Development of a Monitoring and Maintenance Program for Residential Wells Used for Groundwater Abstraction in Lagos State, Nigeria

by

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A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science in Technology

Approved November 2010 by the
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ARIZONA STATE UNIVERSITY

December 2010

ABSTRACT

In rural and urban areas of Nigeria, dependence on groundwater is increasing since the population is growing and high quality, treated municipal water is scarce. Municipal drinking water is often compromised because of old and leaking distribution pipes. About 58% of the water consumed in Lagos State, Nigeria, comes from residential wells. However, a majority of residential wells are shallow wells that are constructed relatively close to septic tanks or pit latrines and are therefore subject to contamination. In certain parts of Africa, there is high potential of severe epidemic if water quality is not improved. With increasing reliance on groundwater, a need exists to monitor the quality of groundwater.

This thesis develops a plan for a monitoring program for residential wells in Lagos State, Nigeria. The program focuses on ways by which owners can maintain reasonably good water quality, and on the role of government in implementing water quality requirements. In addition, this thesis describes a survey conducted in various areas of Lagos State to assess community awareness of the importance of groundwater quality and its impact on individuals and the community at large. The survey shows that 30% to 40% of the households have located their wells and septic tanks in the same general area. Various templates have been created to help the staff of a future monitoring program team to effectively gather information during site characterization. A “Questions and Answers” leaflet has been developed to educate citizens about the need for monitoring residential wells.

ACKNOWLEDGMENT

I would like to thank my family for tolerating me during the course of this project. I would also like to thank my adviser, Dr. David Edwards and also my other committee members, Dr. Olson and Dr. Hild, for all of their input and advice in making this thesis a success.

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ACRONYMS

LSCW	Lagos State Water Corporation
WHO	World Health Organization
WSP	Water Safety Plan (WHO)
NDCP	National Diarrhea Control Program (Nigeria)
FMWR	Federal Ministry of Water Resources (Nigeria)
STWSSP	Small Towns Water Supply and Sanitation Program (Nigeria)
RBD	River Basin Development (Nigeria)
WSQC	Water Supply and Quality Control (WHO)
GDWQ	Guideline to Drinking Water Qualities (WHO)

DEFINITIONS

Aquifer

An underground layer of rock or gravel, sand, silt, or clay that holds pockets of water from which groundwater can be pulled up using wells.

Catchments

These are structures, such as basins or reservoirs, used for collecting or draining water.

Contaminants

Unwanted constituents in another material such as water.

Deep Wells (Bore holes)

Holes in the ground that are drilled by use of cable-drilling machines or rotary-drilling machines. Deep wells, as defined in this thesis, usually have a minimum depth of about 164 ft (Sonou, 1997).

Enteric pathogens

Harmful gastrointestinal organisms spread by contamination of food or water, mainly of animal origin and among people who are carriers.

E. coli (*Escherichia coli)*

Aspecies of bacteria usually found endemically in the lower intestines of animals.

Epidemic

A prevalence of disease affecting many persons adversely at the same time.

Groundwater

Water located beneath the ground surface beneath the water table or potentiometric surface in soil pore spaces and in the fractures of rock formations.

Gastrointestinal

Pertaining to the stomach and intestines of humans or animals.

Latrines

Trenched toilets dug on the ground, generally about 4ft to 5ft deep. Used for human defecation and urination.

Lagosian

A coined word used for people that live in Lagos State, Nigeria.

Potable water

Water of high quality that is safe to drink without harmful effect.

Percolate

Water passing through porous or fractured substance or area.

Precipitation

Process by which water condenses from the atmosphere and falls by gravity to the Earth's surface.

Primacy

The primary enforcement responsibility for public water systems vested in the states by the federal government.

Permeability

Property of a porous material describing the relative ease through which water can pass through it.

Residential wells

Domestic water wells located near a residence in or near small community.

Refereed journals

These are journals that only publish articles that have passed through a peer review process. The review process helps ensure that the published articles reflect solid scholarship in a field.

Shallow Wells

Holes in the ground that are dug by use of shovels or jackhammers or drilled using a drill machine .These wells in Nigeria typically range in depth between 30ft-50ft.

Septic Tank

A septic tank is a buried, watertight container typically made of concrete, fiberglass, or polyethylene. It holds wastewater long enough to allow solids to settle out (USGS, Circular 1139).

Vadose Zone

This is a portion of the earth between the top of the ground surface and the water table (WHO, 2004).

Water Abstraction

The process of taking water from any source, either temporarily or permanently.

Chapter One

INTRODUCTION

According to the World Health Organization (WHO, 2006), ninety-seven percent (97%) of global fresh water comes from groundwater, which is an important source of drinking water for many regions of the world (Schmoll, O., Howard, G., Chilton, J., & Chorus, I., 2006). Residential wells, which have existed for many years, are constructed to abstract groundwater, or remove it from soil or rock. In many developing countries, such as Nigeria, the majority of residences rely on groundwater to supplement treated water from the city's water treatment facilities. Much of this latter water is unreliable in quantity and of questionable quality (Federal Republic of Nigeria, 2000).

In rural and urban areas of Nigeria, dependence on groundwater is growing as population increases and also the quality of municipal treated water is becoming questionable. This is due in part to contamination in municipal drinking water, which is often compromised because of old and leaking distribution pipes. By contrast, groundwater in most areas in Nigeria for many years has been considered relatively pure with little or no contamination, and it generally requires no further treatment. This is the case because few instances of heavy industry exist in most areas, and most of the groundwater is well protected by layers of soil and sediment. As rainwater infiltrates through the soil and percolates into aquifers, the soil and sediment remove most particles and pathogens and, to some extent, toxic chemical constituents. This makes Nigerian groundwater in general a

relatively safe drinking water source. Another advantage of groundwater in Nigeria is that, in most places, the water table tends to be relatively shallow, so it is convenient to abstract the groundwater through shallow wells, usually constructed close to residential buildings.

The surface water supply in Lagos State is delivered by Lagos State Water Corporation (LSWC). The corporation has a potable water capacity of 160 million gallons per day supplying 29 zones covering about 3,577 square kilometers with a population of 15 million as of 2000. With projected population expected to grow to be around 23.2 million by 2025, the LSWC believes that demand for potable water will increase from its current 200 million gallon per day (MGD) to about 1,200 MGD by 2025 (Hall, 2006).

In order to meet demand, owners of most residential buildings in Lagos construct shallow to deep wells to withdraw groundwater as a supplement for an unreliable and an inadequately treated surface water supply. When these wells are constructed, they are typically located close to septic tanks, latrines or garbage disposal areas resulting in possible groundwater contamination.

With the increase in construction of shallow wells in urban and rural areas of Nigeria, there is a need to set up a program to monitor the safety of shallow groundwater sources. According to the World Health Organization (WHO) guidelines for Drinking Water Quality, 3rd Edition (WHO, 2004), communities need to develop a Water Safety Plan (WSP) regardless of the water source. The guidelines define the Water Safety Plan as “The most effective means of

consistently ensuring the safety of a drinking water supply through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in water supply from catchments to consumer."

The WSP provides necessary processes to continuously improve a water supply system regardless of its size and structure. It allows for intervention in controlling possible sources of contamination by providing various control measures and systems for monitoring these measures. With Lagos State following the WSP, timely corrective actions can be made.

Understanding the Major Issues

The population of Lagos State is projected to increase to approximately 23.2 million by 2025 (Hall, 2006). This will make Lagos one of the ten most populous states in the world. One of the biggest issues in Lagos State is scarcity of essential services such as electricity and potable water. About 58% of water consumed in Lagos State comes from residential wells (Federal Republic of Nigeria, 2000). Wells constructed within the state include shallow wells, deep wells and boreholes. However a majority of residential wells are shallow wells usually constructed close to septic tanks or pit latrines (Federal Republic of Nigeria, 2000).

According to the Nigerian government, under the Water Resources Act of 1993, the state has the right to regulate the construction and operation of boreholes, and to revoke the right to use water if public health has been compromised (Okoye and Priscilla, 2007). Few, if any of these provisions

enforced. There are no programs in place regulating well construction or water quality criteria for wells. A high potential exists for severe epidemics if water quality in countries in Africa is not improved (Okoye and Priscilla, 2007).

According to a study published by Egwari and Aboaba (2002), shallow wells and boreholes in Lagos tend to be more contaminated than deep wells and boreholes, and this contamination tends to be higher during periods of heavy rainfall. *E. Coli* and enteric pathogens are found in most of the shallow wells tested. It is assumed that the high bacteria count in shallow wells could be attributed to the indiscriminate placement of the wells (some of the wells might be only a few feet away from septic tank).

As customary in Nigeria, groundwater on private land is considered to belong to the land owner (Kuruk, 2004). This means there is no limit to the amount of water that can be withdrawn from the aquifer on that land. In some cases, landowners withdraw more groundwater than what they need, and they sell the excess water to the public. With the increase in inflation, economic concerns and the paucity of high-quality drinkable water from the Lagos State Water Corporation (LSWC) water treatment plants, demand for clean water is high, and the majority of landowners now sell well water.

Statement of the Problem

With increasing reliance on groundwater, a need exists to regulate well-water production and quality of water pulled from the aquifer. Most literature reviewed for this project discusses the extent of damage done to groundwater in

Lagos State in terms of cross contamination and excessive water withdrawal, but none of the literature comes up with specific plans or programs to manage wells and groundwater in residential buildings in Lagos Nigeria.

Scope of Work

The goal of this thesis was in part to develop a plan for a monitoring program for residential wells in Lagos State Metropolitan Area (LSMA).

- The program focuses on:
    1. Developing solutions to problems related to how owners can maintain reasonably good water quality
    2. Identifying how government can play a role in implementing well-construction and water-quality requirements.
    3. Educating citizens about the need for monitoring of residential wells used to abstract groundwater and the importance of well site placement.

Objectives

The groundwater monitoring plan along with the other research conducted in this study will provide detailed information and background for the successful development of a monitoring and maintenance program for residential well use in Lagos State, Nigeria.

Moreover the project includes but not limited to some of the areas below:

- Collect information on the extent of the dependence on drinking water from residential wells;

- Identify potential water-quality hazards and the hazardous environment around some of the wells in Lagos State;
- Conduct a literature review on possible source of groundwater contamination;
- Discuss the role of Federal and State laws and regulations and Lagos State Water Corporation (LSWC) on water quality and water management;
- Develop a plan for a monitoring program for residential wells in Lagos.

Limitations

The project focused on most of the highly dense population sections of Lagos State. Also since most of the buildings in the study area already have existing wells, less opportunity existed to evaluate newly constructed residential wells. Questionnaires or surveys were developed during the course of the project to determine the extent to which people of Lagos State would be willing to embrace a residential well monitoring program. This thesis provides suggestions on possible cost of water analysis; however, it will not address the cost related to implementation of this program. No analytical test was performed on groundwater from the surveyed area for this project. The intent of this project is to provide a road map on monitoring and maintenance of residential wells used for groundwater abstraction. The focus of this thesis was mainly on groundwater,

occasionally surface water characteristics were mentioned when source of water contamination are compared.

Assumptions

Most of the references and data used for this project came from refereed journal articles and scientific papers from international agencies such as WHO and UNICEF. There is a possibility that some of the groundwater characteristics from surrounding areas near Lagos State may be used to infer expected conditions.

Chapter Two

LITERATURE REVIEW

Contaminated water is still one of the major sources of disease transmission in most third world countries. Enteric pathogens are causes in many cases. Most of these pathogens can be easily transferred among children 0-5 years old (Egwari and Aboaba, 2002). Underdeveloped immune systems in this age group can lead to gastrointestinal infections with acute diarrhea, which may result to death if not properly treated. In Nigeria, with the implementation of National Diarrhea Control Program (NDCP) sponsored by UNICEF, the reduction in incidence of acute diarrhea in juveniles is still minimal. This can be potentially attributed in part to unhealthy conditions of water available to children in both rural and urban areas of Lagos State. Most of the available source water is groundwater abstracted by residential shallow wells typically located close to septic tanks and pit latrines.

Bacteriological Quality of Domestic Water Supplies

Egwari and Aboaba (2002) show the extent of contamination of supposedly treated drinking water in the distribution system in Lagos due to conditions attributed to low residual chlorine and leaks in pipes in most parts of the distribution system. The research also shows that shallow wells are more contaminated than deep wells, and that contamination is statistically higher during periods of heavy rainfall. *E. coli* and enteric pathogens are found in most of the shallow wells. It is concluded that the high bacteria counts in shallow wells could

be attributed to the indiscriminate placement of the wells (some wells might be only few feet from septic tanks). Table 1 shows an extracted table from Egwari and Aboaba (2002) showing seasonal influence on bacteriological quality in boreholes and shallow wells.

Table 1. Bacteriological Quality of Borehole and Well Water

Table 3 - Seasonal influence on the bacteriological quality of borehole and well waters.

Water type	Sampling		Dry Months		Wet Months	
	Number Studied (samples) positive for coliform	Sample* size	Number of borehole or well (samples) positive for coliform	Mean coliform counts/100ml	Number of borehole or well	Mean coliform counts/100ml
Borehole	20	240	0 (0)	0	2 (24)	8
Well water						
Class Ai	5	60	0 (0)	0	0 (0)	0
Class Aii	5	60	0 (0)	0	1 (12)	20
Class Bi	5	60	1 (12)	10	1 (12)	18
Class Bii	5	60	1 (12)	15	2 (24)	36
Class Ci	5	60	2 (24)	48	3 (48)	64
Class Cii	5	60	3 (36)	52	5 (60)	72

*Represents the number of samples collected per season.
i = Deep well; ii = Shallow wells.

Seasonal Influence on Bacteriological Quality of Borehole and Well Water

Risk to Groundwater Supplies from On-Site Sanitation

UNICEF (1999) addresses the impact of septic tanks and other sanitation systems located close to wells. The study focuses on two countries, Bangladesh (Asia) and Uganda (Africa), to determine the extent to which on-site sanitation activity or the lack there of impacts groundwater contamination. Sanitary surveys

of 100 boreholes carried out in Bangladesh found 95% of these boles to be within 15 meters (49ft) of pit latrines. The results indicate significant levels of microbial contamination; however, the numbers of fecal coliform positives are shown to be generally low. The study concludes that with boreholes and existing wells, groundwater contamination in the area might not be primarily due to proximity of pit latrines or septic tanks, but rather to direct routes of contamination such as broken well headworks or polluted water used for pump priming.

In Uganda, groundwater from hand-pumped boreholes and protected springs was sampled. Data collected shows high levels of nitrate and chloride at the hand-pumped boreholes, which suggest that a likely source is pit latrines. However, the result also shows a general absence of faecal indicator bacteria. This is suggested to be due to the long travel time from the pit latrine to the borehole screen. In the spring water area, high levels of bacteria as well as nitrate were observed. It is suggested that the pathway for the feacal contamination might be due to damaged or poorly constructed spring protection works and the high nitrate from on-site sanitation. The study also shows that on-site sanitation contributes to chemical pollution of shallow wells, especially that from nitrate and chlorides.

Water Supply and Sanitation Interim

A study was conducted in 1997 by the Nigeria Federal Ministry of Water Resources (FMWR) on water and sanitation in 37 small towns in Nigeria in preparation for a World Bank backed national Small Towns Water Supply and Sanitation Program (STWSSP). The study shows that only about 5% of the

population had access to water from boreholes that are protected from possible source contamination, while 13% used water from community wells. The small towns have been largely ignored by the government resulting in an increase in private enterprise selling of water through the use of tankers and hand-carried water containers (Federal Republic of Nigeria, 2000). Table 2 shows percentages of water usage from different water sources.

Table 2. Water Use Patterns by Available Water Sources

Water Use Patterns by Available Water Sources	
Rivers/Streams	27.4%
Yard Well	24.5%
Community Well	13.4%
Water Seller	8.6%
Springs	6.6%
Borehole	5.1%
Water Tanker	4.0%
Yard/Shared Street Pipe	0.3%
Public Street Pipe	0.1%
Other	10.0%

Source: Stoveland and Bassey, (2000)

Status of Sanitation Facilities

In Table 3 from the same 1997 survey, shows that about 74.6% of the people still use traditional pit latrines. The survey suggests that the situation might actually be worse than predicted since most of the disposal facilities around the country are non-functional.

Table 3. Disposal Facility in Household

Traditional Pit Latrine	74.6%
No Facility	14.7%
VIP Pit Latrine	0.2%
Flush Toilet	4.9%
Public Toilet	0.4%
Toilet with Septic Tank	0.7%
Other	4.5%

Source: Stoveland and Bassey, (2000)

Groundwater

Groundwater is described as water stored in the subsurface of the earth between grains of sand or sediment or in fractures in rocks. The presence of groundwater is due to movement of water from the surface to the subsurface. Precipitation in the form of rainwater infiltrates the soil and percolates through sediments and rocks. The amount of water that percolates into the ground per unit time per unit area depends to some extent on the porosity but more importantly, on the permeability of the ground. The amount of space available for water

storage within the subsurface divided by the total subsurface volume is referred to as the porosity of that site. The permeability is a measure of the ability of the rock, soil or sand to allow water to pass through. Areas in which surface layers of soil are clays usually have less water infiltration and percolation in comparison to that in areas with loosely bound soil (e.g., tropical areas in Nigeria). Lagos State is located in a tropical area of Nigeria.

Subsurface Classification

Areas of the subsurface in which most of the ground water is stored are classified in different zones (see Figure1). The storage zone above the water table consists of air and water in spaces between soil or sediment grains or area of intact rock. This zone is called the unsaturated zone or the vadose zone. Some water in the shallow vadose zone may be readily available for plant-root absorption, for irrigation water removal, and, possibly, in certain areas where specialized shallow wells or boreholes are constructed, for potable water abstraction for drinking. Below the water table is the saturated zone, where most groundwater is stored. The depth of the water table depends on several factors such as rates of recharge and discharge, the season, the topography, and local geology of the area. Groundwater is always moving by force of gravity from an area where groundwater is recharged to an area where it is discharged. The rate of movement, however, depends on available higher-permeability zones.

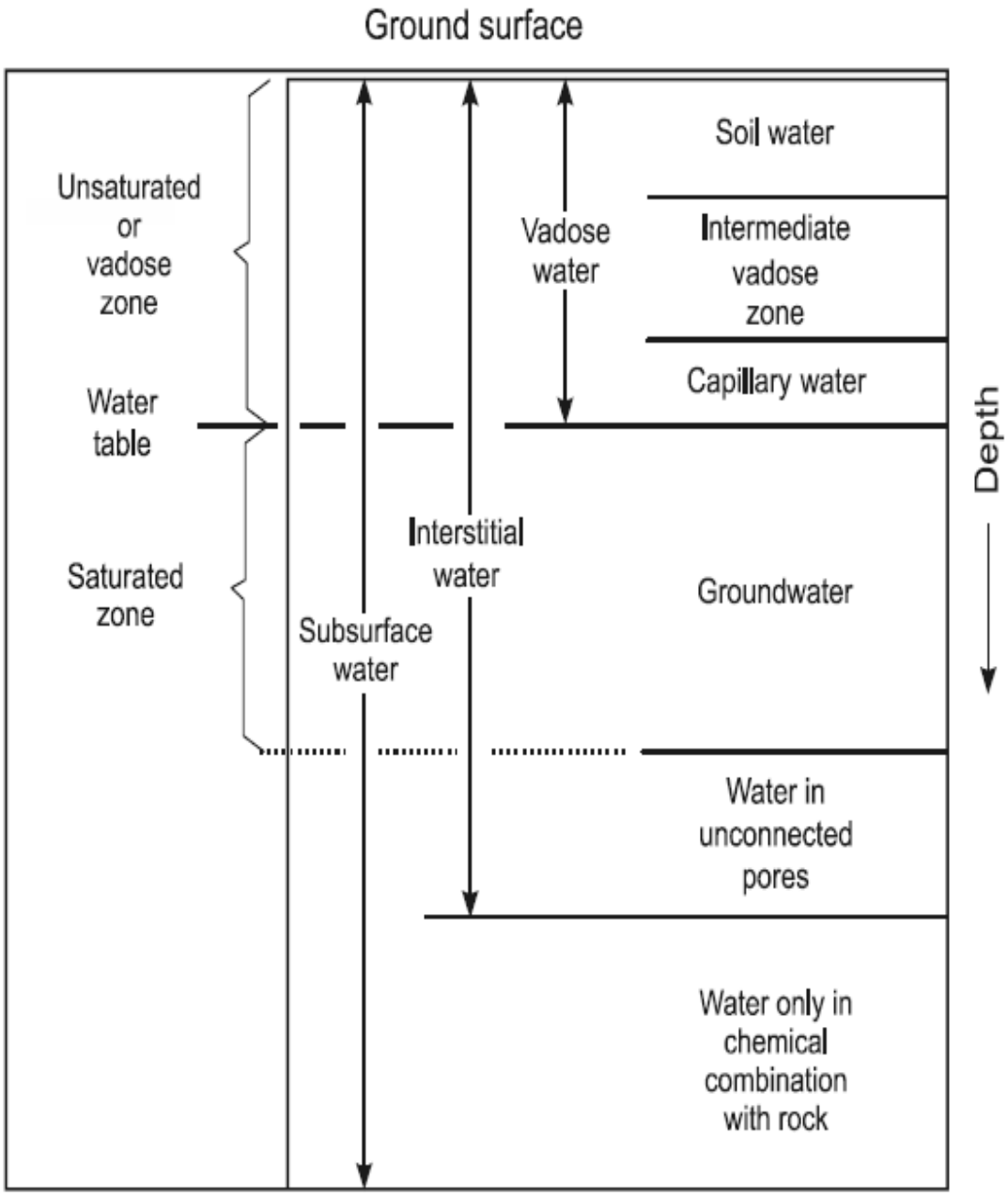


Figure 1. Groundwater Subsurface Classification
Source: World Health Organization (2004)

Hydrologic Cycle

The hydrologic cycle is a continuous cycle of water from land and sea to the atmosphere and back again to the land and sea. Water from the sea may evaporate into the atmosphere. As the amount of water vapor in the atmosphere increases and as this vapor moves over the land, a saturation point maybe reached where water vapor starts precipitating as rain or snow onto land. The precipitation may largely run off into streams and rivers. Some of the water that falls on land can also move into soil and rock where it percolates into the subsurface water table. Because of the movement of ground water due to the presence of permeable zones in the subsurface, water might eventually find its way to streams and lakes for further evaporation to the atmosphere (USGS, 2009).

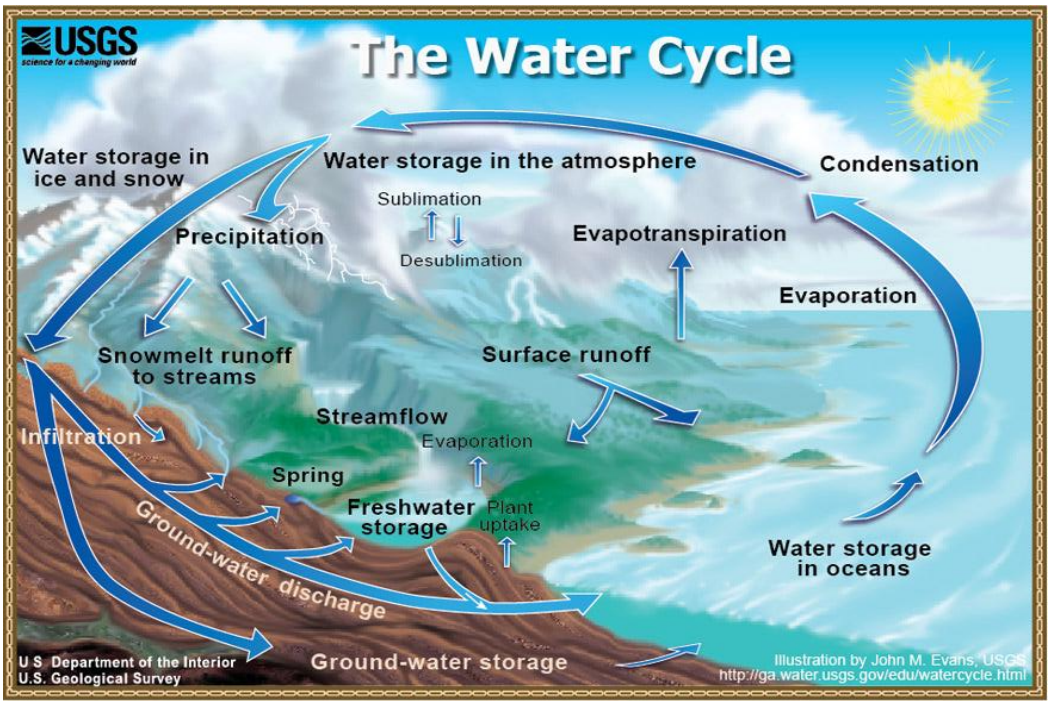
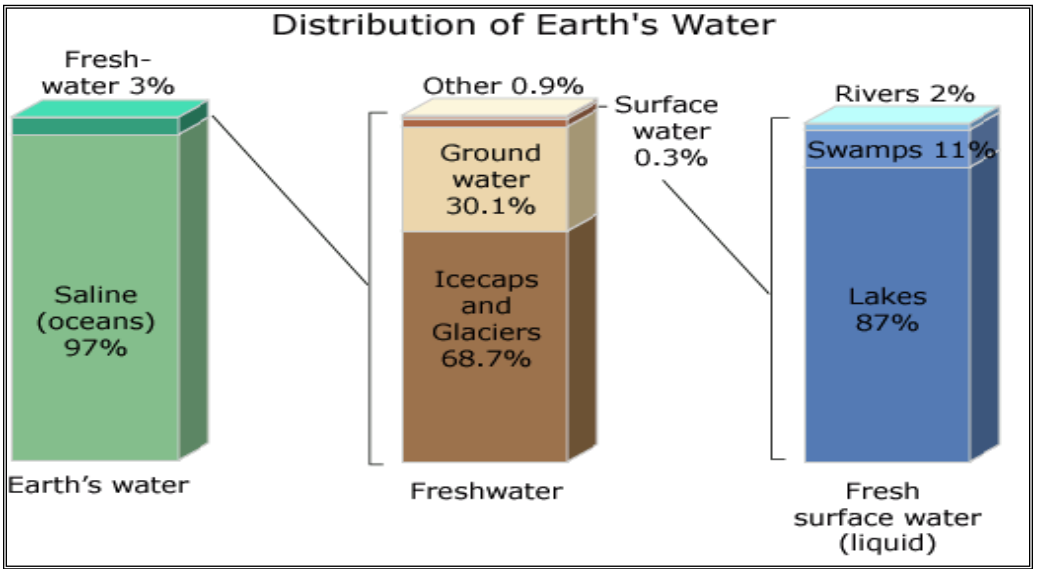


Figure 2. Hydrologic Cycle
Courtesy U.S. Geological Survey (2009)

Distribution of Earth Water

Figure 3 shows that fresh water represents about 3% of total water on earth while 97% of water is in oceans. Of this 3% fresh water, about 30% is groundwater. Surface water from lakes and rivers accounts for only 0.3 % of available fresh water (USGS, 2009).



Source: Gleick, P. H. (1996)
Figure 3. Distribution of Earth's Water

Types of Wells

In Africa, there are different types of abstraction wells depending on whether the area is rural or urban and on a family's economic status. Common wells are classified as shallow wells and deep wells.

Shallow Wells

Shallow wells are relatively shallow holes in the ground that are dug by use of shovels or jackhammers or drilled using a drill machine. In Nigeria, hand-dug wells are very common. The construction depth of these wells typically ranges between 30ft-50ft. The digging usually involves 4 to 8 people who rotate their job functions as they dig deeper. As the laborers dig deeper, the oxygen level inside the hole gets low resulting in discomfort that leads the lead laborer (the digger) frequently switching position with the person at the top that pulls out buckets loaded with loose soil. This digging can take from 4 to 8 weeks depending on the number of laborers digging a well.

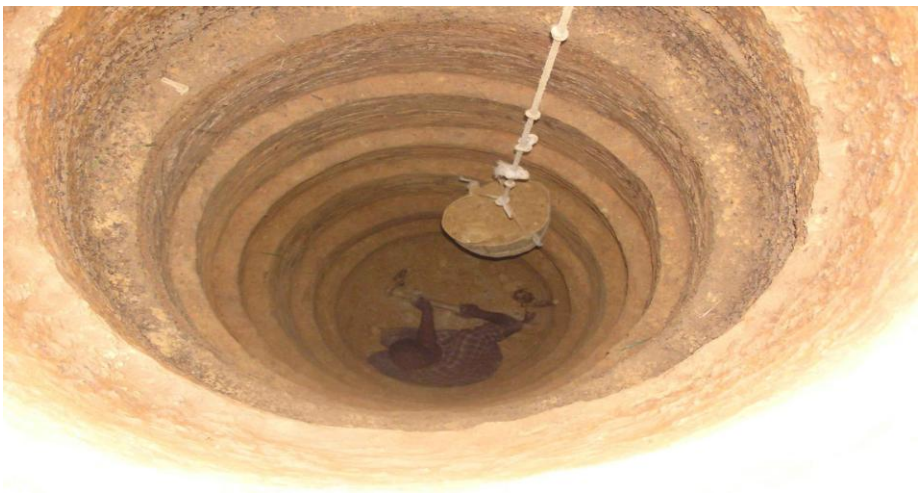


Figure 4:Well Construction in Africa
Source: Cross Based Ministry. http://www.crossbasedministries.org/

It is very interesting to note observations made on the demographics and residential locations of people that are usually involved in the "dug well" business in Nigeria. It has been the researcher's experience while living in Lagos for more than fifteen years that most laborers from the northern part of Nigeria, which is a desert area, can usually dig faster than laborers from the west, which is a tropical area.

Disadvantages of hand-dug wells include the fact that it takes a long time to get to the water table. Sometimes laborers walk away from the job if they cannot reach the water table on time, leaving the area with a big hole. During the course of the digging, there is a high potential for a laborer to die due to insufficient oxygen levels in the dug well (Schotanus, 2005). Because of the large diameters of these dug wells, the presence of laborers in the wells, and the length of time spent in construction, there is a high possibility of contamination. That is why the use of a light cable percussion drilling machine run by a 10-HP pump and the drilling of narrow wells is encouraged. Even though this is more expensive method than using hand-drilled wells, it is much safer and faster for well completion.

Figure 5. Typical Well Drilling in West Africa
Percussion drilling equipment (on left) and hand-dug well (on right)

Deep Wells

Deep wells commence with the construction of boreholes. Boreholes are constructed by a gradual excavation of the soil through the process of mechanical drilling. The purpose of creating a borehole and a well is water abstraction. Tools used for drilling include cable-drilling machines or rotary-drilling machines. Drilled deep wells usually require casing and a screen to prevent inflow of sediment and possible collapse of the hole. Well construction depth varies depending on the geographical location (North Carolina Water Quality, 2008). Deep wells in Nigeria usually have a minimum depth of about 50meters (164ft). Once a well is completed, a pump is inserted close to the bottom of the well to abstract the groundwater.

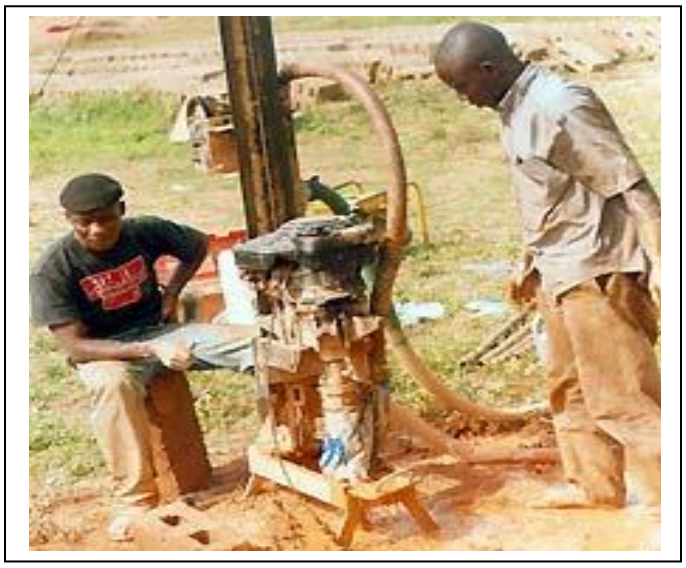


Figure 6. New Borehole Drilling in Nigeria

Policy and Legal System for Groundwater Protection in Nigeria

In Nigeria, the Federal, State and local levels of government are involved in the administration, development and management of water resources. At the Federal level, the Ministry of Water Resources is responsible for River Basin Development (RBD). At the State level, water resources are managed by various ministries, such as Natural Resources, Works and Public Utilities and Agriculture (Okoye and Priscilla, 2007).

The constitution of the Federal Republic of Nigeria (FRN) provides that water from various sources that will impact more than one state should be under the exclusive legislative list. It also empowers the state to create policies that will protect and improve water resources as they relate to water supplies, irrigation, canals, drainage, embankments and water storage (Okoye and Priscilla, 2007). There are two important federal laws that provide safe guards for water management.

The Nigeria Water Resources Act, 1993

The Nigeria Water Resources Act of 1993 provides for the control of water ways and groundwater by the Federal government of Nigeria. It empowers the Federal ministry of Water Resources to regulate surface water and groundwater use. It allows the ministry to grant licenses for groundwater abstraction and construction of wells. The Ministry Water Resources is given the power to provide primacy to the state in terms of water regulation and

management. The Act also grants the citizens the right to use water from different sources for domestic, irrigation and livestock needs (Okoye and Priscilla, 2007).

River Basin Development Authorities Act, 1990

The River Basin Development Authorities Act of 1990 allows the River Basin Development Authorities (RBDA) to guide the development of surface and groundwater resources by providing irrigation infrastructure, flood control, and erosion and watershed management. The RBDA are given the power to construct, operate and maintain dams, wells, boreholes and drainage systems. The act also charges the RBDA to come up with comprehensive water-resources master plans.

In Lagos, the availability of safe, drinkable water from water treatment plants depends on the Lagos State Water Corporation. The local government focus is on rural water supplies and sanitation. However, overseeing national policies, laws, management and regulations is the function of the Federal Ministry of Water Resources (FMWR). The FMWR thus has the overall responsibility for policy advice and formulation, data collection, monitoring and planning, management and coordination of water resources.

According to Okoye and Priscilla, (2007), the Federal Ministry of Water Resources has the following functions:

1. To formulate and implement a Water Resources Master Plan for Integrated Water Resources development, including inter-basin water transfers.
2. To develop and support irrigated agriculture and reduce the nation's dependence on rain-fed agriculture

3. To promote and sustain national food security by minimizing unexpected and undesirable shortfalls in domestic food production and agro-based raw materials caused by the vagaries of weather
4. To collect, store, analyze and disseminate hydro-meteorological and hydrological data
5. To support, monitor and evaluate the programs and performance of the River Basin Development Authorities and the National Water Resources Institute
6. To explore and develop ground water resources
7. To formulate and review from time to time the National Water Legislation
8. To coordinate the development and utilization of water resources for irrigation and water supply
9. To liaise with all relevant national and international agencies on all matters relating to water resources development
10. To support studies and research on the nation's ground and surface water resources potentials
11. To undertake hydrological and hydro-geological investigations
12. To formulate and implement national irrigation policy that is consistent with and complementary to the national agricultural policy
13. To formulate and implement programs and policies towards surface water storage schemes
14. To develop guiding principles for dam construction nation-wide, and
15. To develop anti-desertification programs.

In order for the ministry to carry out its function, the ministry is structured into seven departments of which the department of Water Supply and Quality Control (WSQC) included. The WSQC department is charged with planning,

monitoring, coordination of water supply issues, water quality, and control of treated surface water, ground water and the establishment of water-quality laboratories (Okoye and Priscilla, 2007).

Water Resources in Nigeria

It is estimated that the surface-water resources capacity in Nigeria is about 267.3 billion m^3/yr, while the groundwater resources are estimated to be 51.9 billion m^3/ yr (Okoye and Priscilla, 2007). Looking at Table 4 below, it appears there is no problem in the availability of water; however, according to Okoye and Priscilla, (2007), a large percentage of Nigeria's population does not currently have ready access to potable water. While the table reflects huge potential groundwater resources, these resources are costly to access and not accessible to many in Nigeria today.

Table 4. Distribution of Groundwater Resources in Nigeria

Hydrological Area (HA)	**Groundwater Resources (m^3)**	**Present**		**Towards Year 2020**	
		Demand (m^3)	**Water Use Rate (%)**	**Demand (m^3)**	**Water Use Rate (%)**
North West- I	4,340	20	0.4	290	7
Central West- II	8,180	20	0.2	260	3
Central East- III	6,990	15	0.2	300	4
IV	4,390	5	0.1	180	4
South East- V	7,150	30	0.4	730	10
South West- VI	9,020	70	0.8	830	9
VII	6,280	40	0.7	710	12
North East- VIII	5,580	60	1.0	620	11
TOTAL	51,930	260	0.5	3,920	8

Figure 7 shows a map of Nigeria with its major rivers. Although there are many surface-water bodies, many people in Nigeria do not have ready access to clean, filtered water from these rivers.

Figure 7. Map of Nigeria Showing Major Rivers
(shown in blue lines)

Chapter 3

METHODOLOGY

The methodology of this project is partially based on Section 4 of the World Health Organization (WHO) publication titled, "**Protecting Groundwater for Health**" (2006) and **Guideline to Drinking Water Quality** (GDWQ), third edition, volume one (WHO 2004). The development of GDWQ came from various international conferences that recognize the important need for access to safe drinking water to be part of an international agenda.

The current GDWQ explains necessary steps in ensuring drinking water safety. It includes minimum procedure requirements, specific guideline values and discussion of how these requirements are intended to be used. As mentioned in Chapter one, one goal of this thesis is to develop a monitoring program for residential wells used for groundwater abstraction in Lagos State, Nigeria. This program is developed as follows in this chapter.

Assessing Community Awareness of Water Quality Issues

In order to know if a groundwater monitoring program for residential wells is necessary; this project used a questionnaire to identify the level of awareness of water quality issues in the community in regard to groundwater abstraction. This information was used to determine if the people of the communities understand sources of groundwater and the impact of hazardous environments on the quality of the groundwater. Also, the survey evaluated if the people believe that the quality of groundwater can have a direct impact on the

health of the community. The questionnaire identified the expectation of the communities in regards to water quality and whether they think implementation of a monitoring and maintenance program for residential wells would provide the benefits they need.

A college student in Nigeria was recruited to conduct the survey at the selected local government areas. The student approached various residential homes within the local government areas and requested if they were willing to participate in a survey. A cover letter approved by the Arizona State University (ASU) Institutional Review Board (IRB) was given to potential participant explaining the purpose of the survey. Once the participant agreed to be interviewed, the recruited student asked questions from the questionnaire and recorded the response from the participant on the questionnaire form. On the next three pages are the templates of the cover letter and questionnaire that were used to acquire necessary information.

COVER LETTER

Development of a Monitoring and Maintenance Program for Residential Wells Used for Groundwater Abstraction in Lagos State, Nigeria

Date: _____

Dear _____

I am a graduate student under the direction of Assistant Professor Dr. Edwards in the Department of Technology Management at Arizona State University.

I am conducting a research study to develop a monitoring and maintenance program for residential wells used for groundwater usage in Lagos State, Nigeria. I am inviting your participation, which will involve identifying the level of awareness of water quality issues in the community in regard to groundwater usage. I also will like to know the expectation of your community on the level of water quality they would like to see. The survey is expected to take about 30 minutes.

Your participation in this study is voluntary. You can skip questions if you wish. If you choose not to participate or to withdraw from the study at any time, there will be no penalty. Your participation will help us develop an effective well monitoring plan program that will improve water quality within the community. There are no foreseeable risks or discomforts to your participation. You must be 18 years or older to be part of this study.

Your responses will be anonymous. The results of this study may be used in thesis, reports, presentations, or publications but your name will not be known or used in any of these. Results will only be shared in the aggregate form.

If you have any questions concerning the research study, please contact the research team Binga Talabi at 1-480-570-4770.
If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788. Return of the questionnaire will be considered your consent to participate.

Sincerely,

Omogbemiga (Binga) Talabi

Figure 8. Cover Letter

.

Questionnaire (Survey) on Monitoring and Maintenance Program for Residential Wells in Lagos Nigeria

Date : _____

Gender: **Male** ☐ **Female** ☐

Occupation _____

Rent ☐ Landlord (owner) ☐

Local Government Area: _____

Number of Wells

Boreholes ☐ Dug wells (Konga) ☐

Location of wells

- Front of the Building ☐
- Back of the building ☐
- Side of the building (specify North, South, West or East) ☐

Location of Septic Tanks

- Front of the Building ☐
- Back of the building ☐
- Side of the building (specify North, South, West or East) ☐

What is the distance between wells and septic tanks (circle appropriate

distance)
< 10 meters
>10 meters but < 20 meters
> 20 meters

Is the well(s) entrance constructed with (CONCRETE)/ (NO CONCRETE)

Does the property have pit Latrines (**shalanga**)? (YES)/ (NO)

How often do you clean (sanitize) the bucket and ropes used for drawing water?

Do you believe the bucket and ropes used for drawing water can contaminate wells? (YES)/ (NO)

Do you believe there is a need to monitor your wells (i.e., laboratory and field testing of your well water for contaminants)?

Would you allow your well(s) to be tested if it will prevent sickness?

Do you know of ways in which groundwater in your area can be easily contaminated?

Thanks for answering these questions

Figure 9. Questionnaire Form

The survey was distributed in eight local government areas within the metropolitan area in Lagos State, with the intent of getting enough information needed to identify possible sources of contamination and to understand the communities' knowledge in regard to groundwater quality and why it is important to have a water- quality monitoring program. The survey also examined locations of the wells in relation to the location of septic tanks. It further identified the types of wells used to draw groundwater from the earth.

Figure 10. Map of Lagos State Metropolitan Area
Courtesy: New World Encyclopedia.
http://www.newworldencyclopedia.org/entry/Image:LGA_Lagos.png

The local governments in which surveys were conducted in this study are Oshodi-Isolo, Kosofe, Shomolu, Mushin, Bariga, Lagos mainland, Lagos Island and Alimoso (These are shown in Figure 10). The survey was conducted at random in order not to pre-select certain groups of people within the local government area. This means participants were picked regardless of whether they rent or own their homes. The survey was conducted from August 21st 2009 through August 28th 2009. The data was collected from people from ages 18years and older with different educational backgrounds (see Appendix A).

Groundwater Monitoring Plan

A plan was developed for a monitoring program for residential wells in the Lagos State metropolitan area. The purpose of the plan was to help to mitigate the possibility of groundwater contamination that might be of health risk to the communities. A step-by-step approach was used to identify necessary components of the plan.

Identified Stakeholders

The first task identified stakeholders needed for the successful implementation of the program. These were individuals, state governments, local governments and institutions within the study area. The stakeholders were identified by the following process:

1. Identify the geographical area that would be affected by the implementation of this program;

2. Choose a geographical area; the area selected was Lagos State Metropolitan area;
3. For this area, make a list of local governments and local government officials, health agencies, local universities and laboratories that might be able to provide water quality and health data, as well as a list of aid agencies working on water supplies in the area;
4. In order to effectively implement this program, there is a need to separate the monitoring of groundwater abstraction program from government oversight. The government, however, is to be responsible for enforcement of necessary procedures to mitigate identified water quality problems.

Identified Potential Hazards and Hazardous Environments

In establishing a meaningful plan for a groundwater monitoring program, a systematic approach was used to identify potential hazards and hazardous environments that might influence the quality of groundwater around household wells. Guidelines were developed to better articulate the proper approach in identifying potential hazards. For this project, potential source of hazards were estimated to be the following:

1. Biological and chemical hazards that might be encountered during water abstraction from the wells;
2. Wells located close to sanitary-waste facilities;
3. Wells located close to industrial companies;
4. Improperly maintained groundwater abstraction tools;

5. Contamination arising due to poor construction or damage to the wells;
6. Contamination introduced by buckets used for collecting well water;
7. Contaminated surface water finding its way into nearby boreholes;
8. Leaching of microbial contaminants into aquifer.

Based on the hazards identified, various methods were determined to collect relevant data that would be of use in identifying potential hazards and other hazardous environments and to provide a robust monitoring plan. Templates were created in Chapter four to provide staff in the field with necessary information needed for effective monitoring. The templates provided specific questions that needed to be asked in order to effectively implement the program. Some of the templates are described below:

Initial Site Characterization for Residential Wells in Lagos Nigeria

- This template was developed to identify the site location, number of wells available within the site, location of the wells, and locations of septic tanks and pit latrines. The template was also developed to describe collection of water samples to ascertain physical characteristics of the water from the well such as color, cloudiness, smell, stains and scaling.

Typical Water Quality Concerns

- This template identified water quality concerns for staff in the field to investigate. These include microbiological concerns

(pathogens), nutrients, algae and algal toxins, metals, pesticides, herbicides, insecticides, industrial chemicals, fuels, organic compounds and aesthetic parameters.

- The template also provided possible sources of contamination that may result in water quality concerns and impacts on consumers

Activities and Practices that Pose Risks to Water Quality

- This template identified some of the activities or practices that might be encountered during the course of initial site characterization. These might include inadequate construction of wells, leaching of metals from natural rocks, underground fuel tank leaks, sewage discharge at or near the well area, and the presence of domesticated animals and animal husbandry around the well site.

Characteristics that Indicate the Presence of Potential Water Quality Problems

- This template identified some of the physical and chemical characteristics of abstracted water and its possible relation to the source of contamination. These characteristics may be the turbidity of the water, color and scaling when the water is used. These characteristics can be identified by sight, taste and smell. A salty taste might indicate salt water intrusion; a bitter taste might indicate presence of metal.

Analytical Guidelines

In order for the monitoring program to be successful, various analytical guidelines were put in place. The monitoring program specified the frequency of groundwater monitoring that would be required in order for homeowners to meet safe drinking water requirements. It was anticipated that biological and chemical sampling and testing would be performed by trained staff hired to implement this program.

Minimum testing requirements were established for the initial monitoring of the wells and explained in chapter four. Tables shown in chapter four were created to show each testing parameter, volume of sample required and implication of these parameters if found present in the sample. Sampling techniques discussed in the next chapter were established in order to reduce possible false negatives or positives during sample analysis.

Community Awareness Plan

Based on the information gathered above, a well-water awareness checklist was developed in chapter four. This was a question and answer template that focused on the need to protect a water source from outside contamination and discussed precautions that need to be taken and the potential health effects that might occur if well water is contaminated. This included storage of daily water abstraction, maintenance of a clean area near the well entrance, ability to identify physical changes in water quality or taste, and ability to perform regular disinfection of well tools and the nearby area.

Chapter Four

RESULTS

A questionnaire or survey shown on Table 8 was distributed to people in Lagos to assess community awareness of the importance of groundwater quality and its impact on individuals and the community at large. The questionnaire also identified the expectation of the communities surveyed regarding the level of water quality that they would like to see and identified if they thought that implementation of a monitoring and maintenance program for residential wells would provide the needed benefits. The questionnaire also addressed the question of whether the communities or home owners would pay for groundwater testing if they believed that, in the long run, the program would provide safe drinkable water that would improve the health of the communities.

As was mentioned in Chapter 3, this assessment was designed to help in determining if the people of the communities surveyed understood the source of their groundwater and the impact of hazardous chemicals on the quality of the groundwater. The survey was also performed to see if they believed that the quality of groundwater could have direct impact on the quality of the health of the community.

Survey and Data Collection

The survey was conducted from August 21st 2009 through August 28th 2009. Eight local governments within Lagos State were surveyed. The local governments are Oshodi-Isolo, Kosofe, Shomolu, Mushin, Bariga, Lagos

mainland, Lagos Island and Alimoso. The survey was conducted at random in order not to pre-select certain groups of people within the local government area. This study involved fifty three participants of whom twenty three were males and thirty were females. The next three pages contain tables that summarize the data collected.

Table 5. Data collected from the Survey

Local Government	**Oshodi/Isolo**	**Kosofe**	**Shomolu**	**Mushin**	**Bariga**	**Lagos Mainland**	**Lagos Island**	**Alimoso**
Gender								
Male (23)	6	1	2	4	2	3	4	1
Female (30)	3	4	2	4	5	6	0	6
Total # of Participants (53)	**9**	**5**	**4**	**8**	**7**	**9**	**4**	**7**
Rent	3	3	3	7	6	4	0	3
Owner	5	2	1	1	1	5	4	4
Boreholes	5	5	3	7	5	5	4	2
Dugwells	5	0	1	2	2	4	1	5
Location of wells								
Front	6	3	1	3	1	3	3	3
Back	3	1	1	4	5	4	0	4
Side	0	1	1	0	1	2	1	
Don't know	0	0	1	1	0	0	0	0
Location of Septic Tank								
Front	1	2	2	6	2	2	1	2
Back	8	3	2	2	5	4	2	4
Side	0	0	0	0	0	3	1	1
Well and Septic same location	4	3	0	4	3	3	2	3
Dist b/w Wells and Septic								
<10 meters	4	2		1	2	4	3	4
>10<20 meters	2	0	1	1	0	0	1	0

Table 5. Data collected from the Survey

Local Government	**Oshodi/Isolo**	**Kosofe**	**Shomolu**	**Mushin**	**Bariga**	**Lagos Mainland**	**Lagos Island**	**Alimoso**
>20meters	1	2	2	3	5	4	0	1
Don't know	1	1	1	3	0	1	0	2
Well Entrance								
Concrete	9	3	3	2	6	7	3	7
No concrete					1			
Pit latrine(shalanga)								
Yes	2	2	0	0	1	1	1	1
No	7	2	4	6	6	8	4	6
How often do you clean (sanitize) the bucket and rope use for drawing water								
Daily	1	4	0	1	1	1	0	1
weekly	3	0	0	0	1	0	0	0
biweekly	1	0	1	0	2	0	0	0
Once a month	0	0	0	0	0	1	1	
Don't know	4	1	3	7	3	7	3	6
Do you believe the Bucket and rope use for drawing water can contaminate the wells								
Yes	6	3	4	7	7	8	3	7
No	3	1	0	1	0	1	1	0

Table 5. Data collected from the Survey

Local Government	Oshodi/Isolo	Kosofe	Shomolu	Mushin	Bariga	Lagos Mainland	Lagos Island	Alimoso
Don't Know	0	1	0	0	0	0	0	0
Do you believe there is a need to monitor your wells								
Yes	9	4	4	3	7	7	4	7
No	0	0	0	1	0	1	0	0
Don't Know	0	1	0	4	0	1	0	0
Would you allow your well be tested if it will prevent sickness								
Yes	9	4	4	3	7	8	3	7
No	0	0	0	0	0	0	1	0
Don't Know		1	0	5		1	0	0
Do you know of ways in which groundwater in your area can be easily contanminated								
Yes	6	0	0	1	2	6	2	2
No	3	4	4	2	3	2	2	3
Don't Know	0	1	0	5	2	1	0	2

Data Evaluation

The participants in this survey are from families who rent or own a home. In Nigeria, the community sense of ownership is very much alive. If a person is still living with a parent, then that person is considered part owner of the family house. More people rent in Mushin and Bariga local governments than in Lagos Mainland and Lagos Island areas. Mushin and Bariga are major trading areas where small businesses sell foods, shoes and clothing, whereas in Lagos Mainland and Lagos Island areas, there are more sophisticated industries such as banks, telecommunications and embassies from different countries. Also, most early settlers in Lagos, the so called "Lagosian," live in Lagos Mainland and Lagos Island. The Oshodi/Isolo local government area is a commercial center for small businesses and home owners. There are more residential homes in Oshodi/Isolo

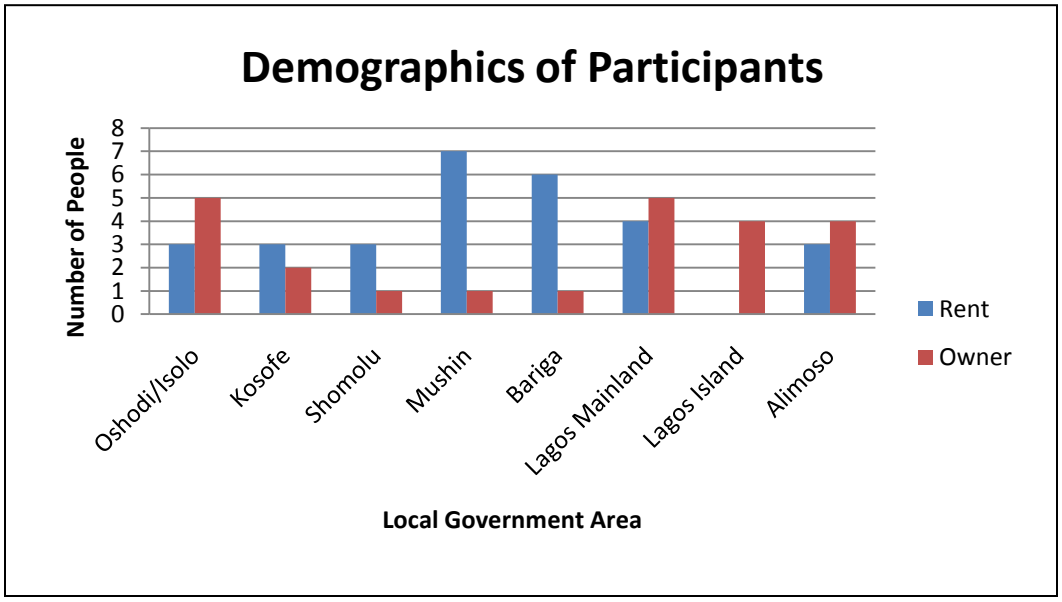


Figure 11. Demographics of Participants

During the study participants were asked about the number of boreholes (deep wells) and or dug wells (shallow wells) in their place of dwelling. In Figure 12, 64% of the total wells from the homes surveyed had boreholes rather than dug wells. In Kosofe local government, 100% of the wells in that area are borehole wells. Other areas with high percentages of borehole wells include Mushin local government with 78% borehole wells and Lagos Island local government with 80% borehole wells. The large number of boreholes constructed can be attributed to increasing population and water demand. Since there is practically no treated surface water delivery by the Lagos State Water Corporation (LSWC) to these houses, most of the residents depend on groundwater. As water demand increases, most wells have to be dug or drilled deeper than what formerly was necessary.

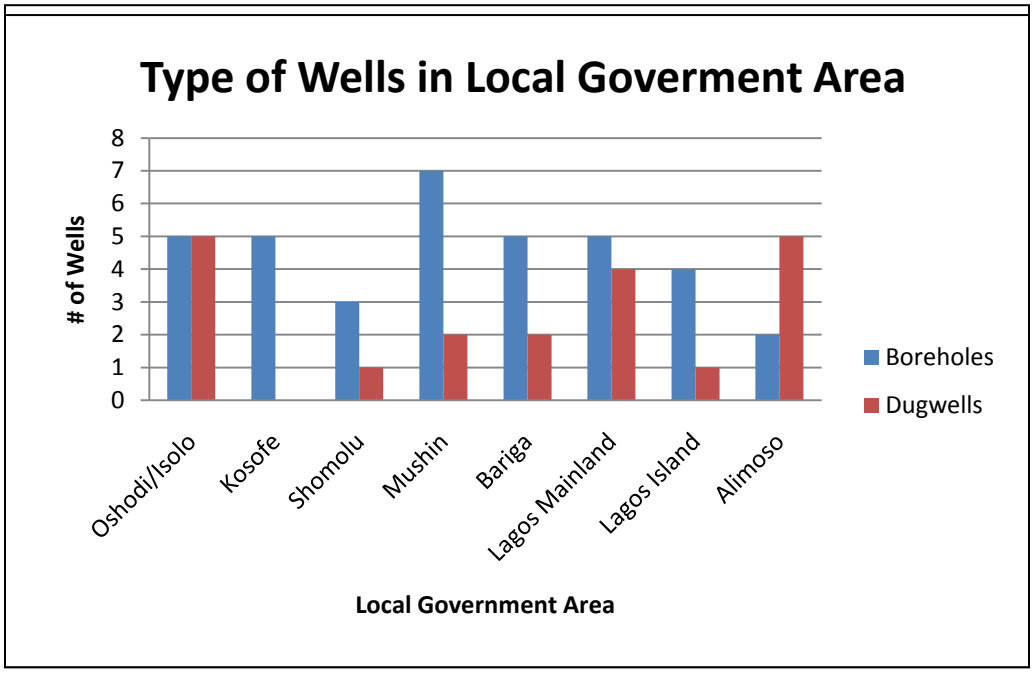


Figure 12. Types of Wells in Local Gov Area

Based on the survey results, all of the houses in this study have septic tanks; most of the houses in Lagos state have some type of septic tanks since there are no municipal wastewater treatment facilities. The location of the tanks usually depends on the lot size and how owners want the house to be positioned. In Figure 13 of the survey, Oshodi/Isolo local government area had 89% of the septic tanks positioned at the back of the house and Mushin local government area had 75% of the septic tanks positioned at the front of the house, while Lagos Mainland had about 33% of the septic tanks positioned at the side of the house. Most of the housing planning does not currently take into consideration the location of septic tanks in relation to wells.

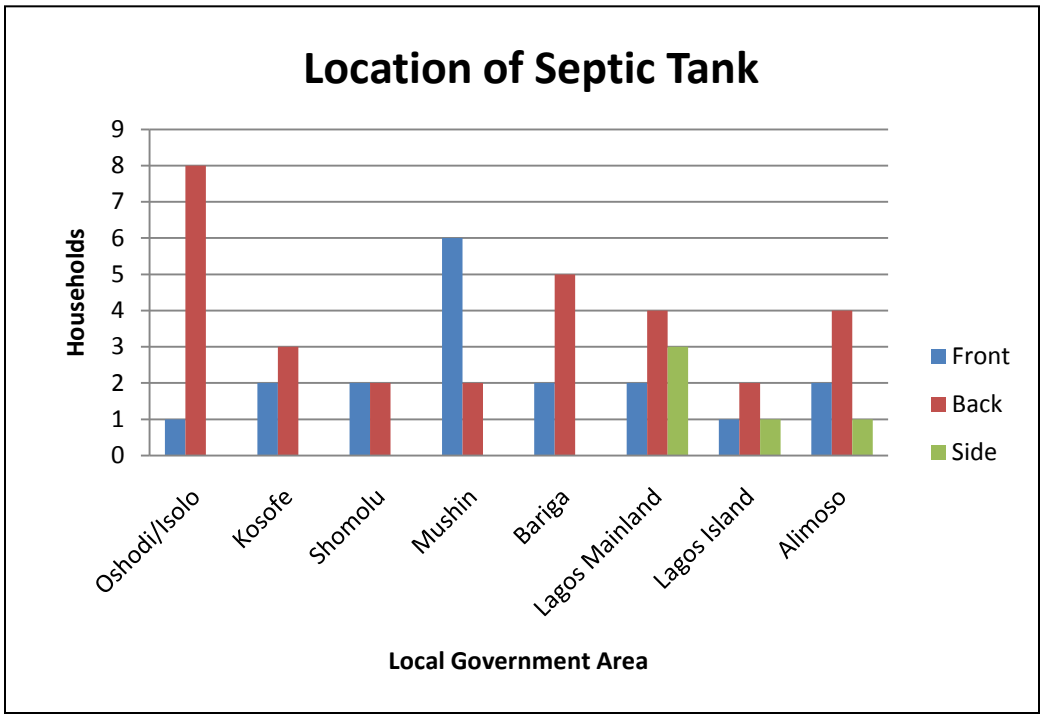


Figure 13. Location of Septic Tank

The survey also looked at households with pit latrines (Shalanga). It should be noted from the survey data, and as shown in Figure 14, about 27% of the household had pit latrines and 73% with regular toilets that feed the septic tank. In Oshodi/Isolo 22% of households have pit latrines while in Lagos Mainland 11% have pit latrines. It is interesting to see that most of the houses in the study used regular toilets rather than pit latrines.

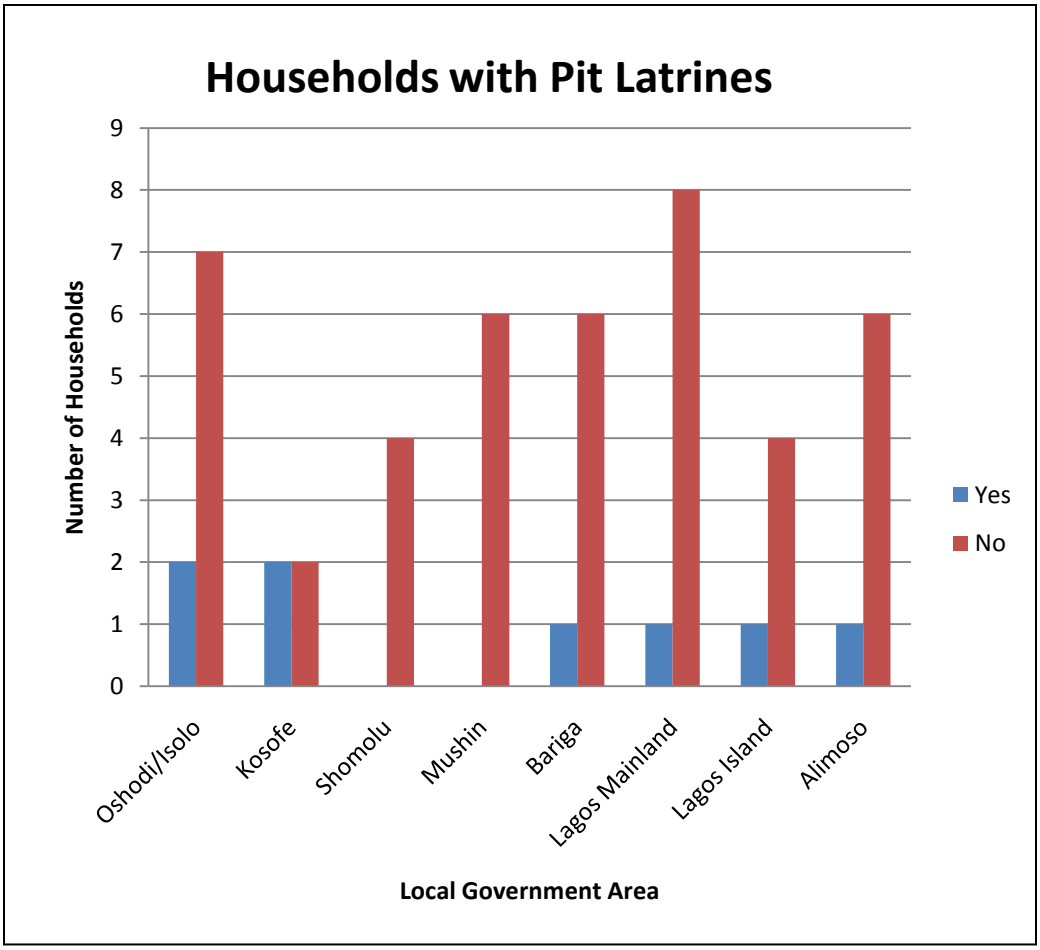


Figure 14. Household with Pit Latrines

The distance between septic tanks and wells was a big concern when it comes to water quality. According to the Centers for Disease Control and Prevention (CDC, 2006) the minimum distance requirement between a well and a septic tank should be 15 meters (50 feet), however; based on the survey results, 38% of the households had septic tanks and wells closer than 10 meters (32.8 feet). Figure 15 shows distances between wells and septic tanks in different local government areas.

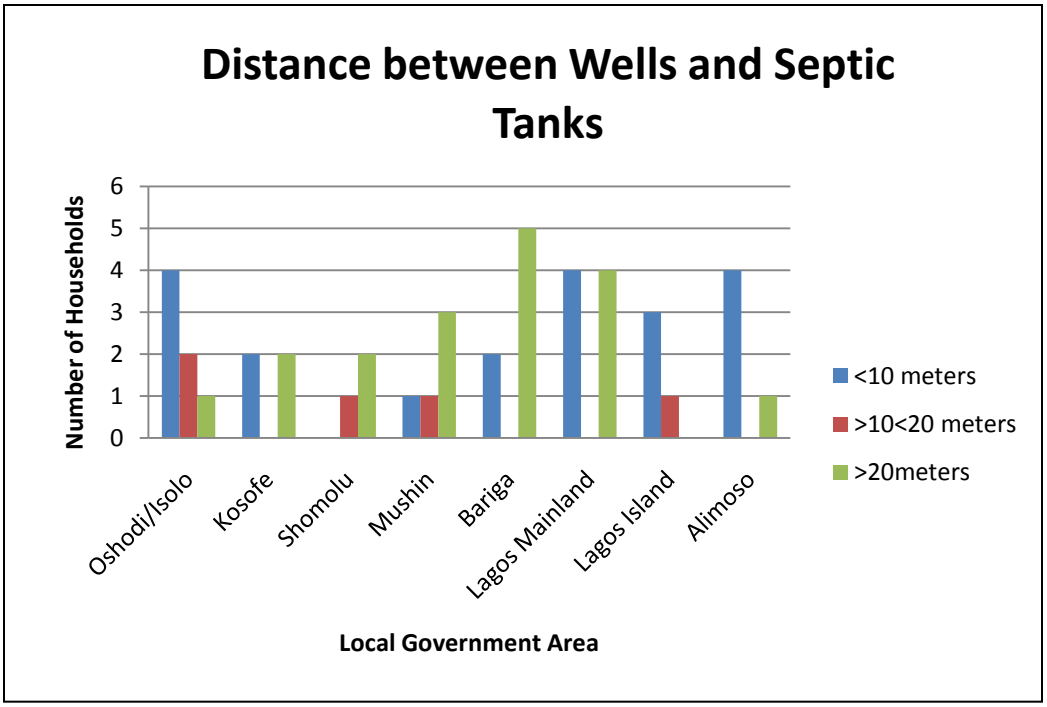


Figure 15. Distance between Wells and Septic Tanks

Other concerns are wells and septic tanks that are in the same location; the survey shows that 42% of the households located their wells and septic tank in the same general area. This presents an extreme hazard of biological contamination to the wells. Figure 16 shows wells and septic tanks at same location within the local government surveyed.

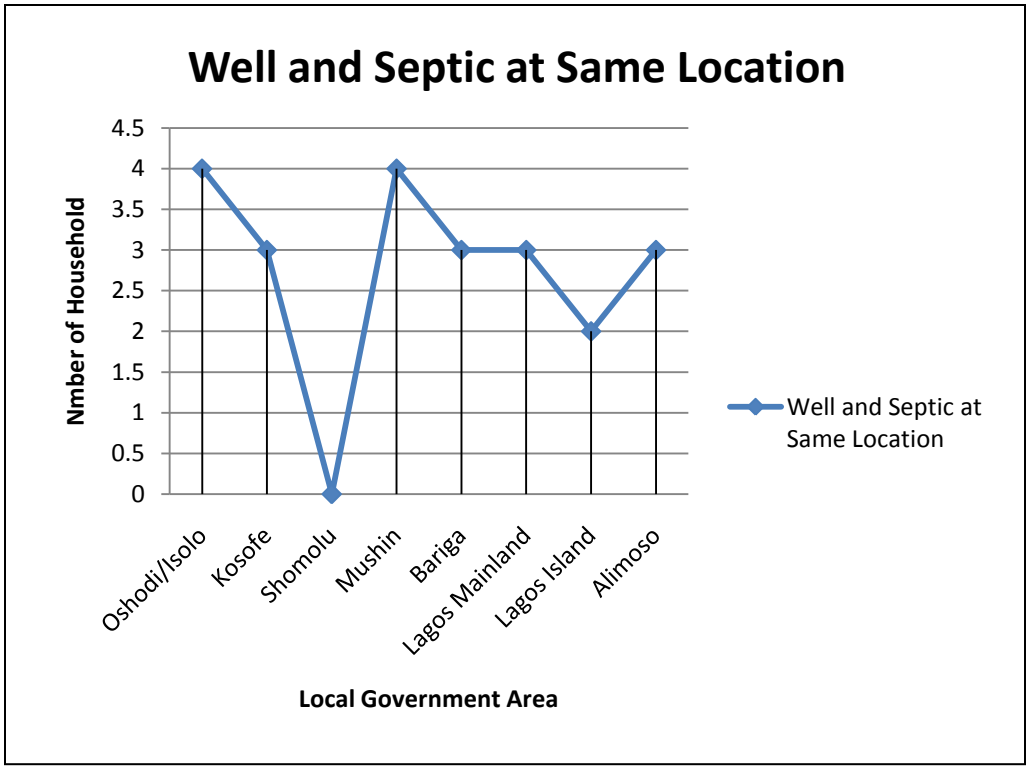


Figure 16. Wells and Septic Systems at Same Location

During the study participants were asked from the questionnaire on how often they cleaned buckets and ropes used for water collection and also if they believed that the buckets and ropes used can contaminate groundwater. About 64% of the people in this survey do not know how often these utilities are cleaned. Most of the cleaning that is usually done consists of rinsing the bucket

with water before withdrawing water from the wells. Cleaning of these appurtenances typically is never assigned and as long as there are no observerable contaminants, there may never appear to be a need to sanitize. Figure 17 shows the frequency at which participant thinks how often buckets and ropes use for groundwater abstraction are cleaned.

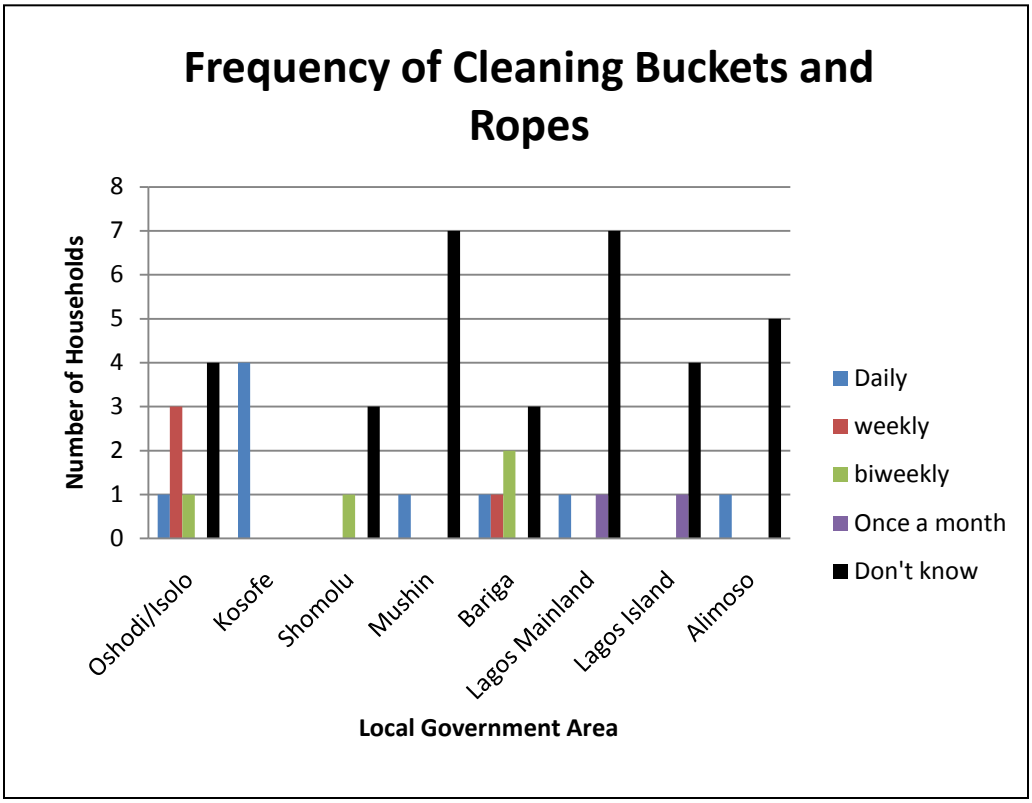


Figure 17. Frequency of Cleaning Buckets and Ropes

However, in Figure 18, when we asked if they believed the buckets and ropes could contaminate the ground water if left unclean, the majority of participants across the eight local governments agreed. This showed that there was some level of awareness of possible groundwater contamination. But the

understanding of possible contamination when septic tanks or pit latrines are located close to wells was limited.

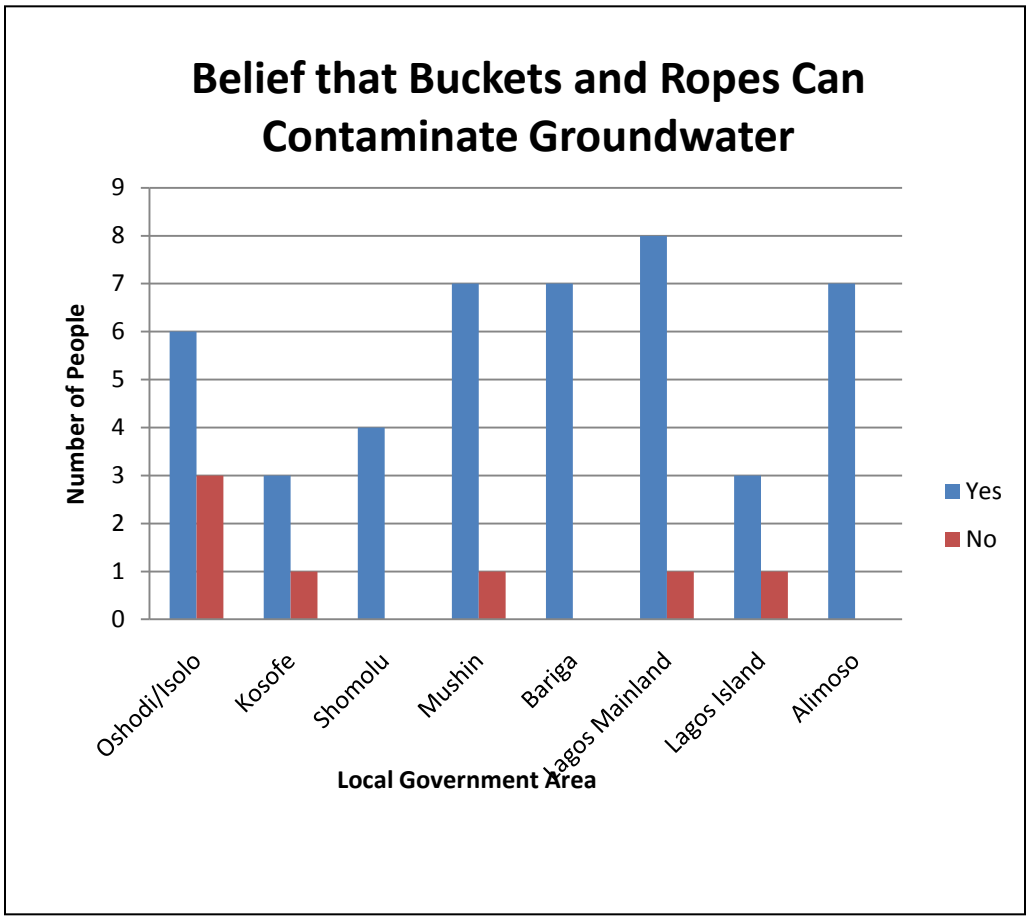


Figure 18. Belief that Buckets and Ropes Can Contaminate Groundwater

In order to determine the extent of groundwater contamination, there is a need for communities to embrace analysis of groundwater. A basic analytical guideline was developed to help the field staff in following the necessary steps needed to provide reliable data. Below are the established guidelines designs for the field staff to follow.

Groundwater Monitoring Plan

Below is the plan developed for a monitoring program for residential wells in the Lagos State metropolitan area. This plan identified necessary agencies and stakeholders that would be involved in implementing an effective monitoring program. It identified potential hazards and hazardous environments within the well areas. The plan established necessary templates and sampling and analytical guidelines needed during the course of the program. It also established community awareness plan needed in educating the communities within Lagos metropolitan area.

Identified Stakeholders

The stakeholders identified were:

- The Lagos State Water Corporation which has been given the right by Federal status to protect citizens from water quality problems.
- Individual local government areas
- Higher educational institutions that may provide necessary data and help in laboratory testing for some of the parameters tested during routine monitoring

The Lagos State Water Corporation

The corporation is charged to provide potable water to the citizen of Lagos State. The mission of the corporation is (Lagos State Water Corporation, 2009):

- "To provide safe drinking water in sufficient and regular quantity in Lagos State."
- "To maintain good quality service by collecting enough revenue to sustain effective operational expenses."
- "To carry out functions to meet customer's expectation by planning for sustainable growth and overall progress of the corporation."
- "To promote good community health by ensuring Customer satisfaction."

Individual Local Government Areas

Table 5 shows individual local development areas that are given the duty to regulate and enforce local regulatory status as it relates to the sustainability of the people within their communities. Lagos State was divided into five Administrative Divisions (AD), which are further divided into twenty Local Government Areas (LGA) and thirty seven Local Council Development Areas (LCDA). Sixteen of the twenty LGAs are within the Lagos metropolitan area.

Table 5. Local Government Areas

Badagry Division	Epe Division	Ikeja Division	Ikorodu Division	Lagos Division
Ajeromi-Ifelodun	Epe	Agege	Ikorodu	Apapa
Amuwo-Odofin	Ibeju-Lekki	Alimosho		Eti-Osa
Badagry		Ifako-Ijaiye		Lagos Island
Ojo		Ikeja (capital of Lagos State)		Lagos Mainland
		Kosofe		Surulere
		Mushin		
		Oshodi-Isolo		
		Somolu (aka Shomolu)		

Figure 19 shows the map of Lagos State metropolitan showing sixteen of the local governments within the state.

Figure 19. Lagos State Metropolitan Map Showing Local Government Areas

The responsibilities for monitoring water quality and adhering to the requirements of the program are proposed to be vested in:

1. Qualified water quality managers;
2. Local agencies that show interest in building healthy communities and the ability to gain the required knowledge and capacity.

Staffs of local agencies that would be involved in water monitoring would undergo specific structured training. The training would focus on areas of water quality monitoring not currently run effectively by agencies. Accreditation requirements of water quality managers needed to carry out this function would be provided. The accreditation and structured training would be performed by the University of Lagos Water Quality department.

Higher Educational Institutions

In Lagos, there are four proposed major institutes of higher education that can provide necessary data and help in laboratory testing of some parameters used in routine monitoring. These institutions are the University of Lagos, Yaba Polytechnic, Lagos State Polytechnic and Lagos State University. There are also research laboratories established by the World Health Organization (WHO). Samples would be collected by field staff and sent to one of the four institutions depending on turnaround time of analytical results.

Identified Potential Hazards and Hazardous Environment

Part of this program entailed identifying potential hazards and hazardous environments; this would help in effective evaluation of the monitoring plan process. The initial step in identifying potential hazardous environment was to take pictures of the entire well area for each home or facility inspected. This would include pictures of observable potential causes of water quality problems in the groundwater abstraction area. It should be noted that taking pictures in certain areas of Lagos could be a problem due to religious and cultural reasons. For example, areas with high population of Muslims would not allow men who are not members of their clan to enter their area. However, agreements were put in place through the local governments identified above to allow photography access to these areas. In certain areas, a schematic diagram clearly identifying water quality problems would be sufficient enough if photographs were not available. Some of the conditions that should be noted in the report on initial potential water quality problems are:

- Location of wells relative to sanitary waste facilities;
- Location of wells relative to industrial facilities (if present);
- Maintenance of tools for water abstraction;
- Potential for contamination due to poor construction or damage to the wells;
- Potential for contamination introduced by buckets;
- Potential for contaminated surface water to enter boreholes;

- Leaching of microbial contaminants into an aquifer;

The next step of developing a monitoring program was to call for a person to inspect the groundwater well currently being used and ask questions of the local residents about how the water tastes and if there are any possible odors or unusual appearances. The person conducting the monitoring would also note if there were any reported adverse events like storms, landslides or bushfires or industrial spills that had taken place in the past, events that might impact the quality of the well water. Another step was to identify seasonal issues that might affect water quality. Lagos State usually experiences about three months of heavy rainfall, which usually results in flooding in most areas due to ineffective drainage systems or lack of drainage systems.

Another task would be to inspect tools used for water abstraction and storage (i.e., tanks) and observe possible contamination. Information collected would be recorded in the initial site characterization form provided for this monitoring program. After looking at various deficiencies or maintenance issues, recommendations would be made in regards to possible solutions. The template on the next page was developed to be use to collect necessary information in characterizing potential well site issues:

INITIAL SITE CHARACTERIZATION for RESIDENTIAL WELLS in LAGOS NIGERIA

Date: _____

Rent ☐ Landlord (owner) ☐

Address: _____

Local Government Area: _____

Number of Wells

Boreholes ☐ Dug wells (Konga) ☐

Location of wells

- Front of the Building ☐
- Back of the building ☐
- Side of the building (specify North, South, West or East) ☐

Location of Septic Tanks

- Front of the Building ☐
- Back of the building ☐
- Side of the building (specify North, South, West or East) ☐

Distance between wells and septic tanks (circle appropriate distance)
< 10 meters
>10 meters but < 20 meters
> 20 meters

Is the well(s) entrance constructed with (CONCRETE)/ (NO CONCRETE)

Pit Latrines (**shalanga**) (YES)/ (NO)

How are the buckets and ropes used for drawing water cleaned (sanitized)?

Mark (x) Appropriate Box:

CHARACTERISTICS	**YES**	**NO**
Turbid, cloudy or dirty		
Color and/or organic odor		
Salty taste		
Bitter taste		
Difficulty forming lather with soap		
Blue stains (corroded copper pipes)		
Rotten egg smell – H2S		
Scaling on pots or kettles (indicator of hardness)		
Any Storm events		

Collected by:_____.

Reviewed by:_____.

Figure 20. Site Characterization Form

Biological and Chemical Hazards

Most of the potential hazards associated with well water abstraction in Lagos State are E. coli, metal and nitrates (Egwari and Aboaba, 2002). However, in commercial areas in Ikeja (Ikeja division) where the majority of industrial and pharmaceutical industries exist, other inorganic and organic compounds common to the industry may be present and would be monitored and evaluated. Guidelines were created to help the field staff during the course of monitoring and data collection at various sites to identify potential sources of contaminants based on the outcome of analytical tests performed. Below are the guidelines provided for staff use.

Typical Water Quality Concerns, Source of Contamination and Their Potential Impact on Consumers

Table 6. Typical Water Quality Concerns

QUALITY CONCERNS	SOURCE OF CONTAMINATION	IMPACT ON CONSUMERS
Pathogens	Contaminated water containing fecal matter entering the aquifer. Possible contamination of the water after water collection due to poor sanitation and hygiene practices.	Impact can vary from mild gastroenteritis to severe and sometimes fatal diarrhea, dysentery, hepatitis, cholera or typhoid fever.
Nutrients, algae and algal toxins	Examples are nitrogen and phosphorus from farming which might result in high levels of algae in water.	Impact on organ-specific diseases, neurological, behavioral disorders reproductive or developmental issues, carcinogenic or mutagenic diseases.

QUALITY CONCERNS	SOURCE OF CONTAMINATION	IMPACT ON CONSUMERS
Metals	Leaching of metals (e.g. arsenic, mercury) from natural rock and soil formations. Leaks from industrial waste dumps or pipes.	Organ-specific diseases, neurological, behavioral disorders reproductive or developmental issues, carcinogenic or mutagenic diseases.
Pesticides, herbicides and insecticides	Leaks into boreholes or wells from abandoned containers near water abstraction areas. Farming close to well and boreholes.	Impact on organ-specific diseases, neurological, behavioral disorders reproductive or developmental issues, carcinogenic or mutagenic diseases. High dose might result in acute or chronic effect.
Industrial chemicals, fuels and organic compounds	Wastewater discharges and spills from industries, and leakage from underground fuel storage tanks into the aquifer. Dumping of chemicals in landfill	Impact on organ-specific diseases, neurological, behavioral disorders reproductive or developmental issues, carcinogenic or mutagenic diseases. High dose might result in acute or chronic effect.
Aesthetic parameters ▪ Turbidity ▪ Color ▪ Salt (TDS or EC) ▪ Temperature/pH Hardness/ ▪ Alkalinity ▪ Iron, manganese or aluminum	A wide range of sources, both natural and from human activities. Color may result from presence of iron and manganese, and salt may result from salt intrusion from the ocean near Lagos State.	Bad taste, odor or appearance. Possible iron poison.

(Australian Government, 2005).

Below are additional tables used to collect information on observed situations during the course of initial sites characterization, where possible groundwater contamination might be occurring. Mark appropriate box base on your observation.

Activities and Practices that Pose Risks to Water Quality

(Please mark appropriate box)

High risk activities	**Pathogens**	**Nutrients leading to algae taste, odor and toxins**	**Metals**	**Pesticides Herbicides Insecticides**	**Industrial chemicals, fuels and organic compounds**	**Aesthetic parameters**
Incorrect or inadequate construction of the groundwater bore, allowing surface water ingress either at the bore site or through porous soil or rock						

High risk activities	Pathogens	Nutrients leading to algae taste, odor and toxins	Metals	Pesticides Herbicides Insecticides	Industrial chemicals, fuels and organic compounds	Aesthetic parameters
Leaching of metals (for example arsenic, mercury) from natural rock or soil formations						
Leaks from underground fuel storage tanks						
Sewage discharge (even if treated) at or near the well area						
Houses with domestic waste leak at the well area						
Intensive agricultural at or near the well area						

High risk activities	Pathogens	Nutrients leading to algae taste, odor and toxins	Metals	Pesticides Herbicides Insecticides	Industrial chemicals, fuels and organic compounds	Aesthetic parameters
Recontamination of the well prior to use either during water storage or distribution						
Domesticated animals and animal husbandry around the well site						
Leaks from chemical processing industry waste dumps in the groundwater recharge area						
Storm water from villages (particularly where wastewater capture, treatment and sanitation are poor) entering the borehole and wells						

Figure 21. Activities and Practices that Pose Risks to Water Quality (Australian Government, 2005).

Characteristics that Indicate the Presence of Potential Water Quality Problems

Characteristics	Pathogens	Nutrients leading to Algae taste, odor and toxins	Metals	Pesticides Herbicides Insecticides	Industrial Chemicals, fuels and organic compounds	Aesthetic parameters
Turbid, cloudy or dirty, particularly after storms	x					x
Color and/or organic odor	x	x	x			x
Salty taste						x
Bitter taste			x		x	x
Difficulty forming lather with soap						x
Blue stains (corroded copper pipes)			x			
Rotten egg smell – H_2S						x
Scaling on pots or kettles (indicator of hardness)			x			x

Figure 22. Presence of Potential Water Quality Problems Indicator Form (Australian Government, 2005).

Basic Observed Quality Parameters and their Implications

Parameters	Implication for water quality
E. coli (Escherichia coli)	Indicates fecal contamination of the water supply. Possible presence of pathogens.
Coliforms	These should not be present after disinfection. Their presence after treatment can indicate that the disinfection was ineffective and that there is a risk of pathogens.
Turbidity	Shows possibility of microorganisms if above 1 NTU
Color	Indicates possibility of organic or inorganic materials in the water, which can interfere with disinfection and produce harmful disinfection by-products. May also indicate the presence of iron or manganese.
Salts	Generally makes the water unpalatable or unpleasant to drink.
Hardness	Can affect treatability of the water and the ability of the water to lather.
pH	Should be in the neutral range (6.5–8.5). At higher pH, scaling may occur if hardness is high. If below 6.5, water can be corrosive and attack metals.
Metals – arsenic, boron, cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc	Can be harmful to humans and animals if consumed.
Metals – iron or manganese	Can cause brown or black water, staining and coloration of laundry and baths, sinks and an iron or bitter taste.

Figure 23. Basic Observed Quality Parameters and their Implications (Australian Government, 2005).

Analytical guidelines

Based on initial potential hazards and hazardous environment identification, private owners of wells would be advised to monitor their wells every six months for the first two to three years and annually for subsequent years. The frequency of testing might vary depending on new activities taking

place within the well sites. Qualified staff or laboratory personnel would perform sample collection. Efforts would be made to incorporate specified sampling techniques as part of the training for the local staff that would be implementing this program.

At a minimum, wells should be tested for coliform (E.Coli) bacteria, nitrates, hardness and turbidity. Separate sample containers should be used for bacteria testing. Below are sampling requirements for various parameters.

Table 7. Sampling

Parameters	Sample volume/container	Maximum contaminants level Goal (MCLG)	Implication for water quality
E. coli (Escherichia coli)	100ml/100ml container	zero	Presence of pathogens (fecal waste)
Turbidity	50ml/50ml	< 1.0 NTU	Possible presence of microorganism
Color	100ml/100ml container		Generally indicates organic material in the water.
Hardness	100ml/100ml container	<1000	Can affect treatability of the water and the ability of the water to lather.
pH	100ml/100ml container	6.5-8.5	At higher pH, scaling may occur if hardness is high. If below 6.5, water can be corrosive and attack metals.
Nitrates	100ml/100ml container	10ppm	High levels of Nitrates can cause serious illness and death, especially in infants

Sample Collection Protocol

Sampling Check List:

Below are items that would be needed to take good representative samples of water from wells:

- ☐ Bottles
- ☐ Gloves
- ☐ Reagents and test strips or vials
- ☐ Bleach solution
- ☐ Ice chest and ice
- ☐ Labels
- ☐ Indelible markers
- ☐ Sample collection buckets

Before sampling, tools needed for sample collection should be sanitized. Prior to coming to the site, the sample collection bucket and any tools that might get in contact with the sample would be placed in bleach solution for two hours. These tools would then be removed and placed in a plastic bag.

Bleach Solution:

Bleach solution for sanitizing the tools can be prepared by buying 6.0% sodium hypochlorite household bleach from the store and adding about half a cup of the solution to 1 gallon of water.

Labeling:

Labels should be prepared with the following information:

- Sample date
- Sample time
- Area location sample number
- Location of the sample (use household address)
- Analysis and the sampler's initials

Each label should be placed on a container before sampling. Sampling would preferably be done early in the morning. This is when there are fewer activities around the wells, thus reducing the possibility of external contamination. It should be essential to make sure the area around the well site was kept clean. If possible a 1:10 dilution of the bleach solution should be used to rinse the area.

The sanitized bucket should be removed from the bag and about 1 gallon of groundwater would be withdrawn from the well. The water would be passed into each container needed for the recommended analysis. Adequate sample documentation and information would be provided as required. All collected samples needed to be transported to laboratory should be in an iced cooler at 4 degree Celsius.

Quality Assurance:

This should include documentation, reporting, and record keeping in relation to data collected on a particular site.

A log book would be maintained for recording the following:

- The unique sample number
- The location where the sample was collected
- The date and time the sample was collected
- The free chlorine residual
- The initials of the sampler
- The name of the laboratory the sample was delivered
- A list of the analyses requested for the sample

Chain of Custody

Chain of custody should include the following:

- Unique sample number.
- Date sample was collected.
- Time sample was collected.
- Location where sample was collected.
- Analyses required.
- Name of the person collecting the samples.
- Name of who submitted and received the sample with their signatures
- Date/time of sample was submitted.

CHAIN OF CUSTODY

Date: Page of

PLEASE FILL THIS FORM IN COMPLETELY. SHADED AREAS ARE FOR LAB USE ONLY.

Contact: Gbenga Talabi

Department: Well Monitoring Program Lagos State

Phone:
Fax:

Sample ID	Sample Location	Date	Time	Matrix	Compliance (Y/N)	LAB ID		TDS	Nitrate	TSS	Turbidity									NUMBER OF CONTA
				W																
				W																
				W																
				W																
				W																
				W																

SAMPLE RECEIPT	
NO. CONTAINERS	pH VERIFIED
CUSTODY SEALS	
RECEIVED INTACT	
RECEIVED COLD	

SAMPLED & RELINQUISHED BY: 1	RELINQUISHED BY:
Signature:	Signature:
Printed Name:	Printed Name:
Date: Time:	Date: Time:

COMMENTS:

Standard Turn-Around Time (10 Day):

Rush Turn-Around (3 or 5 Day):

Other:

RECEIVED BY: 1	RECEIVED BY:
Signature:	Signature:
Printed Name:	Printed Name:
Date: Time:	Date: Time:

Figure 24. Example of Chain of Custody Form

Community Awareness Plan

In order to effectively manage this monitoring program, staff would provide educational materials for community awareness that would be incorporated in the monitoring plan. This would address some of the possible questions of community participants and provide solutions needed to provide safe drinking water. The Questions and Answers template below would be used to educate the community on the need to have safe drinking water. This would be distributed within the local government area.

Table 8. Well Water Awarenees Q&A

Well Water Awareness (Questions and Answers)

Question: What is well water?
Answer: This is water stored in the subsurface of the earth between grains of sand or other sediments or in fractures of rocks.

Question: If I don't have well water, then why should I worry about contamination?
Answer: Whether you have your own well or not, the water that is sold on the streets of Lagos all comes from the ground. Contamination can affect the water you drink.

Question: How does well water get to the surface?
Answer: Well water is an important component of the hydrologic cycle. Groundwater is pulled to the surface through dug wells (Konga) which are holes in the ground that are dug by shovels or jackhammers or drilled by drill machine. Another method to get water is through boreholes (deep wells). These are constructed in soil through the process of mechanical drilling.

Question: If the water is underneath the ground, it should be safe and of high quality, should it not?
Answer: In general, yes. Well water is susceptible to contamination from a number of sources, mostly due to human activities. Sources of contaminants might be malfunctioning pit latrines, septic tanks or landfills. With time, pollutants penetrate the ground and can mix with groundwater, thus polluting valuable sources of drinking water.

Well Water Awareness (Questions and Answers)

Question: Is well water safe for babies?
Answer: It depends on the level of contaminants in the water. A chemical called nitrate is one of the chemicals in water that, at high enough concentrations, can create serious danger to babies. Our soil contains small levels of nitrates. However, because of human activities like farming which involves the use of fertilizers, the levels of nitrate have been shown to have increased in groundwater.
According to the World Health Organization (WHO), babies under six months old who drink water with nitrates may suffer from lack of oxygen, where the blood cannot carry enough oxygen throughout their bodies. This condition can be serious and can sometimes even result in death. If excessive nitrates is present, then boiling the water will only makes the problem worse. When nitrate-contaminated well water is boiled to make baby formula, the boiling concentrates the nitrates in the water and increases the health risk to the baby.

Question: How do we protect ground water?
Answer: We can protect our groundwater by making sure that our activities do not result in groundwater contamination. We need to use the currently established monitoring plan for wells to determine tests needed in order to provide safe drinking water. These tests should be conducted at least once a year.

Source: Kentucky Division of Water, http://www.water.ky.gov/gw/GWB-GW_awareness.htm

As part of the remediation, private owners of wells would be advised to monitor their wells every six months for the first 2 to 3 years and annually for subsequent years. The frequency of testing might vary depending on new activities taking place within the well site. Qualified staff or laboratory personnel would perform sample collection.

Chapter Five

CONCLUSIONS

Lagos is the most populous state in Nigeria, with an expected population in 2010 of 18 million. As the population grows, the need for safe drinking water becomes crucial to the several local governments within the Lagos States. From the literature reviews in Chapter Two, it appears that there is a serious need for communities in Nigeria to take water quality seriously and to effectively manage their water resources. This should include indentifying potential hazards that may impact water supply, identifying companies and activities that are potential sources of contamination, and improving the infrastructure of water treatment and water delivery systems. During the course of this project, the objectives that are mentioned in chapter one were addressed in chapter four. Below are summary of the objectives.

The Extent of Dependence on Drinking Water from Residential Wells

Over the years, water usage in the area has moved from the use of surface water to the use of groundwater in most Lagos State metropolitan areas. This is due to the fact that Lagos State Water Corporation (LSWC) cannot meet the state's water demand due to a breakdown in infrastructure of distribution pipes, and the fact that some of the equipment at various locations of the water treatment plants is in need of serious repair or replacement. Communities use water from dug wells and boreholes for day-to-day water consumption. Because of this shift

to groundwater, it is very important to implement a water quality monitoring plan that will safeguard groundwater quality.

Identified Potential Water Quality Hazards of Some of the Wells in Lagos State

During the course of this project various issues and concerns were identified that might impact groundwater supply. These are associated with social and economic behavior within the communities. The use of pit latrines is due to the ease with which a hole can be dug for fecal depositing, and it is very economical. However, over time a need has developed to move from pit latrines to toilets that directly connect to a septic tank within residential lots. Having a septic tank within a residential area has its own problems as it relates to potential groundwater contamination. Within Lagos State metropolitan area, every household has a septic tank. Construction of these tanks does not require special guidelines or government approval. Some of the septic tanks leak due to bad design or other causes. Various types of wells constructed in Lagos State present a need for monitoring plan that will evaluate the extent of groundwater contamination and provide information to communities about the impact or consequences of ground water contamination. Another social and economic shift in Lagos State is the move from shallow wells to deep wells. More households are constructing deep wells. This creates a class difference between the rich and the poor. Others have moved on towards deep wells because the shallow wells are already contaminated or the water level has dropped.

The Role of Federal, State and Lagos State Water Corporation on Water Quality and Water Management

The Nigeria Water Resources Act of 1993 provides for the control of water ways and groundwater by the Federal government of Nigeria. It empowers the Federal Ministry of Water Resources to regulate surface water and groundwater use. It allows the Ministry to grant licenses for groundwater abstraction and construction of wells. The Ministry of Water Resources is given the power to provide primacy to the state in terms of water regulation and management (Okoye and Priscilla, 2007). In Lagos State, the availability of safe, drinkable water depends on the Lagos State Water Corporation while the local government focus is on rural water supplies and sanitation.

Groundwater Monitoring Program for Residential Wells

In this thesis, a monitoring program was developed to assess potential contamination and help address it. The program includes evaluation of community awareness of water issues, and it indentifies stakeholders and potential hazards and hazardous environments that might impact groundwater quality. Templates were created for field data collection during site characterization. Below are the conclusions on the areas covered by the monitoring program.

Community Awareness of Water Quality Issues

- In order to move forward in developing a successful monitoring program, a community survey was conducted to identify the extent to which people of the communities understand sources of groundwater and the impact hazardous environments on the quality of the groundwater. The survey helped the project prepare for developing a monitoring program that focused in addressing most of the concerns related to water quality around wells.

Indentified Stakeholders

- Stakeholders were identified within the Lagos metropolitan area. This was needed for the successful implementation of the monitoring program. Stakeholders are the Lagos State Water Corporation, individuals within the community, 20 local governments and four higher educational institutions in Lagos State.

Identified Potential Hazards and Hazardous Environment

- A step-by-step approach was used to identify potential hazards and sources of groundwater contamination. Templates were offered in Chapter Four to help a groundwater monitoring staff in the field with necessary information needed for effective monitoring. The templates provided specific questions that need to be asked in order to effectively implement the program.

Community Awareness Plan

- A well-water awareness checklist was developed to provide assessment of possible water quality concerns as it relates to well water. This is a "Questions and Answers" checklist presented to encourage public awareness as it relates to well water. The list focused on where well water comes from, how safe is well water and sources of well water contamination.

The monitoring plan program for groundwater if implemented will provide a basis for safe drinking water within Lagos State. From the survey conducted in August 2009, it is worth noting that the extent of understanding of people within local government areas on whether groundwater can be contaminated is relatively low. In the graph below, it is apparent that out of the eight local governments surveyed, only Oshodi/Isolo and Lagos Mainland begin to approach an adequate understanding of the possibility of groundwater contamination.

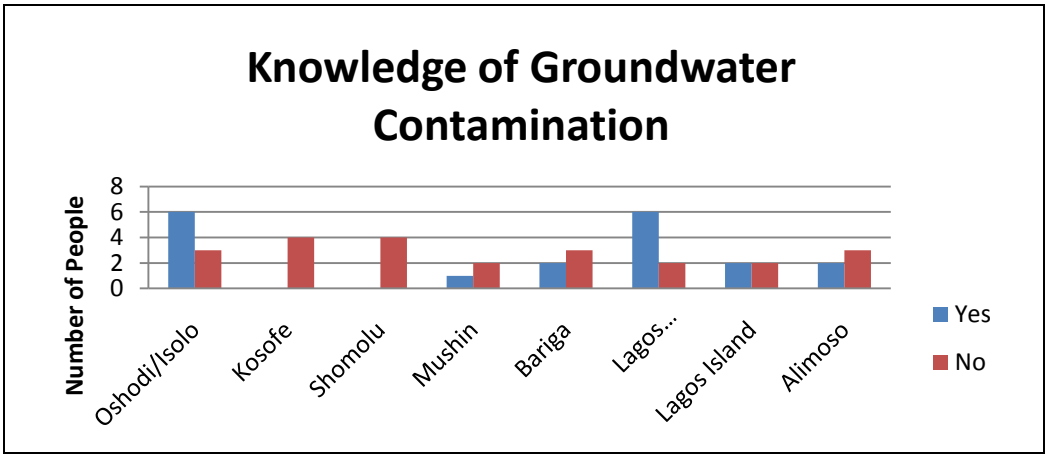


Figure 25. Knowledge of Groundwater Contamination

It is also interesting to note that majority of the people surveyed believe that buckets and ropes used for water withdrawal from the wells can contaminate groundwater. This shows that people believe that due to their activities around dug wells there is a possibility that they can contaminate the water in the wells.

RECOMMENDATIONS

From this project, it is seen to be very important for Lagos State and any communities therein to implement an effective groundwater monitoring program. This will ensure safe drinking water within the State. Having safe drinking water will have a major, positive social and economic impact in any society. The Lagos State government needs to come up with a plan on how the cost of analytical testing of water from residential wells within the state will be funded. This can be funds through World Health Organization (WHO) grant programs, or funds from the Federal government of Nigeria.

With the population of Lagos State increasing, the risk of a possible epidemic through water contamination is high. Safe drinking water will result in fewer people getting sick, and more children growing up to become healthy citizens, which later translates to an increase in productivity of the labor force needed for economic growth. Further research needs to be done on the extent of groundwater contamination and possible remediation plan especially when it comes to salt intrusion from the surrounding Atlantic Ocean and chemical contamination from chemical and pharmaceutical industries within Lagos State.

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APPENDIX A

IRB APPROVAL LETTER

APPENDIX B

CERTIFICATION OF COMPLETION

APPENDIX C

SURVEY DATA

APPENDIX D

MONITORING AND MAINTENANCE PROGRAM