extends to some state government projects. The inability to benefit directly from government projects is a major constraint

mentioned by drilling contractors. Some said they wait for those with the right connections and money to finance the projects to hire their services. Even though the profit margin is reduced, they can ask for a substantial advance payment and cover the perceived risk of a delay in payment.

Contract award in the FMWR, RBDAs and State agencies involves setting, a benchmark for the contract price. This is usually based on the engineer's estimate. All bidders below this price are awarded a contract. This is different to the case of the World Bank projects, where the contract goes to the lowest bidder. Awarding the contract to the lowest bidder could force prices down but it may not build local capacity on the scale required.

The late release of counterpart funds also affects project implementation such as on the EU/FGN/UNICEF project.

FMWR projects tend to be supply driven and top heavy. The State agencies complained that they are not usually informed of FMWR projects, which makes post construction monitoring and operation and maintenance difficult

## 6.2 Borehole design and construction

Boreholes should be designed and constructed to fit their purpose in terms of diameter, depth, casing and screen.

The Federal Rural Water Supply Programme adopted five different borehole designs depending on the terrain and the expected yield for the drilling of 250 boreholes spread all over the country. The geology and aquifer depths were ascertained and the appropriate design selected and bill of quantities prepared. The contractor was paid for the actual measured quantities of work. The designs are summarised in table 10. Table 11 summarises the borehole designs utilised by six different state organisations in Nigeria.

**Table 10 Different borehole designs used by FMAWR**

Terrain	Borehole design
<b>Basement complex and shallow sediments</b>	110 mm dia. uPVC lined max. 60 m depth fitted with a handpump
<b>Sediments with aquifer at depths greater than 60m</b>	150 mm steel lined to 75 m depth fitted with a motorised pump
<b>Sediments with aquifers greater than 120 m</b>	150 mm steel lined to 150 m depth fitted with motorised pump
<b>Sediments with deep aquifers</b>	150 mm steel lined to 300 m depth fitted with motorised pump
<b>Sediments with very deep aquifers</b>	150 mm steel lined to 600 m depth fitted with a motorised pump

**Table 11 Borehole designs used by several state Government Organisations**

Organisation	to 50 m on the basement for handpumps	to 75m on sediments for submersible pumps
<b>Hadejia Jammaare River Basin Development Authority</b>	110 mm diameter uPVC lined	150 mm diameter uPVC lined
<b>Kano State RUWASSA</b>	110 mm diameter uPVC lined	150 mm diameter uPVC lined
<b>Niger State RUWASSA</b>	110 mm diameter uPVC lined	150 mm diameter uPVC lined (to 80m)
<b>River State RUWASSA</b>	110 mm diameter uPVC lined	150 mm diameter uPVC lined (to 80m)
<b>Lagos State RUWASSA</b>	150 mm diameter uPVC lining	150 mm diameter uPVC lining

Lagos State RUWASSA use 150 mm diameter uPVC lining even where the boreholes are fitted with handpumps, because they would like to be able to change to a submersible pump when power is available. Another reason given for the use of 150 mm diameter casing is that if the submersible pump should drop into the hole it is easier to fish it out from a 150 mm casing than from a 110 mm casing.

Lagos State Water Corporation, Lagos State RUWASSA, and Rivers State Water Board have to drill deep boreholes to between 200 and 300 m for which they specify steel lining. To reduce cost, the lining is sometimes telescopic, i.e. done in 2 stages, a 250 mm diameter upper pump chamber to 100 m depth and then reduced to 150 mm casing and screen into the aquifer.

The groundwater in the deep aquifers (200 - 300m deep) of Lagos is aggressive and the steel lining tends to corrode after some years. The boreholes tend to have a short lifespan and have to be replaced after 10 years. Attempts to overcome this by coating the casings in bitumen did not work as the corrosion seems to start between the joints in the casings and the screen. At one stage Lagos State Water Corporation experimented with fibre glass lining but this also failed for reasons unknown. Nigerian Breweries tried stainless steel casing and screen but the corrosion problem did not stop. On the boreholes drilled this year Nigerian Breweries opted for 32 bar Boode uPVC casing and screen.

**Figure 7 PVC Pipes at PANAR Kano**



**Figure 8 Stainless steel screens and new rig in Lagos**



All the drilling contracts in the country specify that boreholes are lined the full depth despite the inherent strength of the underlying hard rock formation on the Basement Complex. As Ball (2004) puts it *“having drilled through a fissure in the rock and achieved a supply of 1000 litres per hour, the driller is then obliged to shield the water flowing into the hole first with a slotted pipe and then place a curtain of gravel between the fissure and the pipe – both actively reducing the water flow and creating a structure likely to be clogged by chemical or microbial action”*. As well as increasing the cost of drilling it blocks water from flowing freely into the hole. All the drillers interviewed, including staff of NWRI, reject the idea of an open hole because it is never certain that the material from the weathered mantle will not migrate down and block the hole. They consider the extra cost of lining material better than the risk of loss of the entire hole.

Some thought and planning is obviously given to ensuring that borehole designs fit the purpose and the expected yield. The 110 mm diameter uPVC casing has become an international standard for handpump boreholes. There are workers who point out that it has been completely forgotten that this came about because of the need to accommodate the cylinder of the India Mark II pump. The new India Mark III/Afridev modifications and direct lift pumps such as the Tara will go down a 75 mm diameter hole. Ball (2004) argues that a 75 mm diameter borehole costs about half that of a 110 mm diameter borehole. And nothing is lost in terms of borehole yield. This has to be practically demonstrated in Nigeria.

Bentonite is still the preferred drilling fluid. Even though the drillers complain of adulterated bentonite in the market, of all the drillers interviewed only one indicated a preference for natural polymers and another who considers it cost effective to drill with air. Bentonite takes about 12 hours after mixing to build sufficient viscosity and it lines the borehole with a wall cake which has to be broken on completion

of the hole either by a chemical or a water jet. Where there is delay in development, it may take several months of pumping to completely get rid of the bentonite in the water. In some countries it has been banned from use in water well drilling. The extra time and cost will be avoided if natural polymers which are biodegradable are used particularly on the basement where drilling time is short. Drillers in the sedimentary areas of Lagos and Port Harcourt involved in deep drilling justify the use of bentonite in that natural polymers will biodegrade before the borehole is completed and could lead to collapse.

### 6.3 Appropriate technology rigs

For the purpose of this study a light duty rig is one that can drill up to 100 m, a medium duty rig is one that can drill between 100 and 300 m and a heavy duty rig is one that can drill more than 300 m.

Since about 75% of the country is underlain by the basement complex and shallow sedimentary aquifers where drilling depth is not more than 100 m light duty rigs are required most of the time. In the early days of drilling, expatriate companies brought big, multipurpose, truck mounted rigs into the country. SCOA in the early 80s imported and sold Ingersoll Rand rigs in the country. Adenle and Beale (1989) made an inventory of 68 Ingersoll Rand rigs operating in the country in the 80s.

Experience and market forces have led the drillers to the realisation that it is better to acquire light and medium rigs than heavy duty rigs since this is what is mostly required. Thus most of the newly emerging drilling outfits are patronising smaller trailer mounted rigs. PAT Drill Nigeria this year have sold 12 light to medium duty rigs. Also the local rig manufacturers are patronised. The rigs are much cheaper than imported ones and the spare parts are easily available

Also it has been realised that it is better to have the pieces of equipment as separate components i.e. the rig, the compressor, the mud pump and the truck each on its own rather than all mounted on one truck. Once a trailer rig is towed to the site, the truck is available for other purposes such as getting people, fuel, pipe and water to the site instead of just standing on the hole. The compressor is brought to site when required and can be used for other purposes such as flushing other holes or even hired out to other contractors. Having all the components on board means a rather big truck is required and permanently dedicated to the rig.

Of course there are areas of deep aquifers 500 – 800 m in the country the southern parts and north east where heavy duty rigs are required. Those drillers who have identified such markets are investing in the appropriate equipment.

**Figure 9 Newly fabricated light duty trailer rig in Ibadan**



Table 12 lists the prices of locally made rigs. A brand new imported rig of the same capacity will cost 4 times. The availability of the locally made rigs has provided an opportunity for the new drilling outfits most of who start out with personal savings. Table 13 shows a cross section of rig types being used in the country. 50% of the rigs can be classified as light to medium, 30% were made in Nigeria. Most of the heavy duty rigs are between 20-30 years old and are found mostly in the southern sedimentary terrain.

**Table 12 Prices of Made-in- Nigeria Rigs**

Source	Type	Depth Capacity (m)	Price Naira	Price US\$
Deepwell Hydraulics Lagos	DW 1000	100	1,700,000	14,407
	DW 2000	100	2,200,000	18,644
	DW 3000	150	2,700,000	22,881
	DW 4000	220	3,200,000	27,119
Heaton Ibadan		150	2,500,000	21,186
Frilucson Ibadan		150	3,000,000	25,424
A.U. Drilling Kaduna		100	2,500,000	21,186

A common feature in Lagos and Rivers States is the use of manual drilling by conventional drillers who own rigs. They use manual drilling where they consider it more cost effective. See the RWSN Field Note: Hand Drilling in Nigeria, by Adekile and Olabode..

**Table 13 Drilling rigs in use by some of the drillers interviewed**

Drilling Company	Make	Type	Capacity depth (m)	Year of manufacture	Country of manufacture
Agrofountain Lagos	Gardner Denver 1000	Rotary	300	1988	USA
	George Failing	Rotary	300	1976	UK
A.M. Dung, Jos	PAT-401	Trailer	100	2004	Thailand
Arfisco Niger Kaduna	A.U. Kaduna	DTH/truck mounted	100		Nigeria
BEE Drilling (Port Harcourt)	Gardner Denver x 3			1979- 1984	USA
Bistar (Port Harcourt)	Gardner Denver x3	Rotary/truck mounted	750	1980	USA
	Failing Speedstar	Truck mounted		1983	UK
	Ingersol Rand TH 55			1990	USA
Deepwells Lagos	DW 3000	Rotary	150	2000	Nigeria
	DW 4000	Rotary	220	2004	Nigeria
Devtec Ibadan	KLR rigs x4		300	2003-2007	India
DLosha Kaduna	Mackgross x3	Truck mounted	100	2000-2006	Germany
Dumson, Lagos			300	NA	German
			100	2005	Nigeria
Eauxwell Lagos					
Fatigen Jos	PAT -301		60	2005	Thailand
	PAT-401		120	2007	Thailand
Finning Port Harcourt	Gardner Denver 2500	Rotary/truck mounted	660		USA
	Gardner Denver 1500	Rotary/truck mounted	360		USA
Fortia Water Kano		Rotary	400	1979	USA
		Rotary	150	1980	Sweden
			500	1974	UK
			450	1979	USA
Frilucson Ibadan					Nigeria

Drilling Company	Make	Type	Capacity depth (m)	Year of manufacture	Country of manufacture
<b>Geo Afrik Kaduna</b>	AUD Kaduna	DTH (trailer)	60	2004	Nigeria
	AUD Kaduna	DTH Truck mounted	100	2008	Kaduna
<b>Geological Drilling Investment Kano</b>		Truck mounted	300	NA	NA
<b>Geowater, Abuja</b>	Tone	Truck mounted		1986	China
<b>Heaton Ibadan</b>	X3	Trailer			Nigeria
<b>Hydroconstruction Lagos</b>	Ingersoll Rand TH60 x4	Rotary /truck mounted		1980	USA
<b>Kayfem Consult</b>	Gardner Denver 1000HT	Rotary truck mounted	300	1980	USA
	Bomag 500		250	1983	Germany
<b>Kopila Water Tech</b>	Schramm T660		350	1989	USA
<b>Richdrill Port Harcourt</b>	Hans England x2	Rotary/truck mounted	300	1986	UK
<b>Water Hope Line Kaduna</b>		Trailer	100	2008	Nigeria
<b>Water Team Solutions</b>	Deep Rock		150	2006	USA
<b>Water Surveys Nigeria Ltd</b>	PAT 301		100	2008	Thailand
<b>Water Wells &amp; Test Boring Ltd, Kaduna</b>	Ingersol Rand T3	Rotary/truck mounted	100	1989	USA
	International Harvester	Crawlers	100	2004	Korea
<b>Waterworkx Ibadan</b>	Heaton	DTH/Rotary	75	2007	Nigeria
<b>WED Kaduna</b>	AUD Kaduna	DTH Trailer	60	2000	Nigeria
	AUD Kaduna	DTH Trailer	100	2004	Nigeria
		DTH (truck mounted)	100	2008	Nigeria
<b>Y.A. Choice</b>		DTH/truck mounted	1000	2002	Nigeria

Chapter 7 provides an overview or hand or manual drilling, which is widely practiced in different parts of Nigeria.

#### 6.4 Contract Packaging

One of the means of cost effectiveness in drilling is for the contracts to be packaged for multiple boreholes in close proximity and for boreholes with similar geology. This allows the contractor to benefit from the economies of scale and to reduce travel time and cost between drilling sites. Table 14 sets out examples of contract packaging in Nigeria.

**Table 14 Contract Packaging Arrangements for Selected Projects**

<b>Organisation/Project</b>	<b>Contract Packaging Arrangements</b>
<b>FMWR 250 borehole project</b>	Handpump borehole contract packages varied between 6 and 9 boreholes  Motorised schemes: 191 deep boreholes. One borehole was given to each contractor (included supply, installation of a submersible pump, generator and overhead tank).
<b>Hadejia-Jammare RBDA 2006 project</b>	Contracts packaged in lots of 3 motorised schemes and lots of 7 handpumps
<b>Niger State RUWASSA - EU/FGN/UNICEF 50 borehole projects</b>	Boreholes packaged in lots of 4 and 5.
<b>Niger State RUWASSA</b>	Contracts were in lots of 20 handpumps but no consideration was given to geology or proximity of locations. Payment made in lots of 5 completed boreholes.
<b>UNICEF B office supported project</b>	Contracts in lots of 5 at a time. Some contractors on completion of one lot are awarded more lots. In this manner some drillers have done up to 50 boreholes for handpumps.

Table 14 shows that some consideration is given by projects to package contracts in multiples of boreholes but the contract packages are small. There seems to be some caution in awarding too many boreholes at one time to a particular contractor. Also it seems, as in the case of the FMWR project there is a tendency to satisfy as many contractors as possible. Once reliable contractors have been identified, bigger contract packages can be awarded to them which would increase their credit ratings with bankers and allow for credit facilities to upgrade their equipment.

Presently on UNICEF projects even where there are multiple borehole packages a mobilisation fee is still allowed for each borehole to be drilled whereas there should be one mobilisation for the lot and an amount allowed for moving from site to site and setting up.

### **6.5 Compilation of Hydrogeological Information and Borehole Siting**

The Geological Survey Department published several geological maps of parts of the country at the scale of 1:250,000. They also produced a 1: 2,000,000 geological map of the country. These maps have been used over the years by hydrogeologists to predict probable terrain and drilling conditions of a proposed site. Although not very accurate they can be used in most cases to predict whether a site is on the basement complex or on sediments and the type of sediments.

The Hydrological and Hydrogeological Department of the FMWR which is currently being transformed to the Nigeria Hydrological Services Agency has for over 10 years been compiling hydrogeological data to produce a hydrogeological map of the country. The data gathering is presently at the stage of ground confirmation of data collected from previous drilling projects. It is understood that the map and other information will be available to the public.

Borehole siting procedure is a combination of geological reconnaissance and geophysical surveying. In unconsolidated sediments, not much geophysics is required except in areas of suspected saline intrusion. On the Basement Complex and consolidated sediments geological reconnaissance is followed by resistivity depth sounding. Not many outfits have the electromagnetic metering equipment which is usually used for a quick geophysical reconnaissance to locate possible fracture zones on the crystalline terrain and consolidated sediments.

Over the last 15 years there has been a better understanding of the use and interpretation of geophysics on the Basement Complex and borehole success rate has increased. Water Surveys Nigeria Limited siting

boreholes on the Bauchi State ADP borehole project recorded an 80% success rate in 1983 and recorded the same success rate on the Kaduna ADP 400 borehole project in 1992. On the PTF 100 borehole project a success rate of 100% was recorded. Similar success rates, above 80 - 90% are being recorded by other hydrogeologists and drilling consultants. Most of the contractors now have their own geophysical equipment and employ geologists. Others use consultants. Table 15 shows the success rate recorded by some drillers in Kano State.

**Table 15 Borehole Siting Percentage success rate in 2007**

Company	Percentage
Global Earth Solve Ltd	85
Fortia Water	97
Geological Drilling Investments Limited	80
Mongo Hydro & Geoconsult Ltd	85

Most projects as a matter of routine include geophysical survey as the first item on the bill of quantities. As stated above, this is not required in all cases. Two bills of quantities were prepared for the Niger State RUWASSA project, one for the sedimentary terrain and one for the basement complex. Both stipulated geophysical surveys despite the fact that it is highly unlikely to be required on the sediments. A recent review of the bill of quantities for a project in Enugu State also showed the same requirement, although resistivity survey data are often not interpretable in that area because of the presence of ironstones, lateral variation in lithology and the great depth to the aquifers in some parts of the state. A World Bank supported project in the Surulere area of Lagos metropolis also specified resistivity survey even though the Lagos aquifers are well documented and established as regional aquifers. A geological reconnaissance and a review of existing borehole data to ascertain the probable depth to the aquifer would have been a more useful exercise.

The issue of responsibility for siting by drilling contractors and none payment for dry holes by most projects remains contentious. In the time of the ADP mass borehole projects consultants were hired to carry out geophysical investigation and do the siting. The client allowed for a certain percentage of dry holes in the budget accepting that geophysics at best is an approximation of several ground parameters and not 100% accurate. The drilling contractor was paid for whatever work was done until the borehole was declared abortive. However over the years the trend changed to the contractor being responsible for geophysics and not getting paid for dry holes. The issue is not limited to Nigeria. It was discussed at a drillers meeting in Mozambique in August 2008. It was agreed that drillers associations should engage governments and funding agencies in dialogue to review the situation.

**Figure 10 Resistivity survey in Niger State**



## 6.6 Pumping test matched to borehole purpose

Matching pumping tests to the purpose and expected yield of the borehole is one aspect of cost effectiveness that has been accepted by most projects. As a result of the moderate yield of boreholes on the Basement Complex and the capacity of a handpump, the duration of pumping test is usually between 2 to 6 hours of pumping. On the other hand because of the high potential of the sedimentary aquifers and the need to install motorised boreholes for greater yield the duration of pumping test is usually 24 hours of pumping and 24 hours of recovery monitoring.

The FMWR contract specification for the sedimentary areas states that ‘the test period will vary between 12 and 72 hours depending on the aquifer characteristics’. It allows for 2 hour pumping test on the handpump fitted boreholes on the basement complex.

On the UNICEF assisted Kaduna State project the logs showed that the pumping tests were carried out for 4 hours at a yield of 0.8 l/s appropriate for a handpump need. Also the UNICEF B field office borehole guidelines stipulate pumping for 3 hours or until the water level stabilises. Some of the UNICEF projects ask for a step drawdown test after the constant discharge test. This is really not necessary on a handpump fitted borehole particularly as there is no evidence that the data is ever analysed for well efficiency.

For the Hadejia –Jamaare RBDA project an 8 hour pumping test was stipulated for the proposed mechanised boreholes and 3 hours for the handpump fitted holes.

Lagos State Water Corporation stipulates a 24 hour pumping test at a rate of 75 m<sup>3</sup>/hr for boreholes designed to deliver 50 m<sup>3</sup>/hr.

## 6.7 Supervision of borehole drilling

FMWR employ consultants to supervise their contracts. The roles and responsibilities of the supervisor are clearly spelt out in the drilling contract. Lagos State Water Corporation on the World Bank supported rehabilitation works also employ consultants to manage and supervise the projects. Apart from the agency’s geologists who are on site during the drilling, UNICEF also employs consultants to supervise and monitor the process.

Niger State RUWASSA has 8 geologists who carry out the supervision of the projects and report back to the Chief geologist but they have only one vehicle between them. The Hadejia Jamaare RBDA has 3 geologists and one engineer to carry out the supervision. Kano State RUWASSA has 1 geologist to supervise their drilling contracts. A supervisor is meant to be on site to monitor the whole process of drilling and it is doubtful if the single geologist could supervise all the contracts effectively. UNICEF B office personnel complained of weak contract management at state level particularly in supervision, monitoring and documentation.

Some of the agencies could benefit from the NWRI course on drilling supervision. Kaduna State Ministry of Water Resources realising that they do not have enough competent staff to supervise their drilling programmes recently engaged the institute to carry out a training program for the staff.

Proper supervision of contracts requires trained and experienced personnel who know what to look for. It takes training to know whether a casing is of the correct pressure rating or screens are of the right slot size or gravel pack is of the right material or grain size. The documentation on some of the contracts shows inexperience on the part of the supervisor. The description of some of the drill samples is difficult to understand. For example a sample from a borehole on the basement is described as “sand and stone”. A systematic description of samples based on weathering grades, strength or particle size of rocks is yet to be adopted. Also from the drill logs, there may be cases of over drilling where drilling goes beyond 50 m on the basement. A driller might have taken advantage of a supervisor’s absence from site or inexperience to drill extra meters.

## 6.8 O&M procedures to ensure the sustainability of pumped groundwater

The National Rural Water Supply and Sanitation Strategy (FMWR 2002) stipulate that O&M are the responsibilities of the communities. FMWR contracts and those of other agencies specify the training of the communities in the operation and maintenance of the facilities during the execution of the contract. However in many cases the training is ineffective as many of the facilities break down shortly after construction and remain in a state of disrepair.

Niger State RUWASSA stated at any one time up to 30% of the installed facilities could be broken down. Hadejia Jammare RBDA reckon they have reduced the rate to 20 %. In Lagos State breakdowns used to be as much as 40% but it was gathered that this has been reduced to about 25%. Rivers State RUWASSA doubted if any of the systems they installed were still working as they had been handicapped by funds and the unrest in the Niger Delta to monitor the performance of the facilities.

This constitutes a major source of wastage and is probably the main drawback to rural water supply coverage. Training in VLOM has to be stepped up and the supply chain improved. In a lot of cases the problem is not with the borehole but with the pump. In 2007 an NGO in Kaduna State, Afaka Initiative working with the communities in Igabi LGA successfully rehabilitated 40 boreholes that were drilled in the 1993 by flushing the boreholes and replacing or repairing the pumps.

UNICEF trains the State and Local Government personnel in Water Information Management System (WIMS) which monitors the use, effectiveness of use, and sustainability of the water facilities.

**Figure 11 A non functional handpump under repair**



## 6.9 Rigorous evaluation of groundwater resources

A single handpump in a rural community is not likely to pose a threat to groundwater sustainability but it may be contaminated by the use of fertilisers and pesticides. Boreholes drilled close together in urban, with higher levels of abstraction could lead to water level decline as was experienced in Lagos in the past. Thus there is need for regular, long term monitoring.

All the projects specify water quality testing after the construction of the borehole but after that there is hardly any monitoring to check changes in water quality or water levels. Also the parameters specified to be measured have to be reviewed in line with National Drinking Water Quality Standards. WaterAid in a recent survey found higher levels of arsenic than the safe limit in 11% of samples tested in Benue State. None of the projects specify arsenic in the water quality test.

From the drilling programmes information continues to accrue on the groundwater resources of the country but they are scattered in different agencies and departments and need to be collated. The present knowledge of the groundwater resources of the country is better than 30 years ago although a

lot of useful data is lost through uncontrolled drilling exercises. Some concerted effort by FMWR, ESAs, universities, research institutions and the private sector is required to evaluate and document the groundwater resources of the country.

Lagos State government has proposed a Ground Water Monitoring, Regulatory and Licensing Strategy and a Borehole Repository Format and Coding System which were presented at the 19<sup>th</sup> meeting of the National Council on Water Resources in July, 2008. The proposals were approved by the Council and it further recommended that all states adopt the initiative.

### **6.10 Support to the private drilling contractor**

There are not many manifest cases of support to the drilling sector. The contract packages are small and the work flow is not always certain. There is no consistent budget for borehole contracts. FMWR have not gone ahead with the Federal Rural Water Supply Programme after the budget of 2005. Hadejia Jamaare RBDA said they put in proposals every year for borehole construction but they are not sure of what will be approved in the budget. The situation was the same in Niger, Rivers and Kaduna States.

There is no waiver on duties for the importation of drilling equipment as given to the agricultural sector. Drilling contractors still have to pay import duties of about 7% on their goods, although it was generally accepted that the process of importation has improved in the past 5 years.

The local rig makers complain of lack of recognition from the government. RWSN has supported the formation the Water Well Drilling Association of Nigeria which aims to identify the committed drillers and lead to professionalising of the drilling sector.

WaterAid in 2004 gave some support to a young private drilling contractor by asking him to manage a drilling rig on a commercial basis. The drilling rig had been brought to the country for a specific project in Benue State by WaterAid. On completion of the project the rig was handed over to the contractor. The arrangement was very successful, enabling the contractor to buy his own rigs and today his is one of the most successful drilling outfits in the country. It was thought that this was a model to be replicated but this year WaterAid and the state agency decided to recall the rig.

### **6.11 Improving networking, communication and management in public and private sectors**

The Nigeria Water and Sanitation Association for many years provided a forum for drillers to meet but as its objectives were not specific to drilling and it was never a drillers' forum. The Kano and Jigawa State drillers formed themselves into an association and there is the current initiative to form a drillers association in the country. It is hoped that the Nigerian Drillers Association will provide the forum for networking amongst the drillers and between the drillers and governments. And also provide training opportunities for its members.

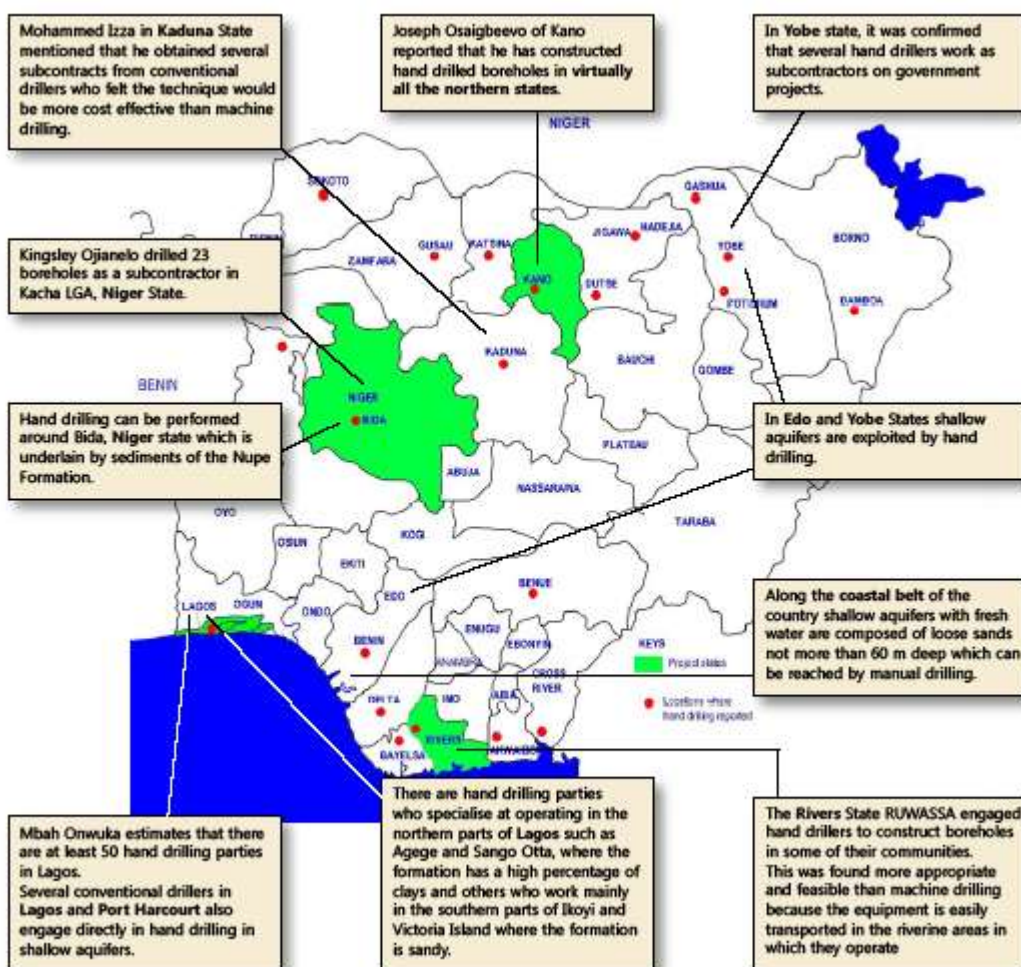
## 7 Hand Drilling in Nigeria

Hand digging to construct a water-well requires a person to be working inside the hole; hand drilling allows the driller to stand at ground level. This may be achieved using a number of techniques:

- Hand augering: drilling a small-diameter hole with a soil auger.
- Hand percussion: manually lifting and dropping a cutting tool suspended at the end of a rope into the hole.
- Jetting (or washboring): injection of water into the hole through a drilling pipe to loosen and remove material
- Hand sludging: raising and dropping a drill pipe and use of water to carry the drilling cuttings up the drill pipe.

Manual or hand drilling is widely practised in different parts of Nigeria for both domestic water supply and irrigation. Hand drilling techniques started to be used in the 1980s to tap water for agricultural purposes from the river floodplains. It is estimated today that there are over 30,000 hand drilled wells in Nigeria. The techniques are practiced by farmers, artisan and conventional drillers, university graduates and retired civil servants. The field note *Hand Drilling in Nigeria: Why Kill and Ant with a Sledgehammer* by Adekile and Olabode (2009) provides more information on the use of this niche technology in Nigeria, including the historical background, profiles of hand drillers and prevalence of hand drilling (Figure 12).

Figure 12 Annotated map showing areas of hand drilled boreholes (Source: Adekile and Olabode ,2009)



## 8 Borehole costing and pricing

This chapter looks at the cost and prices of boreholes, factors that affect them and how to achieve some cost reductions.

### 8.1 The Difference between Borehole Cost and Price

The price of the borehole is what the customer be it government, project or the householder pays for it. The cost is what the driller pays to deliver the product. The difference between the cost and tender price is due to the need to allow for

- profit, overhead and taxes
- risks such as drilling a dry hole, delay in payment, insecurity, difficult access, breakdowns
- contingencies such as loss of circulation
- competition which in some cases may make a contractor to even go lower than his costs if he is desperate to win the job

### 8.2 Costing

The costs incurred in producing a borehole can be broken into four major components:

- **Mobilisation/demobilisation:** Mobilisation cost includes transporting men and equipment (drilling rig, compressor, support vehicles, drill pipe, casing and screen, gravel, cement, drill fluids, fuel, water, tools) to site and back to base.
- **Drilling cost** includes equipment depreciation, labour, fuel, lubricants and drill fluids, replacement of drilling tools.
- **Casing and completion** cost includes supply and installation of casing and screen, gravel pack, sanitary seal, and well head construction.
- **Development** refers to the cleaning of the borehole following construction, pumping test for an assessment of the borehole and aquifer parameters.

Each of the four components contributes significantly to total cost therefore cost saving on one particular item will not necessarily have a major impact on the overall cost. However there are some costs such as those for fuel and labour that affect all four elements of the total figure. Some of the ways in which cost savings can be made are analysed below.

#### 8.2.1 Mobilisation

Mobilisation cost is calculated based on capital equipment depreciation, i.e. full cost of rig, compressor, mudpump etc, assuming a particular lifespan and utilisation rate, plus daily cost of support trucks (this may be based on commercial rental rates) plus fuel cost and manpower cost on daily basis (Carter et al, 2006). The method of calculation is outlined in table 16 and has been used to calculate the mobilisation cost for a hypothetical project 100 km from the contractor's base, using equipment purchased at US\$ 170,000 (~N20 million) and US\$85,000 (~N10 million), both with an assumed lifespan of 10 years and 60% utilisation.

Table 16 shows the mobilisation (and demobilisation) cost for a hypothetical project, 100 km from the contractor's base. Three examples are given:

- equipment purchased at US\$ 500,000;
- equipment purchased at US\$ 170,000 and
- equipment purchased at US\$ 85,000.

**Table 16 Basis for calculation of mobilisation and demobilisation cost**

<b>Mobilisation</b>	<b>Calculation Method</b>	<b>Amount (a)</b>	<b>Amount (b)</b>	<b>Amount (c)</b>
Capital equipment depreciation	Cost of rig, freight insurance, loan charges converted to daily cost based on a 10 year lifespan and 60% utilisation	\$228	\$78	\$39
Vehicles	Rental market rate/real running cost of: (a) 2 trucks and 1 pickup; (b) 1 truck and 1 pickup.	\$407	\$297	\$186
Fuel and lubricants	For a travel distance of 100 km (20 l of fuel/vehicle at \$0.58/l)	\$58	\$46	\$35
Human Resources	Salaries and per diems on daily basis for hydrogeologist, driller, assistant driller, 2 labourers, security person and 1 driver (rig a)/2 drivers (rig b).	\$199	\$149	\$141
<b>Sub-total Mobilisation</b>		<b>\$892</b>	<b>\$570</b>	<b>\$401</b>
<b>Sub-total Demobilisation</b>	Estimated at 80% of mobilisation cost	<b>\$714</b>	<b>\$456</b>	<b>\$321</b>
<b>Total</b>		<b>\$1,606</b>	<b>\$1,026</b>	<b>\$721</b>

Table 16 shows that the mobilisation component of the borehole cost alone is US\$720 to US\$1,600 depending on the cost of the drilling equipment. Clearly the use of lighter and less expensive rigs has a significant effect on reducing mobilisation cost. This is due to the fact that cost of depreciation (and the human resources costs) of the lighter equipment is lower.

A borehole far from the contractor's base incurs greater mobilisation costs not only because of the cost of fuel but also because of the time spent on the road not drilling. One way to reduce cost is to award contracts in multiples of boreholes in close proximity so that the mobilisation cost is spread over several boreholes. In the above case, it would be more economical to spread the mobilisation cost over 10, 20 or 50 wells relatively close in distance (i.e. a clustered contract) than to pay this amount for each individual well drilled.

It is pertinent to mention that on UNICEF supported projects, even where projects are in lots of five or 20 boreholes, the bill of quantities is prepared for one borehole. Consequently there is an item for mobilisation on each contract. The contractor is therefore paid for mobilisation on each borehole. In order to reduce the price (paid by UNICEF or the government partner), the mobilisation should be once and the contractor should be allowed a realistic percentage for moving from site to site. This is the case with FMWR contracts.

### **8.2.2 Drilling**

Rowles (1995) presents a systematic cost calculation procedure for the drilling component of borehole construction, taking account of fixed and running costs, equipment lifetime and drilling performance. The costing assumes mud drilling through overburden, followed by down-the-hole hammer (DTH) drilling in rock. The procedure is shown in Table 17 with a worked example in Table 18.

**Table 17 Calculating drilling cost component**

Item		Explanation	Cost (US\$)	
Capital equipment		Cost of rig, freight insurance, loan charges	\$170,000	
<b>Fixed costs</b>	<b>Lifetime (Hours)</b>			<b>Cost per hour</b>
Depreciation	20,000	Capital cost divided by lifetime (ie 10 years at 60% utilisation) US\$/h		\$8.50
Maintenance	-	Maintenance (5% of depreciation) US\$/h		\$0.43
Labour	-	US\$/h		\$17.00
Fuel and Lubricants	-	US\$/h		\$10.00
Mud/foam	-	US\$/h		\$13.00
<b>Sub-Total (Naira/h)</b>		<b>Sum of above US\$/h</b>		<b>\$48.93</b>
<b>Cost per meter</b>		<b>Convert to US\$/m by dividing by drilling speed</b>		
<b>Variable Costs</b>	<b>Lifetime (meters)</b>	<b>Explanation</b>	<b>Replacement Cost</b>	<b>Costs per meter</b>
Drilling string	20,000	Convert to US\$/m by dividing replacement cost by lifetime	\$15,254	\$0.76
Hammer	3,000	Convert to US\$/m by dividing replacement cost by lifetime	\$8,136	\$2.71
Hammer bit	300	Convert to US\$/m by dividing replacement cost by lifetime	\$1,186	\$3.95
Drag bit	300	Convert to US\$/m by dividing replacement cost by lifetime	\$508	\$1.69
<b>Sub-Total Rock</b>		<b>Sum of drill string and drag bit US\$/m</b>		
<b>Sub-Total Overburden</b>		<b>Sum of drill string, hammer, and hammer bit US\$/m</b>		

**Table 18 Example of drilling cost**

Example		
Formation	Depth (m)	
Overburden depth (m)	20	
Rock depth (m)	30	
Total depth (m)	50	
Drilling speed (m/h)	3	
Calculation		Cost
Fixed costs	= 50m x (48.93/3)	\$816
Variable cost: overburden	=20m x (0.76 +1.69)	\$49
Variable costs: rock	= 30m x (0.76 + 2.71 + 3.95)	\$223
<b>Total Cost - Drilling</b>		<b>\$1,104</b>
<b>Drilling cost per m</b>		<b>\$22</b>

If the same procedure is applied to equipment costing \$85,000 (N10 m) the drilling cost comes to about US\$800, i.e. US\$16 per m. So where possible it is more cost effective to use smaller less expensive equipment. In general this has been taken on board by Nigerian drillers. Smaller and less expensive rigs are being used where possible. Several of the newly emerging drilling contractors are using locally manufactured rigs. Even conventional drillers are using manual drilling where they consider it more appropriate than machine drilling.

### 8.2.3 Casing and Completion

After the completion of drilling the borehole has to be cased, gravel pack material installed and the well head constructed. Where plastic can be used it is obvious that this will be cheaper than steel casing. This has been accepted by the drilling sector. Drillers and projects in Nigeria invariably use uPVC on the basement complex and shallow sediments up to 80 m depth and steel casing is only used for the deep holes. The prices of different types of casing as obtained from manufacturers (uPVC, in Kano) and suppliers (steel in Port Harcourt) are presented in Table 19.

**Table 19 Prices of casing and screen**

UPVC	Price for 3m length (Naira)	Price per m (Naira)	Price for 3m length (US\$)	Price per m (US\$)
4 inch casing	3,200	1,067	27.12	9.04
4 inch screen	3,500	1,167	29.66	9.89
110mm casing	3,800	1,267	32.20	10.73
110mm screen	4,080	1,360	34.58	11.53
5 inch casing	5,100	1,700	43.22	14.41
5 inch screen	5,600	1,867	47.46	15.82
6 inch casing	7,200	2,400	61.02	20.34
6 inch screen	7,900	2,633	66.95	22.32
Steel	Price for 12m length (Naira)	Price per m (Naira)	Price for 12m length (US\$)	Price per m (US\$)
6 <sup>5/8</sup> inch casing	85,000	7,083	720.34	60.03
150 mm casing	90,000	7,500	762.71	63.56
9 <sup>5/8</sup> inch casing	200,000	16,667	1,694.92	141.24
13 <sup>5/8</sup> inch casing	190,000	15,833	1,610.17	134.18
15 <sup>5/8</sup> inch casing	230,000	19,167	1,949.15	162.43
Steel	Price for 3m length (Naira)	Price per m (Naira)	Price for 3m length (US\$)	Price per m (US\$)
6 inch 20-23 bar stainless steel screen	60,000	20,000	508.47	169.49
6 inch 60- 72 bar stainless steel screen	95,000	31,667	805.08	268.36
150 mm screen	75,000	25,000	635.59	211.86

Tables 20 to 22 show examples of the cost of casing and completion for three very different scenarios:

- (i) 110mm UPVC lined borehole to 50m in the basement complex (Table 20)
- (ii) 110 mm diameter uPVC lined borehole 80m deep (Table 21);
- (iii) 150mm steel lined borehole to 150m in the sediments (Table 22).

**Table 20 Cost of Casing and Completion for Well Design (i):110 mm diameter uPVC lined borehole 50 m deep**

No	Description	Unit	Qty	Unit Rate (US\$)	Amount (US\$)
<b>3</b>	<b>Casing and Completion</b>				
3.1	110 uPVC casing	m	40	11	429
3.2	110 uPVC screen	m	10	12	115
3.3	Supply sand pack river gravel	No	1	102	102
3.4	Backfill	LS	1	34	34
3.5	Grouting (6 bags of cement)	No	6	11	68
<b>Total - Casing and Completion</b>					<b>\$748</b>

**Table 21 Cost of Casing and Completion for Well Design (ii): 110 mm diameter uPVC lined borehole 80 m deep**

No	Description	Unit	Qty	Unit Rate (US\$)	Amount (US\$)
<b>3</b>	<b>Casing and Completion</b>				
3.1	110 uPVC casing	m	70	11	751
3.2	110 uPVC screen	m	9	12	104
3.3	Supply sand pack river gravel	No	1	102	102
3.4	Backfill	LS	1	54	54
3.5	Grouting (6 bags of cement)	No	6	11	68
<b>Total - Casing and Completion</b>					<b>\$1,079</b>

**Table 22 Cost of Casing & Completion for Well Design (iii): 150 mm diameter steel lined borehole 150 m deep**

No	Description	Unit	Qty	Unit Rate (US\$)	Unit Rate (US\$)
<b>3</b>	<b>Casing and Completion</b>				
3.1	150 mm steel casing	m	140	64	8,998
3.2	150 mm screen	m	9	212	1,907
3.3	Supply sand pack river gravel	No	1	102	102
3.4	Backfill	LS	1	102	102
3.5	Grouting (6 bags of cement)	No	6	11	68
<b>Total - Casing and Completion</b>					<b>\$11,076</b>

Analysis of above tables shows that the cost of casing and completion increases with depth as would be expected. However it highlights the significant impact on cost that is caused by the use of steel rather than uPVC casings.

#### **8.2.4 Development and Pumping Test**

After completion of construction, the borehole has to be cleaned, developed, and a pumping test carried out, water samples taken and analysed and a report prepared. Although the duration of development varies from place to place, each of the activities involved can be costed on time basis for the required equipment and personnel.

Borehole development cost is worked out on:

- daily depreciation cost of rig, compressor, fuel and lubricants
- vehicle running
- manpower

Pumping test requires:

- the mobilisation of pump, rising main, and generator
- installation of submersible pump
- pumping for an agreed period with water and flow monitoring
- monitoring of recovery for an agreed period

The main elements of cost are transport, depreciation of capital items (generator and pump) fuel and running costs for generator and manpower. The specific cost break down depends particularly on location and duration of the site.

Tables 23 and 24 provide two different scenarios for well development and test pumping.

**Table 23 Cost of well development and test pumping (scenario 1)**

No	Description	Unit	Qty	Unit Rate (US\$)	Amount (US\$)
<b>4</b>	<b>Development and pumping test</b>				
4.1	Borehole cleaning (compressor running for 4 hours)	No	4	34	136
4.2	Pumping test (pump and generator for 3 hours)	No	3	102	305
<b>Total - Development and pumping test</b>					<b>441</b>

**Table 24 Cost of well development and test pumping (scenario 2)**

No	Description	Unit	Qty	Unit Rate (US\$)	Amount (US\$)
<b>4</b>	<b>Development and pumping test</b>				
4.1	Borehole cleaning (compressor running for 4 hours)	No	10	34	339
4.2	Pumping test (pump and generator for 3 hours)	No	24	102	2,441
<b>Total - Development and pumping test</b>					<b>2,780</b>

### 8.2.5 Costing Scenarios

Tables 25 to 29 provide three different drilling scenarios. They are based on the costing principles set out in section 8.2.1 to 8.2.4 above. For details of the drilling calculations see Appendix 2.

**Table 25 Cost of a 110mm diameter uPVC lined borehole 50m deep (basement complex); rig cost of \$170,000**

No	Description	Unit	Qty	Unit Rate (US\$)	Amount (US\$)
<b>1</b>	<b>Mobilisation/demobilisation</b>	LS	1	1,026	1,026
<b>2</b>	<b>Drilling</b>				
2.1	Site clearing and preparation		1	17	17
2.2	Drilling (fuel and lubricants cost \$10 per h)	m	50	22	1,100
<b>3</b>	<b>Casing and Completion</b>				
3.1	110 uPVC casing	m	40	11	429
3.2	110 uPVC screen	m	10	12	115
3.3	Supply sand pack river gravel	No	1	102	102
3.4	Backfill	LS	1	34	34
3.5	Grouting (6 bags of cement)	No	6	11	68
<b>4</b>	<b>Development and pumping test</b>				
4.1	Borehole development (compressor running for 4 hours)	No	4	34	136
4.2	Pumping test (pump and generator for 3 hours)	No	3	102	305
	<b>Total Cost</b>				<b>3,332</b>

**Table 26 Cost of a 110mm diameter uPVC lined borehole 80m deep (sedimentary); rig cost of \$350,000**

No	Description	Unit	Qty	Unit Rate (US\$)	Amount (US\$)
<b>1</b>	<b>Mobilisation/demobilisation</b>	LS	1	1,026	1,400
<b>2</b>	<b>Drilling</b>				
2.1	Site clearing and preparation		1	17	17
2.2	Drilling (fuel and lubricants cost \$20 per h) <sup>2</sup>	m	80	25	2,000
<b>3</b>	<b>Casing and Completion</b>				
3.1	110 uPVC casing	m	70	11	751
3.2	110 uPVC screen	m	9	12	104
3.3	Supply sand pack river gravel	No	1	102	102
3.4	Backfill	LS	1	54	54
3.5	Grouting (6 bags of cement)	No	6	11	68
<b>4</b>	<b>Development and pumping test</b>				
4.1	Borehole development (compressor running for 10 hours)	No	10	34	339
4.2	Pumping test (pump and generator for 24 hours)	No	24	102	2,441
	<b>Total Cost</b>				<b>6,797</b>

<sup>2</sup> See Appendix 2

**Table 27 Cost of a 150mm diameter steel lined borehole 150m deep (sedimentary); rig cost of \$500,000**

No	Description	Unit	Qty	Unit Rate (US\$)	Amount (US\$)
<b>1</b>	<b>Mobilisation/demobilisation</b>	LS	1	1,606	1,606
<b>2</b>	<b>Drilling</b>				
2.1	Site clearing and preparation		1	17	17
2.2	Drilling (fuel and lubricants cost \$30 per h) <sup>3</sup>	m	150	34	5,100
<b>3</b>	<b>Casing and Completion</b>				
3.1	150 mm steel casing	m	140	64	8,898
3.2	150 mm screen	m	9	212	1,907
3.3	Supply sand pack river gravel	No	1	102	102
3.4	Backfill	LS	1	102	102
3.5	Grouting (6 bags of cement)	No	6	11	68
<b>4</b>	<b>Development and pumping test</b>				
4.1	Borehole development (compressor running for 10 hours)	No	10	34	339
4.2	Pumping test (pump and generator for 24 hours)	No	24	102	2,441
	<b>Total Cost</b>				<b>20,580</b>

Tables 25 to 27 show the wide variations in cost, ranging from about US\$ 3,300 for a 110mm uPVC lined hole, drilled into the basement to about US\$20,600 for the 150mm steel lined borehole in the sedimentary formation. Table 28 (below) compares the % of each of the four sub-components.

In the case of well (i) (110mm UPVC lined borehole to 50m in the basement complex) it is the mobilisation and drilling that dominate the cost, at about one third each. In the case of scenario (ii) (110 mm diameter uPVC lined borehole 80m deep) the extensive development and pumping test costs almost half of the total cost. This highlights the importance of ensuring that these items are in line with the actual requirements of the borehole. Finally, in the case of well (iii) (150mm steel lined borehole to 150m in the sediments), the steel casing and screen constitute over 50% of the well cost.

### 8.3 Pricing

#### 8.3.1 Price Comparisons

Once 30% is added for overheads and profit, and a further 10% for taxes and other costs, the borehole prices are about (i) US\$4,800 (50m in basement, 110mm diameter and uPVC lined); (ii) 9,700 (80m in sedimentary) and (iii) 29,400 (150m in sedimentary, 150mm diameter and steel lined).

Table 29 shows the prices of boreholes on several projects across the country. These prices are within the same ball park as the figures from the scenarios given in Table 28. However, it should be noted that the prices in Table 29, are mostly taken from bills of quantities. They include mobilisation, drilling, casing and development only and excluding other contractual demands. Waiting time, for example can have a significant impact on the price of a well if paid according to a bill of quantities.

<sup>3</sup> See Appendix 2

**Table 28 Costs and prices of example boreholes**

Borehole Details	Sub-Component	Cost (US\$)	% of total cost	Total cost (US\$)	Price (US\$) <sup>4</sup>	Price per m (US\$)
110mm diameter uPVC lined borehole 50m deep (basement complex)	Mobilisation	1,026	31%	3,332	4,765	95
	Drilling	1,117	34%			
	Casing & completion	748	22%			
	Dev. & pumping test	441	13%			
110mm diameter uPVC lined borehole 80m deep (sediments)	Mobilisation	1,400	21%	6,796	9,718	121
	Drilling	1,537	23%			
	Casing & completion	1,079	16%			
	Dev. & pumping test	2,780	41%			
150mm diameter steel lined borehole 150m deep (sediments)	Mobilisation	1,606	8%	20,580	29,429	196
	Drilling	5,117	25%			
	Casing & completion	11,077	54%			
	Dev. & pumping test	2,780	14%			

**Table 29 Prices of boreholes from different programmes**

Project	Geology	Price (Naira)	Price (US\$)	Price per m (US\$)	Remarks
River State RUWASA	Sedimentary	450,000-740,000	\$3814 - \$6271	Ave = \$84	Hand drilled borehole 150 mm diameter to 60 m by direct labour
Kano State RUWASSA	Basement Complex	400,000 - 500,000	\$3,390 - \$4,237	-	Charge for drilling borehole for private householders
Niger State RUWASSA	Sedimentary	840,000	\$7,119	\$89	Payment records for an 80 m deep uPvc lined borehole
Lagos RUWASSA	Sedimentary	900,000	\$7,627	\$95	Contract price for 150 mm diameter uPVC lined borehole to 80 m depth
Private driller Ibadan	Basement Complex	400,000	\$3,390	\$97	Charge for drilling a 35 m borehole for private householders using a locally made rig. Cost to driller is US\$2,034 (N240,000)
Niger State RUWASSA	Sedimentary	740,000	\$6,271	\$105	Payment records for a 60 m deep borehole
Kaduna State RUWASSA	Basement Complex	657,000	\$5,568	\$111	Contractors payment certificate for drilling a 50 m deep borehole, lined with 110 mm uPVC casing

<sup>4</sup> Includes a 30% margin for overheads and profit followed by a 10% margin for taxes.

Project	Geology	Price (Naira)	Price (US\$)	Price per m (US\$)	Remarks
Kano State RUWASSA	Basement Complex	667,000	\$5,653	\$113	Contract price for drilling a 50 m deep borehole lined with 110 mm uPVC casing
Hadejia Jamaare RBDA Kano	Basement Complex	673,000	\$5,703	\$114	Contract price for drilling a 50 m deep borehole lined with 110mm uPVC casing
FMWR	Basement Complex	723,016	\$6,127	\$123	Contract price for drilling 60 m hole but reduced to 50m for comparison. Total contract price is N1,404,000 <b>inclusive of services to the engineer &amp; supply of pumps</b>
Niger State RUWASSA	Basement Complex	621,000	\$5,263	\$132	Contractors payment certificate for a 40 m deep borehole lined with uPVC casing
Kaduna State RUWASSA	Basement Complex	635,000	\$5,381	\$135	Contractors payment certificate for a 40 m deep borehole lined with 110 mm uPVC casing
Hadejia Jamaare RBDA, Kano	Sedimentary	1,315,050	\$11,144	\$149	Engineers estimate for 150 mm diameter uPVC lined, 75 m deep borehole
EU Project Adamawa State	Sedimentary	2,177,000	\$18,449	\$154	Contract price for 250 mm diameter steel lined borehole 120 m deep at Demsa
FMWR	Sedimentary	5,889,500	\$49,911	\$166	Contract price for drilling 150 mm diameter borehole to 300 m deep lined with steel
EU Project Adamawa	Sedimentary	2,451,665	\$20,777	\$173	Contract price for 250 mm diameter steel lined borehole 120 m deep at Banjiram
FMWR	Sedimentary	3,110,000	\$26,356	\$176	Contract price for drilling 150 mm diameter borehole 150 m deep lined with steel
Lagos RUWASSA	Sedimentary	6,562,500	\$55,614	\$222	Contract price for a 300mm diameter borehole to 250 m lined with steel without the pump
EU Project Enugu State	Sedimentary	3,303,900	\$27,999	\$467	Contract price for 350 mm diameter steel lined borehole to 60 m
Lagos State Water Corporation	Sedimentary	7,111,300	\$60,265	\$464	Contract price for a 225 mm diameter borehole 130 m deep lined with steel, 48 hour development and 36 hour pump test
Lagos State Private driller	Sedimentary	120,000,000	\$1,016,949	\$1,271	Contract price for drilling an 800 m deep borehole
River State Private Driller	Sedimentary	60,000,000	\$508,475	\$2,542	Contract price for 200 m deep borehole in Escravos

### 8.3.2 Discussion of factors that influence actual drilling prices

**Different contracts have different demands.** The Federal Rural Water Supply Programme and World Bank supported projects allow for preliminaries like the insurance of the works, services to the engineer, site office, project sign board, and setting up of mobile office. UNICEF supported projects ask for the insurance of the works in the specification but there is no item for it in the bill of quantities so it is assumed that the bidder will include it in his unit cost for other items. Thus even when one tries to compare prices by focusing on the items pertaining to mobilisation, drilling, casing and development one is never sure that like is being compared with like as there could be hidden costs. The mobilisation cost may not just be for drilling equipment and men but other items such as signboard, base camp etc. FMWR and Lagos State Water Corporation contracts ask for geophysical logging of the borehole and the latter for grain size distribution analysis of the drilling samples to select screen slot size. Some contracts put gravel packing as a lump sum whilst others put it as a depth rate. The Hadejia-Jamaare River Basin Development Authority put pumping test and borehole disinfection as one item.

The **geology** has a bearing on the occurrence and depth of the aquifers and therefore on the drilling depth and the type of rig that can be used in a particular terrain and the lining material.

On the basement complex that underlies about 55% of the country, aquifer depths are on average 35 m and maximum depth is 60 m. For this depth, a light rig can be used and in most cases if the overburden is thick enough the depth can be reached by manual drilling. uPVC lining is used. The borehole can be completed in a day or two. Therefore borehole prices are in the range US\$ 3,400 (N 400,000) to US\$ 6100 (N 723,000). The lower end is represented by drillers using locally manufactured rig and drilling to 35 m depth and the upper end is government contracts specifying drilling to 50 m. On most drilling projects the price is of the order of US\$5100 (N 600,000).

The tendency to base contracts and bills of quantities on an assumed maximum drilling depth on the basement complex provides an opportunity for the driller to drill extra meters that are not required, especially where the supervisor is inexperienced, leading to wastage. FMWR project assumes a maximum drilling depth of 60 m and the State agencies assume a drilling depth of 50 m. It would be more cost effective if contracts were based on realistic depth estimates derived from the geophysical survey.

In contrast with the basement, in most of the coastal areas of Nigeria and other sedimentary areas such as the Niger Benue trough and the Chad Basin there are several aquifer horizons ranging from 40 m depth to 250 m and 800 m. Different drilling techniques are required for the different aquifers and therefore the prices vary. The shallow aquifers may be accessed by hand drilling or a light rig whilst the others need medium to heavy duty rigs. uPVC lining could be used on the shallow aquifers but steel lining are required for the deeper aquifers. The deep boreholes take longer to drill and so labour, drilling fluid and fuel costs are higher. Hence a much higher borehole cost.

Apart from the drilling depth, movement of equipment may be hampered by the terrain. In the creeks of the Niger Delta barges are required to move drilling rigs to some of the sites which results in additional costs. Barge movement depends on the tide so there may be delays. One driller narrated how he lost a rig when it slipped off the barge into a river.

The **expected yield** from the aquifer may also cause a variation in the prices. Even within the same geology and terrain the demands from the boreholes may be different and therefore different diameters of lining will cause differences in price. Also the requirements for a pumping test will be different.

**Varying distances to the site** means differences in mobilisation costs. A Kaduna based driller going to work in Ebonyi State, 700 km away, incurs greater mobilisation cost than a local driller.

Another factor that affects borehole price is the proximity of the location of the operator to sources of drilling materials. uPVC pipes are produced in Kano and Kaduna and Lagos. It is therefore easy for those operators close to these cities to procure the lining material at a cheaper rate than those further away. Steel casings are imported mainly by the oil industry into Port Harcourt and Warri. Where these are required for water wells in Lagos or Maiduguri they are hauled over distances of up to 800 km.

Hidden costs in providing borehole services will cause different prices. Some drillers in Lagos have to engage a police escort to get their equipment to site to protect them from theft and also for ease of passage through police check points. The unrest in the Niger Delta has led several drilling contractors to give up the business and those left have increased their prices.

**Light drilling rigs** are being manufactured locally and their prices are about a quarter of imported rigs of the same capacity. They thus have a potential of reducing the cost of mobilisation and drilling. This is discussed in section 6.

**Hand drilling** is also carried out in the country by several entrepreneurs. The cost of a hand drilled borehole is about a quarter of a machine drilled hole of the same depth and casing material. An estimated 30,000 boreholes have been drilled manually in the country, mostly for household supplies and irrigation but hand drillers have not yet been brought into the mainstream of government contracts. Hand drilling has the potential to contribute to reducing the overall cost of borehole provision in the country. This is further discussed in the Hand Drilling Field note.

If **non-productive boreholes** are considered, the cost of a borehole to a project is even higher. Carter et al (2006) considered the impacts of both the short term and the long term failure on the all inclusive cost of a borehole. They found that for a drilling success rate of 80% and post construction failure rate of 25% and cost ratio of dry to productive holes of about 0.60 the all inclusive cost of drilling is 53% higher than that of a productive sustainable borehole.

#### 8.4 Evaluating Bills of Quantities

It should be noted that a systematic costing procedure is not always reflected in the priced bill of quantities because of other considerations. This is illustrated in table 25, which is taken from a driller's payment certificate by a driller based in Kaduna State for a job done within the state. The total price is within the acceptable range but the percentage of each item of the total cost ensures that the driller earns as much of the contract sum as possible. Over 70% of the total price is on lump sum items such as geophysics and mobilisation so even if he had to drill only 25m instead of 50 m he would still be earning over 80% of the contract sum. This should have been noticed during tender evaluation and a more realistic distribution negotiated.

**Table 30 Priced Bill of Quantities by a Kaduna based driller**

Item	Mobilisation	Unit	Qty	Rate (US\$)	Amount (US\$)	% of Total Cost
1	Geophysics	LS	1	1,695	1,695	29%
2	Mobilization/demobilization	LS	1	1,441	1,441	24%
3	Drilling basement	M	50	13	636	11%
4	Supply & installation of casing	M	41	14	556	9%
5	Supply and Installation of screen	M	9	16	145	2%
6	Gravel packing	Each	1	593	593	10%
7	Borehole cleaning	Each	1	177	177	3%
8	Pumping test	Each	1	85	85	1%
9	Water Quality analysis	Each	1	232	232	4%
10	Sanitary seal	Each	1	169	169	3%
11	Reports	Each	2	102	203	3%
	<b>Total</b>				<b>5,932</b>	

## 9 Conclusions

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Nigeria has experienced some 60 years of water well drilling. When considering what much has happened in this period one realises how far the country has progressed. From the first cable tool rig in the late 1940s and the first British drilling company in 1951 to over 1,000 Nigerian drilling enterprises today. In all the states there are committed drillers who have invested personal savings in the industry. The year 2008 saw the inauguration of the Water Well Drillers Association of Nigeria – a national body which aims to professionalise the drilling sector, including checking the activities of the quacks..

In addition to the production of the casings and screens required for drilling in Nigeria, the country now boasts a growing drill rig manufacture industry. Manual drilling also continues to grow and it is estimated that about 30,000 wells have been drilled in this manner across the country. The National Water Resources Institute in Kaduna trains drillers and supervisors but the needs of the country are not met.

Such dynamism with respect to drilling sector is, however not without its challenges. The study found that where the borehole costs can be determined such as on the basement complex, current drilling prices are not excessively high. Drilling cost depends on the location, geology and required abstraction rate. Prices can be influenced by hidden costs such as the risk of loss of circulation, drilling dry holes and providing security for personnel and equipment. Despite this, there is much that needs to be done to further improve drilling and supervision practices, tendering, contract management and the operation and maintenance of completed wells installed with pumps.

The private sector has taken over the drilling of boreholes in the country. Further increases in sector finance will bring about continuity of work for the drillers and an increased ability to invest in equipment. However, current practices of awarding small contract packages do not encourage long term planning or investment in equipment by the contractors. Small contract packages also unnecessarily increase the mobilisation cost incurred in drilling. Lack of transparency and delays in the award process discourage some good drillers from participating in government contracts. In addition, third party involvement leads to reduction of profit margins and compromise on quality and standards.

Smaller rigs are being patronised by the drillers and used where appropriate and more use could further reduce drilling costs. Hand (or manual) drilling has been going on for a long time in the country both for irrigation and domestic water supply and has the potential to contribute to increased access to water supply. Conventional drillers use manual drilling where found more cost effective than mechanised drilling. The hand drillers are presently being patronised by householders and owners of small scale industries. Some are well educated and display a high level of entrepreneurial skills and can be brought into the mainstream of government contracts and projects at a much reduced cost than conventional drilling. The price of hand drilled boreholes is presently about a third of that of machine drilled boreholes and the costs are fairly uniform throughout the country. Unfortunately this technology is not as widely known as it should be and there are some concerns with respect to construction quality.

The knowledge of hydrogeology of the country has improved over the years as well as the success rate of borehole siting by geophysics on the basement complex. Unfortunately there is a tendency by some projects to specify geophysics on all drilling sites even where it is not necessary. The areas with poor groundwater potential in the country still need to be identified for the benefit of the drillers and the users. The Nigeria Hydrological Agency is preparing hydrogeological maps of the country. However, data collection has been going on for several years. The process needs to be speeded up so that the maps can be published.

Most contracts on the Basement Complex are based on an assumed maximum drilling depth of either 50 m or 60 m. This provides an opportunity for the driller to drill extra meters that are not required. It would be more cost effective if drilling depths were based on a realistic figure derived from the geophysical survey. The Federal government and external support agencies engage consultants to carry out supervision. At state level, the capacity for proper supervision in terms of experienced personnel and equipment is limited.

It is encouraging to note that both the Federal Ministry for Water Resources (FMWR) and the state projects design the pumping tests to fit the purpose of the borehole.

Intensive drilling in the urban areas of Lagos and Kano States could lead to water level decline. Groundwater resources monitoring of quantity and quality is inadequate to monitor trends and prevent deleterious effects of over pumping and contamination.

It is estimated that 30% to 50% of handpump boreholes in Nigeria are broken down at any one time. This constitutes a massive waste of investment and is probably the main factor in pulling down rural water supply coverage. The problem is often not with the borehole but with the pump. A 25% failure rate means that the all inclusive cost of drilling a sustainable borehole is 50% higher. However, in order to improve maintenance of existing boreholes there is a need for FMWR approaches to be less supply driven and for more investment in monitoring.

## 10 Recommended Strategic Actions for Cost Effective Boreholes

The principles of cost effective borehole drilling are not new in Nigeria and have been accepted to some extent. This chapter provides specific recommendations for improving cost-effective borehole provision in Nigeria.

### 10.1 Federal level

1. The Federal Government and its agencies should concentrate on **policy formulation and coordination** whilst providing financial support to the states and local governments to implement borehole drilling projects.
2. FMWR/UNICEF should develop an **action plan for cost effective borehole drilling** which takes the following recommendations into consideration:
  - i. Increase the transparency of the award process
  - ii. Reduce payment delays
  - iii. Accelerate the production of hydrogeological maps for the country
  - iv. Improve the sustainability and maintenance of existing handpumps
  - v. Ascertain capacity development requirements of Government staff and improve it as necessary
  - vi. Improve groundwater resources monitoring (quality and quantity)
  - vii. Base drilling depths in the basement complex on realistic figures from the geophysical survey rather than a standard assumed depth of 50m or 60m
  - viii. Cluster boreholes together in terms of location to reduce mobilisation costs
  - ix. Develop the capacity of drillers and supervisors in construction
  - x. Identify the areas in Nigeria where hand drilling is feasible and promote this technology
  - xi. Set up a system to ensure the quality of hand drilled wells

The action plan should be presented as a memorandum to the National Council for Water Resources for adoption by all stakeholders. It should also set standards of materials and practices in the drilling industry and ensure compliance.

3. The Federal Government should spearhead a **national water supply programme** involving all stakeholders and determine the number of water supply sources, including boreholes required in each state to meet the MDGs. The programme needs to be in harmony with the National Water Resources Policy. This requires more participation at the lower levels of Government. The budget and the financing options to meet the targets have to be worked out and the roles and responsibilities of every stakeholder identified.
4. The **investments required** to meet the water supply targets, available financing options and the responsibility of each stakeholder should be identified. Government should ensure timely provision of its share of the cost.
5. The Federal Government should instigate actions to **determine the available capacity in the country** i.e. the number of drilling contractors, the number of rigs and their location so that if there is a shortfall in meeting the targets, options to bridge the gap can be identified and mobilised.
6. The Federal Government should provide **support to the drillers association** as a forum for discussion with the drillers, professionalizing borehole drilling and increasing the capacity of the drillers for cost effective drilling.

## 10.2 State level

7. The State Governments should **identify the manpower and capacity development requirements** of their staff for effective supervision of borehole drilling and provide the training, tools and enabling environment.
8. The National Water Resources Institute in Kaduna should better market itself, in order to fulfil the large demand for water well drilling and supervision expertise.
9. The State Governments and the RUWASSAs should ensure that borehole contracts follow the principles of cost effective borehole drilling as enunciated in the study report, reflecting transparency, and equity. Also ensuring where possible that
  - larger contract packages are awarded with boreholes in close proximity and similar geology
  - drilling depths are based on reality
  - contracts are supervised by experienced personnel
  - water quality tests reflect the National Drinking Water Standards

The State Governments should work with local governments and develop guidelines for **continuous monitoring** of water sources, both quality and output, and operation and maintenance. Groundwater resources monitoring, both the quantity and quality, needs to be stepped up to check the trends and prevent deleterious effects of over pumping and contamination.

10. They should also provide **training and technical** support for LGA staff to be able to continue the training of community members in operation and maintenance of their facilities.
11. State Governments should **identify** those areas in their states where **hand drilling is feasible** and hand drilling operators with entrepreneurial skills who can be engaged in hand drilling. This technology should be promoted as a cost effective means of meeting the demands for community and household domestic water supply. However, there is need to set up a quality assurance system to ensure the quality of the drilling process and the product.

## 10.3 Local Government level

12. Local governments should keep an **inventory of the boreholes** within their area and monitor their functionality and support the communities in the maintenance of the facilities
13. LGAs should **identify and train handpump mechanics** in their areas and promote the setting up of sources of spare parts for handpumps within the locality.

## 10.4 External Support Agencies

External Support Agencies are to support governments in sector and institutional reforms including the development of policy, strategy and regulatory frameworks, and build capacity of government institutions at all levels to monitor and drive progress. They should support other processes that promote equity, transparency and good governance such as fiscal discipline, free and dynamic political processes, and civil society participation.

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## Appendix 1- Institutions and companies met during the study

No	Institution and location	Persons met and position
1	Federal Ministry of Water Resources, Abuja	Mr. Akin Aletan, Deputy Director
2	UNICEF, Abuja	Mohamed El Fatih Yousif, Chief, Water, Sanitation and Hygiene Section Dr Olufumilayo Ndububa
3	UNICEF, Abuja	Dr Olufunmilayo Ndububa
4	UNICEF B Field Office	Mr. Patrick Osuocha - WES Specialist
5	UNICEF B Field	Mr. Monday Johnson Environmental Sanitation Officer
6	WaterAid, Bassan Plaza, Abuja	Jonathan Burton, Country Representative Orji Ogbuneke, Head of Programmes
7	National Water Resources Institute, Kaduna	Dr. Dogara Bashir, Deputy Director Martin Eduve,
	National Hydrological Agency	Mr. Osifo
8	Ministry of Water Resources and Rural Development Kano State	Alhaji Balarabe, Director Hydrology and Hydrogeology
9	Ministry of Water Resources and Rural Development Kaduna	Mr. Bungwon, Director Water Supply, Kaduna State Ministry of Water Resources
10	Niger State Water Board	Engr. Abdulrahaman Baba General Manager
11	Niger State Water Board	Engr. Abdulkarim - Assistant General Manager
12	Niger State RUWASSA	Engr. Hussaini Babanna – Director
13	Niger State RUWASSA	Engr. Saleh U. Waziri – Head of Water Supply
14	Niger State RUWASSA	Mr. Shuaib Hussaini – Chief Geologist
15	Niger State ADP	Mr. M. K. Abdulahi – Managing Director
16	Niger State ADP	Mr. Samuel Mamman – Deputy Director, Fadama Development
17	Upper Niger River Basin Development Authority	Engr Simeon O. Yeesuf- Chief Engineer,
18	Water Team Solutions Minna	Mr. Sadiq Idris - Manager,
19	Adex Drilling Engineers Minna	Mr. Akin Adebayo – Manager
20	Audu Drill (Hand Driller) Minna	Mr Audu Dimba – Manager,
21	Hand driller Minna	Mr. Tanimu Ibrahim
22	Hadejia-Jammare RBDA, Kano	Engr Yusuf Abba Mailadi – Director of Operations
23	Hadejia Jamaare RBDA, Kano	Engr. Babayo M. Chinade – Assistant Director
24	Hadejia Jamaare RBDA, Kano	Aisha Ibrahim – Geologist
25	Kano State RUWASSA	Mallam Adamu Salihu – M.D
26	Kano State RUWASSA	Engr. Suleiman Salisu – Director of Planning
27	Kano Agriculture and Rural Development Authority	Engr. Adamu Alli – Director, Rural Institutions and Fadama Coordinator
28	Wash bore driller, Madobi LGA	Mallam Mawoje A. Bako,
29	PANAR Pipes Kano	B. Panda – Manager
30	Neat Drill Limited, Kano	Joseph Osaigbera – Managing Director
31	Fortia Water Kano	Baffa Bello - Managing Director,
32	Geological Investment Consultants	Nura Alkali – Managing Director
33		Takai Bello – Managing Director

No	Institution and location	Persons met and position
34	Mongo Hydro Geoconsult	Sunday Ekarika, Managing Director
35	Lagos State Water Corporation	Mr. Tunji Ogunlana – Deputy Director – Hydrogeology Section
36	Lagos State Ministry of Rural Development	Engr. R.A. Ayeni- Director,
37	Eauxwell Nigeria Limited Lagos	Mr. Edwin Enwagbara – Managing Director
38	Eauxwell Nigeria Limited, Lagos	Mr. Boniface Enyi
39	Dumson Nigeria Limited, Lagos	Engr. Mba Onwuka- Managing Director
40	Kopila Nigeria Limited, Lagos	Kingsley Isong
41	Kayfem Consult, Lagos	Engr. Femi Dickson- Managing Director
42	Shamadek Nigeria Limited, Lagos	Engr. Kunle Samo – Managing Director
43	Link Hydroengineering Limited, Lagos	Mr. Olumide Bamisaiye
44	Agrofountain Nigeria Limited, Lagos	Mr. Raphael Konyebagu – Managing Director
45	Hand driller, Lagos	Mr. Tolu Ogunfehintimi
46	Deep Well Hydraulics, Lagos	Mr. Omogbolahan Onashile
	Gauff Consultants, Lagos	Engr. Sunkanmi Somoye
47	Male Integrated Science Consultants, Ibadan	Mr. Michael Ale – Facilitator
48	Frilucson Limited, Ibadan	Engr. Friday Ojikeri
49	Heaton Nigeria Limited, Ibadan	Oluwatimilehin Oluwatobi – Managing Director
50	Waterworkx Borehole Services Ibadan	Mr. Wasiu Sola Lawal – Managing Director
51	Rivers State RUWASSA	Mrs. C.N. Iragunima – Managing Director
52	Rivers State RUWASSA	Mr. F. Odungeru – Director
53	Rivers Sate Water Board	Engr. M.M. Mmeo – Deputy Director
54	Bi-Star Limited Port Harcourt	Engr. Max Ugwu – Chairman
55	McTonis Technical Services Port Harcourt	Mr. Martins Ekpo –
56	Finning Drilling Engineers Ltd, Port Harcourt	Sir Ngah – Managing Director
57	Jiro Plastics, Port Harcourt	Mr. Raphael Owhe
58	WED Nigeria Limited, Drillers, Kaduna	Mohammed Dalami, Managing Director
59	J.R. Gushing Wells, Drillers, Kaduna	Mr. Hamidu Usman, Operations manager
60	Water Well Test Boring Limited, Kaduna	Mr. Gene Magasan
61	Boart Longyear Rig Manufacturers, Kaduna	Piet Hein van Bakergem, Area Sales Manager, Africa
62	Nogwill Drilling Company Limited, Kaduna	Mr. William Ikpomnwomba
63	Afaka Initiative, Kaduna	Mr. Tunde Ajobiwe
	Water Surveys Nigeria Limited, Kaduna	Mr. J.R.T. Hazell, - Director
64	Fatigen Drilling Nigeria Ltd, Jos	Sunday Arafan Mangai, Managing Director
65	A.M. Dung Drilling Limited, Jos	Mr. James Dung, Managing Director
66	Devtek Contracts Limited, Ibadan	Mr Dayo Adesuyi, Managing Director

## Appendix 2- Further Drilling Cost Calculations

Calculating drilling cost component – Rig Cost US\$350,000 – Drilling to 80m in sediments

Item		Explanation	Cost (US\$)	
Capital equipment		Cost of rig, freight insurance, loan charges	\$350,000	
<b>Fixed costs</b>	<b>Lifetime (Hours)</b>			<b>Cost per hour</b>
Depreciation	20,000	Capital cost divided by lifetime (ie 10 years at about 60% utilisation) US\$/h		\$17.5
Maintenance	-	Maintenance (5% of depreciation) US\$/h		\$0.88
Labour	-	US\$/h		\$17.00
Fuel and Lubricants	-	US\$/h		\$20.00
Mud/foam	-	US\$/h		\$13.00
<b>Sub-Total (Naira/h)</b>		<b>Sum of above US\$/h</b>		<b>\$68.38</b>
<b>Cost per meter</b>		<b>Convert to US\$/m by dividing by drilling speed</b>		
<b>Variable Costs</b>	<b>Lifetime (meters)</b>	<b>Explanation</b>	<b>Replacement Cost</b>	<b>Costs per meter</b>
Drilling string	20,000	Convert to US\$/m by dividing replacement cost by lifetime	\$15,254	\$0.76
Hammer	3,000	Convert to US\$/m by dividing replacement cost by lifetime	\$8,136	\$2.71
Hammer bit	300	Convert to US\$/m by dividing replacement cost by lifetime	\$1,186	\$3.95
Drag bit	300	Convert to US\$/m by dividing replacement cost by lifetime	\$508	\$1.69
<b>Sub-Total Rock</b>		<b>Sum of drill string and drag bit US\$/m</b>		
<b>Sub-Total Overburden</b>		<b>Sum of drill string, hammer, and hammer bit US\$/m</b>		

### Calculation

<b>Example</b>		
<b>Formation</b>	<b>Depth (m)</b>	
Sediments depth (m)	80	
Rock depth (m)	0	
Total depth (m)	80	
Drilling speed (m/h)	3	
<b>Calculation</b>		<b>Cost</b>
Fixed costs	= 80m x (68.38/3)	\$1,823
Variable cost: sediments	=80m x (0.76 +1.69)	\$196
Variable costs: rock	n/a	
<b>Total Cost - Drilling</b>		<b>\$2,019</b>
<b>Drilling cost per m</b>		<b>\$25</b>

**Calculating drilling cost component – Rig Cost US\$350,000 – Drilling to 150m in sediments**

Item		Explanation	Cost (US\$)	
Capital equipment		Cost of rig, freight insurance, loan charges	\$500,000	
<b>Fixed costs</b>	<b>Lifetime (Hours)</b>			<b>Cost per hour</b>
Depreciation	20,000	Capital cost divided by lifetime (ie 10 years at about 60% utilisation) US\$/h		\$25
Maintenance	-	Maintenance (5% of depreciation) US\$/h		\$1.25
Labour	-	US\$/h		\$25.00
Fuel and Lubricants	-	US\$/h		\$30.00
Mud/foam	-	US\$/h		\$13.00
<b>Sub-Total (Naira/h)</b>		<b>Sum of above US\$/h</b>		<b>\$94.25</b>
<b>Cost per meter</b>		<b>Convert to US\$/m by dividing by drilling speed</b>		
<b>Variable Costs</b>	<b>Lifetime (meters)</b>	<b>Explanation</b>	<b>Replacement Cost</b>	<b>Costs per meter</b>
Drilling string	20,000	Convert to US\$/m by dividing replacement cost by lifetime	\$15,254	\$0.76
Hammer	3,000	Convert to US\$/m by dividing replacement cost by lifetime	\$8,136	\$2.71
Hammer bit	300	Convert to US\$/m by dividing replacement cost by lifetime	\$1,186	\$3.95
Drag bit	300	Convert to US\$/m by dividing replacement cost by lifetime	\$508	\$1.69
<b>Sub-Total Rock</b>		<b>Sum of drill string and drag bit US\$/m</b>		
<b>Sub-Total Overburden</b>		<b>Sum of drill string, hammer, and hammer bit US\$/m</b>		

**Calculation**

Example		
Formation	Depth (m)	
Sediments depth (m)	150	
Rock depth (m)	0	
Total depth (m)	150	
Drilling speed (m/h)	3	
Calculation		Cost
Fixed costs	= 150m x (94.25/3)	\$4,713
Variable cost: sediments	=150m x (0.76 +1.69)	\$368
Variable costs: rock	n/a	
<b>Total Cost - Drilling</b>		<b>\$5,081</b>
<b>Drilling cost per m</b>		<b>\$34</b>