FEASIBILITY OF RAIN WATER HARVESTING IN IKOLE EKITI FOR DOMESTIC USE A FOCUS ON QUALITY AND QUANTITY

BY

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ABSTRACT

Water scarcity is a problem in many parts of the world. In some regions, there is physical water scarcity because there are not enough resources of water to meet the increasing demand, while other parts of the world have an economic scarcity, where resources are more abundant but poor governance and other problems render water unavailable for most of the population. Where the problem is economic water scarcity, there are many solutions that could ameliorate the problem, but most times the solutions require a change in government, more economic resources and a better willingness. The quality of water sources in the Ikole-Ekiti has been questioned due to activities that pollute and decline the availability of water in the area. Therefore, there is the need to ascertain the quality and quantity of water obtained by rainwater harvesting. For the rain water quality, the samples were analyzed for Turbidity, Color, Electrical conductivity, Total hardness, Total alkalinity, Nitrate., Fluoride, Water PH, Coliform count, Temperature, Total dissolved, BOD, Chloride, Magnesium, Lead. In addition to this, survey questionnaires were administered to 40 households to obtain data on their water usage. Results showed that on the chemical characteristics of the water samples from rainwater, hand dug well and borehole were within the WHO and NSDQW acceptable range in relation to the total solid and Nitrate test and Iron. However, the rain water sample had it distinction from other samples in most of the test such as turbidity, electric conductivity, Nitrate, Total alkalinity, magnesium etc. except from the chloride and PH value test due to its acidic nature. The biological parameter such as the bacteria count test, the rain water and borehole sample met required standard for drinking water quality, while the hand dug well water samples did not meet the standards for drinking water quality.

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DEDICATION.

I dedicate this project to Almighty God who has been our source of guidance and provider throughout the years of study in this great institution and to my wonderful families for all the love, care and support they have been given us. We will be forever grateful.

CERTIFICATION

This is to certify that this project was written by Fowora Oluwadamilare Samson CVE/13/1060 under my supervision and is approved for its contribution to knowledge and literary presentation. All sources of information are specifically acknowledged by means of references, in partial requirements for the award of Bachelor of Engineering (B.Eng.) degree in civil engineering, Federal University Oye- Ekiti, Nigeria.

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LIST OF ABBREVIATION.

RHW	Rain water harvesting
NGOs	Non-Governmental organization
TTC	Thermo-tolerant coliforms,
TC	total coliform
FC	Feacal coliform
EC	Enterococci
PCR	polymerase chain reaction
QMRA	Quantitative microbiological risk assessment
EDTA	Ethylenediaminetetraacetic acid
APHA	American Public Health Association
NTU).	Nephelometric Turbidity Units
TDS	Total Dissolved Solid
NSDQW	Nigerian Standard for Drinking Water Quality
WHO	World Health Organization.

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CHAPTER 1

INTRODUCTION.

1.1 Historical Background.

Water is our most precious natural resource (Sustainable Earth Technologies, 1999). Its uses are innumerable and its importance cannot be overestimated. Its role ranges from domestic uses agriculture and industry to religious ceremonies, recreation, landscape decoration and even therapy. Water is basic to life. Despite the obvious need for a sufficient, year-round water supply to sustain life, there is still a lack of water, much less clean water for many of the world's poor. The lack of water is bound to get worse. Estimates of the number of people without water put Number at about one-fifth of the world's population. For developing countries, the number could be one-half, (Weatherall, 1999). The problems that plague current water resources are numerous, but so are the possible solutions. This paper presents rainwater harvesting as "one of the most promising alternatives for supplying freshwater in the face of increasing water scarcity and escalating demand" (United Nations Environmental Programme, 1997). The objective is to support rainwater-harvesting systems in the developing world. A brief review on the history of rainwater harvesting and a feasibility assessment, the criteria of which are first defined and then applied to an example, are used to show the potential of such systems.

1. Approximately thirty percent of the world uses groundwater and it is the primary supply of water in many non-urban settings. Over-use has resulted in a drop in water table levels and has made the cost of water rise. (Weatherall, 1999)
2. Large amounts of contaminants are filtering into ground waters (Weatherall, 1999). Other sources have been contaminated by fluoride, (naturally occurring) arsenic, or salt (in coastal areas) (Development Technology Unit, 1987). In Bangladesh, for example, arsenic has affected 18 million people already and millions more are susceptible (Weatherall, 1999).

3. Surface waters are also being contaminated from industry, mining, and agriculture. In northern Mali, pesticides were found to have polluted the water, and in Mauritius, industrial and sewage pollution is threatening the livelihood of fishermen (Smith, 2002).
4. It is difficult to transport infrastructure for water supply where terrain is mountainous or otherwise unleveled, as is the case, for example, in many islands (United Nations Environmental Program, 1997).
5. Cost is a limiting factor to the implementation of high-tech systems in many developing countries (Development Technology Unit, 1987).

Rainwater harvesting, henceforth RWH, is defined here as the collection of water from surfaces on which rain falls, and subsequent storage of this water for later use (Sustainable Earth Technologies, 1999). The practice of harvesting rainwater is an old tradition adopted in many parts of the world, as well as a new technology that is growing in popularity. Rooftop catchments and cistern storage have been used in the Caribbean, and in the Middle East, for over three hundred years (Global Applied Research Network, 2003). Rainwater is also harvested in large rural areas such as Honduras, Brazil, and Paraguay as an important source for domestic water supply (United Nations Environmental Programme, 1997). In Thailand, there is evidence of rainwater collection from roofs or gutters into jars (Prempridi and Chatuthasry, 1982). In Asia, the history of RWH dates back to the 10th Century (Global Development Research Center, 2002). It is also popular in rural Australia, parts of India, Africa and parts of the United States.

For more than a decade, accelerated interest in domestic RWH has lead to both the formation of national RWH associations and the expansion in RWH research worldwide (Global Applied Research Network, 2003). Water policies of developing countries often list RWH as a source of domestic supply. (International Rainwater Catchment Systems Association, 2004). Moreover, individuals and groups have developed many varieties of RWH systems for use (United Nations Environmental Programme, 1997). This technology has been adapted in arid and semi-arid areas (United Nations Environmental Programme, 1997), rural and urban areas, and can serve as a primary or supplementary water source. While there are some disadvantages to harvesting rainwater, (dependency on climatic patterns, storage capacity limitations, and contamination from poor collection and storage methods) these disadvantages can be avoided with proper planning and management. Relieves demand and reduces reliance on underground sources, and surface waters.

1. Avoids many surface-water pollutants (Texas Water Development Board, 1997)
2. Cost effective: reduces water bills and running costs are low.
3. Is a simple yet flexible technology. Local people can be trained to build, operate and maintain a RHW system.
4. Does not depend on terrain, geology, or infrastructure management schemes (United Nations Environmental Program, 1997).
5. Water can be delivered nearer or directly to the household, relieving the women and children from the burden of carrying it, saving time and energy (International Rainwater Catchment Systems Association, 2004).
6. Can be used for agricultural purposes.
7. Can be used for ground water replenishment.

1.2 Rainwater Harvesting

Two main approaches can be defined for rainwater harvesting (RWH). It is either the collection of land based runoff in any kind of storage tank, reservoir or direct infiltration into the ground to recharge the groundwater table or the collection of rainwater runoff straight away from rooftops. The idea of both systems is basically the same. During a period of precipitation, the rainwater is falling down on the surface, either land or rooftops, and from there it is directly guided into storage tanks. This collected water can then be used for every purpose like irrigating fields, to bathing or washing laundry and, if several precautions are made, even as drinking water. If the collected water should serve as a drinking water source it is advisable to only use water collected from rooftops since the land based collected water would need some treatment to make it potable (Khoury-Nolde, 2013).

A proper design for a RWH-system depends on three basic components: the catchment area or roof surface as collection device, the delivery system comprising gutters and drainpipes and last but not least the storage reservoir or tank including and extraction device (Worm & Hattum, 2006). These three components are found in any kind of RWH system regardless which final design and method is chosen.

A division between three major designs can be made. The most common and know system is to use the roof from the house or a shed as catchment area and store the collected water in a nearby tank.

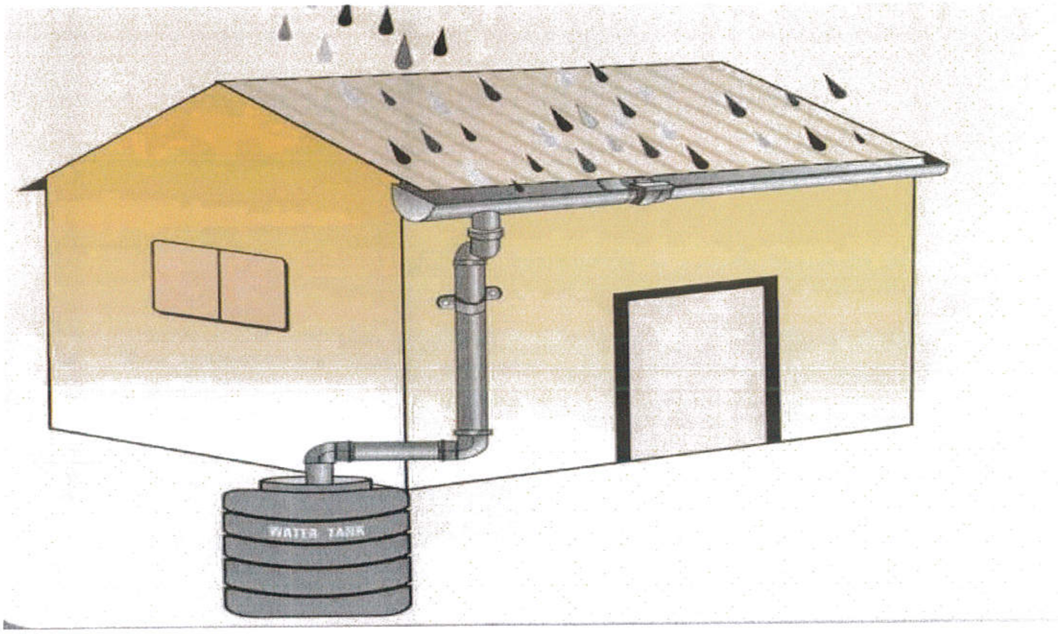

Figure 1.1: A roof catchment

A second technique is "Land surface catchments" (GDRC, 2013). It involves collecting rainwater as surface and sub-surfacing runoff by improving the runoff and guiding it into a storage tank. This can be done by either introducing drain pipe in the chosen area or manipulate the present vegetation to increase the runoff capacity.

Additionally, the flow of small creeks and streams can also be used to fill the storage tanks

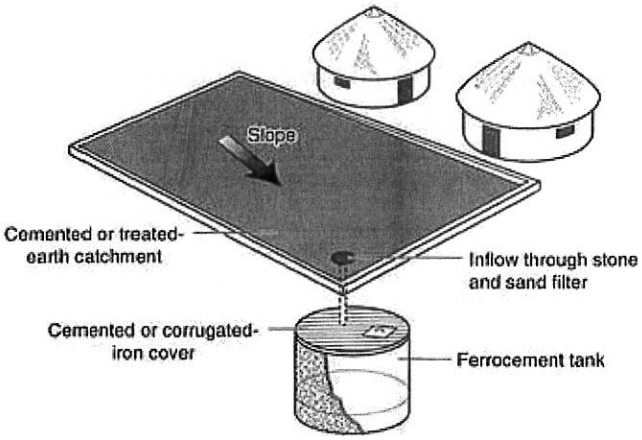

Figure 1.2: Land surface catchment (GDRC, 2013)

As a third method the "Rain Saucers" (Rain Saucers, 2009) design can be mentioned. In this technique the idea of the roof catchment is comprised to use an alternative catchment area, a "Saucer" (Rain Saucers, 2009) which catches the rain. This approach aims for a house independent solution, enabling a higher flexibility of the actual location where the water is needed and preferably collected.

Figure 1.3: Rain saucers 2009

1.3 Rationale of Rain Water Harvesting

RWH can AUGUMENT water supply in all sectors; Rainwater harvesting increases food production - For instance, according to studies carried out in Zambia, maize yield can be tripled with RWH through Conservation agriculture; RWH minimizes the risk of crop failure during droughts and floods; RWH eliminates women's burden of collecting water for domestic use. The time saved can be used for other productive activities; RWH gives opportunity for the girl child to attend school; It provides a relatively safe and clean source of drinking water thus minimizing incidences of water borne diseases; When applied at watershed level, it improves the environment and minimizes the effects of drought and floods; RWH is a decentralized water supply system encouraging community participation and self-reliance. Local communities who have an enormous capacity to invest labor and time can do it; the systems are varied and can therefore be built according to the ecological characteristics of the particular region or locality.

1.4 Feasibility Assessment of the Rain Water Harvesting.

There are three important questions that should be asked when undertaking any project in a developing country: Does the community need it? Does the community want it? And can it be done? For a rainwater harvesting system, these translate into assessment of the physical, social, and technical environments.

A physical assessment requires taking inventory of the current situation. For example, what sources of water currently exist? Are these sources for potable or non-potable uses? What are their conditions? Are they local? Are they accessible to the community? What is the quality of the water? Is it a reliable source, or is it available only in certain seasons or at certain times? Answers to these questions will begin to answer whether or not there is a need for a new or improved water supply. A public water supply, i.e. a well or a nearby river, may already be available. The quality and reliability of this water supply and the preferences of the people must be taken into account. For the given location, does it rain and how often? Does the amount of rainfall per month or per season warrant the usefulness of a rainwater harvesting system? According to one source, the recommended minimum amount of rain required for a RWH system is 50mm per month for at least half the year (Development Technology Unit, 1987). Another source recommends 400mm per year (United Nations Environmental Programme, 1997). Rainfall data can be obtained from the World Meteorological Organization, from local weather bureaus, or by direct observation over a period of time. Asking the locals for this information will also give a general idea. An additional observation should be in regards to local building materials. For example, what kind"s surfaces exist for catching rain? It should be noted that some types of materials are not suitable for rain water harvesting system for portable use.

1.4.1 Social Assessment

Social assessment must begin with a definition of community and the identification of key persons. How many people exist in the community? Who are the real respected leaders of the community? The social assessment goes on to answer the why"s of the physical assessment. For example, why is one source of water more preferred than another? Is a water source located in an area by choice or by circumstance? Why does a community not practice rainwater harvesting? Is there a real felt need for better water provision (United Nations Environmental Programme, 1997)? A community may have the need for an improved water supply, but there are several reasons the community may not be receptive to the idea of a RWH system. Depending on the kind of system presented, the technology may be above the education level of the community. There may be other priorities, depending on the season. It may not be considered an immediate need, or there may already be multiple sources of water, each with its own specified purpose. There may be traditional RWH systems already in place. Cultural perceptions and religious views regarding the use of water, as well as traditional preferences for its location, taste, smell or color are all important and to be taken into consideration. "Too often, non-community agencies (government, NGOs, and outside donors) will seek to implement a new technology without taking into account the cultural traditions and social roles of that community" (United Nations Environmental Programme, 1997). It is those very traditions and social roles that will determine the successful implementation and use of a rainwater harvesting system

In many developing countries, women are primarily responsible for water, but decisions to undertake investments, such as installing a RWH system, are typically undertaken by men. Both sexes need to be included in any discussions regarding the implementation of a RWH system. Pacey and Cullis (1986) recommend forming community water groups to be responsible for the system. It is important to know the people, to be aware of their concerns, and to encourage their participation in every step of the process. It has been shown that the more a community is involved, the more potential for a successful project (United Nations Environmental Programme, 1997). Other aspects regarding assessment of community dynamics include level of cohesion and communication, community politics and relations with surrounding communities, amount of enthusiasm (often evaluated in terms of willingness to contribute), and assistance from outside groups. These and likely other factors not mentioned here can positively or negatively affect a RWH system. For example, the identification of key persons can extend to outside groups, individuals in surrounding communities as well as those in regional government agencies or from NGOs who can provide resources or knowledge. Local community leaders must agree on the inclusion of such individuals or groups.

1.4.2 Technical Assessment

The technical assessment seeks to answer the question „Can it be done?" by taking into consideration the resources required for the implementation of the system, by determining expected supply and demand for water based on gathered data, and, where applicable, by taking into consideration previously-attempted projects and their reception by the community.

Determining available resources will require taking inventory of local building materials and discussing with those involved which materials are necessary, which can be supplied by the local community, which must be brought from outside and the transportation options that exist. Available resources must also take into consideration the financial contribution of the community and that from outside sources. Human resources will include skills, training, management abilities as well as labor. A plan outlining future maintenance and safety requirements is key from the outset to ensure the sustainability of the system. A site assessment is also important as this determines the location of the water storage catchment or catchments and how the water will be supplied. Remember, rainwater harvesting can be done on a large scale or local to individual households.

Finally, a review of existing projects or previous efforts to implement water supply systems can contribute valuable knowledge and prevent past mistakes from reoccurring. A local community may not always volunteer such information. It is critical, in the case of existing projects, to know their owners and any contract or stipulations associated with them. This can prevent making changes in an area where changes are limited, not allowed, or not aligned with the original intentions of the project already there. Some knowledge of regional or country water policies may also be useful.

1.5 Statement of Problem

As rainwater is one of the cleanest water source however, contamination may result from the environment and also from the roof materials and containers which is used during the periods of water storage. And also effectiveness of the storage tank for preserving water depends on preventing sunlight, organic matter and also contaminant from entering the tank.

The storage tank materials can also impact the quality of the water stored. Research has shown that the type of storage tank materials has some effects of the water, as also rain water collected from metal roof can react with steel tanks to cause corrosion.

The situation is also worsened by wear and tear conditions of metal tanks which increases the concentration of heavy metals such as iron, which can be toxic to human if exceeded certain condition.

1.6 Justification of the Study

The material for constructing rainwater harvesting and water storage system components is related to the efficiency of rainwater harvesting and can be a source of contamination through leaching of materials. Water quality from roof catchment is a function of the type of roof material, climatic conditions, and the environment (Vasudevan, 2002). Ground and surface water supply for drinking is often directly sourced from ground without biochemical treatment, and the level of pollution has become a cause for major concern. Water hardness is caused by dissolved polyvalent metallic ions, predominantly Ca2+ and Mg2+ cations. High concentration of total hardness in water may be due to dissolution of polyvalent metallic ions from sedimentary rocks, seepage and run-off from soil (Gupta and Saharanb, 2009)

The quality of water stored is also influenced by the type of storage tank materials. According to Jawas et al. (1988) storage tank materials can impact on the quality of water stored and this has become a major concern for research. The size of storage tank required to meet household water demand is dictated by rainwater supply, household water demand, length of dry spell, roof catchment area, and budget (TWDB, 2005). A properly sized storage facility could meet household water demand during the critical period of drought.

So as this study is being conducted in order to see if rainwater harvesting can be made feasible in Ikole-Ekiti despite looking at the constraint of the problem with storage tank, contaminated rooftops, house hold demands and other problems not been made mentioned now that are part of the plan of not making it feasible

1.7 Aims of study

The major aim of this study is to evaluate the viability or feasibility of rain water harvesting in Ikole-Ekiti for domestic use using quality and quantity.

1.8 Objectives of the study

1. Conduct a literature review of material relevant to rainwater harvesting.
2. To determine the quantity and quality of rainwater consumed by each household in Ikole- Ekiti
3. To determine the appropriate rainwater storage capacity for households.

CHAPTER 2

LITERATURE REVIEW

2.1 Water quality aspects of rainwater harvesting

The need for conserving public potable water supplies continues to increase throughout the world and RWH is a valuable tool that may be used to fulfill this need; however, the lack of knowledge regarding the quality of harvested rainwater has prevented widespread use of this practice (Lye 2009). This section presents a review on the origin, transport and fate of potential RWH contaminants; including sediment, nutrients, heavy metals and other chemicals, and the implications these pollutants and processes have on the use of RWH as a supplemental water source. Previous studies on harvested rainwater quality have produced contradictory conclusions, with some claiming harvested rainwater was severely polluted while others concluded that it was unpolluted (Abdulla & Al-Shareef 2009; Forster 1996; Sazakli et al. 2007; Zhang et al. 2010a). As more research has become available, it has become apparent that the quality of harvested rainwater is determined by the environment in which a given system is located and the materials used to construct said system (Abbasi and Abbasi 2011; Lee et al. 2010). As a result, it is imperative that designers and users of RWH systems understand the potential contaminants associated with their use and how these contaminants interact with each other and their environment, as these interactions will often dictate the necessary design, treatment and maintenance protocols to ensure harvested rainwater does not present a safety hazard to those using it (Magyar et al. 2007). It is anticipated that this compilation of literature and data may be useful to RWH system designers and users in identifying potential sources of contamination and incorporating the elements needed for a given system to improve the quality of harvested water to an acceptable level.

Study by Herrmann and Hasse (1997) describe the development and performance of rainwater utilization systems in Germany. The study specifically looks into rainwater harvesting system efficiency and the impact of rainwater harvesting systems on reducing potable water demand and reduction of storm water volume entering the combined sewer system. Study results show that rainwater harvesting reduces demand on potable (drinking) water. Also it concludes that rainwater harvesting is most effective for the storm water drainage system when it is applied in multi-storey buildings and densely populated districts.

In a follow up study by Herrmann and Shmida in (1999) reported that for a private household, depending on the consumption habits, roof area, and size of storage tank, the average water (drinking water) saving will be between 30% to 60%.

Coombes at al. (2002) developed a series of models that determine the economic and environmental benefits of water source controls on centralized municipal water providers in New South Wales, Australia. Source control measures in the model include rainwater harvesting tanks, infiltration trenches, grassed swales, detention basins and constructed wetlands. These control measures can be used in housing allotments and subdivisions to reduce storm water and supplement domestic water sources.

2.2 Water quality issues of rainwater harvesting

Atmospheric deposition and organic sources, including animal feces and deposition of tree leaves, are sources of contamination of rainwater harvesting systems. Water quality from different rooftop catchment systems are affected by the surrounding environment, climatic conditions, and roof material (Thomas and Green 1992). Microbial and chemical contamination of rooftop runoff is considered potential issues of rainwater harvesting water quality.

2.3 Microbial contamination

Storage tanks and cistern water may contain high levels of microbes of great variety including protozoa, algae, invertebrates and insects (Lye 1992). Bacteria that are commonly found in cistern water supplies are coliform, fecal coliforms (thermotolerant *Escherichia coli*), eugonic bacteria, dysgonic bacteria and hemolytic and/or cyotoxic bacterial activity (Lye 1992). Other bacteria including non-fecal sources of contamination and pathogenic organisms that are not commonly found in cistern water supplies, but still raise grave concern, are *Pseudomonas, Aeromonas, Legionella,Legionella pneumophila, Salmonell, Salmonella arechevalata*, and other heterotrophic bacteria (Lye 1992).

Lye (1987) reported on several studies related to microbial contamination of harvested rainwater. After surveying the bacterial content of 30 rural northern Kentucky cistern systems, it was found that coliforms and heterotrophic bacteria are common to cistern storage systems. In general, levels of bacteria in cistern water supplies are high enough to be unsuitable even though they are generally lower than that of surrounding surface waters and higher than those found in rainfall (Lye 1992).

A study of 83 cisterns in Nova Scotia (Lye 1987) showed that 50 percent of the cistern systems contained coliforms, 8 percent contained fecal coliforms and 95 percent contained *Pseudomonas*. Another study of the bacterial quality of 100 rainwater cistern supplies in the Virgin Islands (Lye 1987) indicated that 64 percent of cistern tanks contained coliforms, fecal streptococci was detected in 39 percent, 11 percent contained *Salmonell*, and *Shigella* was detected in 44 percent of cisterns.

Evans et al. (2006) reported that bacterial loads in roof runoff are source dependent and therefore influenced by weather patterns, wind speed and direction in conjunction with other factors such as relative source location.

2.4 Chemical contamination

Natural and anthropogenic sources of toxic metals and other inorganic compounds contaminate water supplies, including cistern water supply systems (Amirtharajah and Jones 1995). Chemical contamination sources include particulates from auto emission, industrial manufacturing emissions, and from airborne soil, corrosion of chemical from within the distribution system, corrosion of roof paints and material, and dissolution of chemicals from sediments in storage tanks. Indicators of chemical contamination include asbestos fibers, pH, suspended solids, and very important, heavy metals- cadmium (Cd), copper (Cu), lead (Pb), zinc (Zn), chromium (Cr) (Lye 1992; Quek and Forster 1993).

Several studies report on chemistry of rooftop runoff collected in cistern and water storage tanks. Thomas and Green in 1992 analyzed water quality of collected rainwater from different roofs in rural, urban and industrial areas in Australia to ascertain its appropriateness for domestic use. They reported that the rainwater collected from roof catchments was mainly polluted from atmospheric deposition and that the number of antecedent dry days affects water quality, meaning the quality of rainwater collected decreased with an increase of number of antecedent dry days. The two roof types influenced the runoff quality where the concrete tile roof catchment had higher turbidity, conductivity, and pH levels, while the galvanized iron roof catchments had higher zinc concentrations. Industrial area roof catchments had higher concentrations of lead in the suspended solids due to emissions from motor vehicles and zinc and turbidity. Urban area roof catchments also had high levels of lead due to motor vehicle emission, but were less than industrial concentrations. Rural area roof catchments were affected by agricultural activities and had higher concentrations of nitrate and pH. The study concluded that galvanized iron roof catchments provide the best water quality and that surrounding environment conditions greatly affect water quality. Yaziz et al. (1989) reported that acid rain causes leaching of zinc from galvanized-iron roofs.

Several studies have reported on the chemical composition of roof catchment water of cistern systems, primarily the metal content. Young and Sharpe (1984) analyzed the impact of atmospheric deposition on the water quality of 40 roof catchment cistern systems in rural Clarion and Indiana counties, PA. They studied the inflow of the heavy metals lead, cadmium and copper in the precipitation and in the water distribution system. The study showed that lead did not meet drinking water standards in bulk precipitation samples and corrosiveness predominated bulk precipitation samples (incoming rainwater samples). Corrosiveness was also present in cistern water samples and mean lead, cadmium and copper concentrations were below drinking water limits of cistern water samples. Lead and cadmium concentrations exceeded drinking water limits in the cistern bottom sediment/water amassed from the metal deposits on the roof catchments. Also, the study found that the corrosive bulk precipitation was moderated in all cement-based cisterns construction materials due to the dissolution of CaCO3 from cistern walls and floors except those vinyl-lined. Vinyl-liners prevent the dissolution of CaCO3 and thus the water stored in vinyl-lined cisterns was almost as corrosive as the bulk precipitation. Notable reduction of sediment metal contamination of cistern was noted when roof water filters were employed. It was concluded that cistern systems had several drinking water problems at the tap and were considered a hazard to its users due to the acidic precipitation that corroded the household distribution system and the atmospheric deposition of the metals lead, cadmium and copper that accumulated in cistern bottom sediments.

Another study was conducted on 46 roof catchment cistern systems of single-family dwellings in St. Maarten, Netherlands Antilles to determine heavy metal concentrations, Cd, Cr, Pb. and Zn (Gumbs and Dierberg 1985). They found that heavy metal concentrations were well below US drinking water limits in most cases. There were higher levels of Zn, Pb. and Cd at the tap water due to the increased dwelling time of the water in the pressure tanks which caused the corrosion of galvanized metal parts. The removal of dissolved heavy metals was facilitated in the surface waters of the cistern due to increased pH, calcium, and alkalinity due to the dissolution of the cistern masonry by the corrosive rainwater.

Good (1993) reported on the source of metal and aquatic toxicity in storm water of roof runoff of sawmill on the coast of Washington. It was observed that the collection of atmospheric deposits on roof-tops contributed to the relationship between Zn concentrations in roof runoff and the antecedent dry days between storm events. Zn concentrations were detected throughout the storm event due to the leaching of Zn from the galvanized roof surface and were considered to be toxic to aquatic life but, not human life. It was concluded that roof runoff was a source of pollutants, including high Zn concentrations, that exceed water quality limits for marine water and may be a source of and aquatic toxicity and storm water contamination. The rapid corrosion of galvanized metal roofs and leaching of zinc were attributed the acid rain and the coastal climate of Washington.

2.5 Microbiological characteristics of rainwater harvesting systems

In addition to the various water quality constituents identified in the previous sections, a variety of micro-organisms have also been detected in RWH systems. These organisms range from indicator bacteria (such as enterococci, fecal coliform fecal streptococci) to pathogens (E-coli, Salmonella, Giardia, Cryptosporidium, etc.) and even viruses. While some of these organisms may be harmless, others warrant considerable concern with respect to human health. The following sections will discuss the sources of microbiological contamination, the presence and associated risks of micro-organisms in rainwater harvesting systems, methods of treatment to reduce contamination and risk and the implementation of design modifications and/or maintenance protocols to reduce the likelihood of contamination.

2.6 Sources of contamination

To effectively manage and reduce microbial contamination and associated health risks within RWH systems, one must first identify its sources (Ahmed et al. 2012a). A primary source of bacteria and pathogens in collected rainwater has been identified as fecal contamination from wildlife such as insects, birds, small mammals (bats, possums, squirrels, rats, etc.) and small reptiles or amphibians (lizards, frogs) that is washed into the RWH system during rain events (Ahmed et al. 2012.

Some studies have identified correlations between the presence of overhanging trees or fecal droppings on roof surface and microbial contamination of collected rainwater (Ahmed et al. 2012a; Ahmed et al. 2012b).

Ahmed et al. (2012a) reported that 4 out of 5 RWH tanks containing Campylobacter had overhanging trees or visible evidence of fecal matter on the roof surface. Furthermore, 2 of the 3 RWH systems containing Giardia had rooftop evidence of fecal droppings (Ahmed et al. 2012a). Ahmed et al. (2012b) used binary logistic regression analyses to confirm a positive correlation between the number of Enterococci spp. and the combined factors of overhanging vegetation and fecal droppings on the roof surface.

Other potential sources of microbial contamination include atmospheric deposition of organisms, the presence of organisms in rainwater proper and the introduction of contaminants via extraction and handling methods of harvested rainwater (Ahmed et al. 2012a; Evans et al. 2006; Evans et al. 2007; Kaushik et al. 2012; Zhu et al. 2004; Schets et al. 2010)

Table 1: Data on microbial contamination of 50 water samples.

Reference	**Study Location & Details**	**Data**		
			#positive	Range
Kaushik et al. 2012	Singapore; 50 samples taken; real-time PCR method used for analyses	E-coli	21 (42%)	0-1.4×10^4
		P.aerunginosa	16 (32%)	0-4.2×10^3
		K.pnuemoniae	6 (12%)	0-1.2×10^3
		A.hydrophila	1 (2%)	0-33.2
		All values in gene copies per 100mL		

Table 1 in the previous page shows that Rainwater prior to contact with a roof surface. In this study by Kaushik et al. 2012 identified the scavenging of airborne micro-organisms and bio aerosols to be the primary contributor of E-Coli and P. aeruginosa in rainwater. Accordingly, the presence of regional smoke haze from burning biomass as well as the path of weather-driven air masses played a significant role in the composition and concentration of microbial contamination. Zhu et al. (2004) theorized that high FC in runoff could be due to the influence of nearby cattle and poultry manure, suggesting atmospheric deposition to be a primary contributor of micro-organisms. Evans et al. (2006) and Evans et al. (2007) also suggested atmospheric deposition to be the predominant source of microbial contamination in rooftop runoff (as opposed to fecal matter from wildlife). This conclusion was based upon data that showed wind direction and speed significantly affected the concentrations of heterotrophic plate count (HPC) and Pseudomonas spp. in roof runoff (Evans et al. 2006; Evans et al. 2007).

Zhu et al. (2004) theorized that high FC in runoff could be due to the influence of nearby cattle and poultry manure, suggesting atmospheric deposition to be a primary contributor of micro-organisms.

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Schets et al. (2010) reported similar findings regarding the concentration of C. perfringens and its correlation with wind speed. When collected rainwater is extracted from the storage tank by dipping containers into the water, bacteria and pathogens can be introduced from the container or hands of the person collecting water (Pinfold 1993).

2.7 Microbiological quality of rainwater harvesting systems

Factors such as cistern size, cistern materials, usage patterns, maintenance practices, storage volume, antecedent dry period length, stored water temperature, physio-chemical properties of runoff water, seasonal variations, weather conditions and presence/absence of inlet screens can impact the concentrations of bacteria and pathogens within a RWH system (Lye, 1987; Schets et al. 2010; Dillaha and Zolan 1985; Despins et al. 2009).

Two studies reported that microbial contamination tended to improve during winter months, most likely due to reduced animal activity on the roof and decreased temperatures of stored water resulting in a decline in microbial growth (Vialle et al. 2012; Despins et al.2009).

Ahmed et al. (2010a), Schets et al. (2010) and Birks et al. (2004) reported elevated concentrations of pathogens and fecal indicator bacteria following rain events (especially those with high-intensity rainfall). Fecal indicator organisms, such as thermo-tolerant coliforms (TTC), TC, FC, enterococci and EC are often used as surrogates for pathogen presence and to characterize microbial contamination within RWH systems (Ahmed et al. 2011a; Australian, 2000). Several studies have expressed concern with this convention due to a lack of correlation between fecal indicator and pathogen concentrations (Ahmed et al. 2009; Ahmed et al. 2008; Ahmed et al. 2010b; Ahmed et al. 2011a; Crabtree et al. 1996; Evans et al. 2006); however, it should be noted that the majority of data supporting this conclusion was published by the same author (Ahmed) in the same location (Australia). Ahmed et al. (2009) and Ahmed et al. (2011a) suggested the use of Bacteriodes spp. and Bifodobacterium spp. as indicators of fecal pollution, as opposed to EC, TC or enterococci, due to their higher sensitivity, shorter survival time outside of host and a stronger correlation with fecal pollution. Ahmed et al. (2012b) suggested the use of enterococci in lieu of E-coli as a fecal indicator due to its higher prevalence in rainwater and shorter survival time outside of host.

Evans et al. (2006) and Evans et al. (2007) concluded that the majority of the bacterial load within a RWH system can originate from airborne, non-fecal sources versus fecal matter; therefore, traditional fecal indicators would not adequately predict the presence of pathogens in these systems 65 (Evans et al. 2006; Evans et al. 2007). While each indicator has benefits and drawbacks when used to predict fecal contamination and pathogen presence, using multiple indicators when possible can greatly increase the accuracy of these predictions (Ahmed et al. 2010b; Ahmed et al. 2012b).

2.8 Treatment options

Despite the variation in the species and concentrations of micro-organisms found in RWH systems, most studies concluded that the level of microbial contamination in harvested rainwater warrants treatment prior to drinking (Appan, 1999; Li et al. 2010; Ahmed et al. 2011b; Ahmed et al. 2008; Ahmed et al. 2010a; Ahmed et al. 2010b; Ahmed et al. 2011a; Dillaha and Zolan 1985; Lye 1987; Mendez et al. 2011; Vialle et al. 2012; Schets et al. 2010).

There are many treatment options for RWH systems that, when used, offer adequate disinfection for harvested rainwater. These include sand filtration, membrane filters, reverse osmosis, boiling, ozone, ultra-violet (UV) light, pasteurization, chlorination and silver nitrate (Bradford and Denich 2007; Li et al. 2010; Ahmed et al. 2011b; Lye, 1992; Islam et al. 2010a; Zhu et al. 2004; Ahmed et al. 2012b; Nawaz et al. 2012). Pasteurization involves the combination of UV light and heat and is an effective method of removing E-coli and pathogens; however, its effectiveness is limited when TSS concentrations exceed 10 mg/L. Boiling can be used in the event of high concentrations or the presence of viruses, but can be very expensive and require substantial maintenance (Li et al. 2010).

Abdel-Shafy et al. (2010) and Islam et al. (2010a) showed extremely low concentrations of TC and other fecal indicators when sand filtration/UV light and sand filtration treatments were applied, respectively. Despins et al. (2009) reported a significant decrease in TC and FC concentrations via multiple treatment types, including UV light and sand filtration. The combination of a 20-μm particle filter and UV light was also effective at reducing TC and FC in stored rainwater (Despins et al. 2009). An exception to these positive results was reported by Ahmed et al. (2012a), who saw no significant difference between storage tank and household tap fecal indicator concentrations despite the use of undersink filtration (0.5μm pore-size filter). Perhaps the addition of UV light would produce acceptable water quality, such as that seen by Despins et al. (2009).

Li et al. (2010) recommends concentrations of 0.4-0.5 mg/L free chlorine for proper disinfection. Approximately 150mL of bleach (assuming 4% active ingredient) can be added per 1 m3 of storage tank volume to achieve a 0.5 mg/L residual after 30 minutes (Islam et al. 2010a). Lye (1992) reports that chlorine levels up to 2 mg/L will effectively reduce microbial contamination, but warns that regrowth may occur within 4-5 days.

Filtration may need to accompany chlorination to insure removal of all micro-organisms (Li et al. 2010; Crabtree et al. 1996). Chlorination is an inexpensive and effective form of disinfection (Islam et al. 2010a); however, there are some drawbacks to its use. When chlorine reacts with organic matter present in the storage tank, undesirable byproducts form and accumulate (Li et al. 2010). This can be avoided by applying chlorine after water is extracted from the tank, thereby reducing contact with organic matter (Li et al. 2010). Alternatively, chlorine dioxide or silver nitrate may be used in lieu of chlorine when byproduct formation is a significant concern (Zhu et al. 2004; Nawaz et al. 2012). Some find the use of chlorine unacceptable due to taste and odor issues, in which case other forms of disinfection should be used (Pinfold 1993).

2.9 Associated risks.

Numerous studies have reported the occurrence of illness and gastroenteritis due to the consumption of harvested rainwater (Ashbolt and Kirk 2006; Koplan et al. 1978; Franklin et al. 2008; Simmons et al. 2008; Merritt et al. 1999; Kuroki et al. 1996; Eberhart Phillips et al. 1997; Schlech et al. 1985; Murrell and Stewart 1983; Crabtree et al. 1996). Table 19 shows some of the diseases reportedly linked to the consumption of harvested rainwater, as summarized by Ahmed et al. (2011a) and Lye (2002).

Ashbolt and Kirk (2006) found a significant correlation between the consumption of untreated rainwater and Salmonella Mississippi illnesses in Tasmania. The presence of

Salmonella arechevalata in a water supply fed by a RWH system led to 48 confirmed cases of illness at a rural camp in Trinidad (Koplan et al. 1978). An outbreak of illness due to Campylobacter at a resort in Australia was linked to fecally contaminated RWH storage tanks, as was a Cryptosporidium-induced outbreak at a public building in Japan (Merritt et al. 1999; Kuroki et al. 1994). The presence of Salmonella typhimurium 9 and Legionella pneumophila in RWH tanks resulted in illnesses at a rural camp in Australia and in 2 private households in New Zealand, respectively (Franklin et al. 2008; Simmons et al. 2008). The New Zealand outbreak was believed to be caused by the deposition of aerosolized Legionella pneumophila onto the collection surface by a water blaster used nearby (Simmons et al. 2008).

There are been numerous risk assessments conducted on RWH systems, though the results and conclusions of these assessments vary greatly. Several studies have compared the health risks associated with harvested rainwater to those of alternative water sources (Kelly-Hope et al. 2007; Garrett et al. 2008; Few et al. 2009; Heyworth et al. 2006; Saadi et al. 1995; Marcynuk et al. 2009; Eberhart-Phillips et al. 1997)

Eberhart-Phillips et al. (1997) compared the risks of consuming rainwater with those of consuming improved sources in a New Zealand study. It was concluded that there were greater risks of gastrointestinal illness associated with harvested rainwater based on data collected from a small number of rainwater collectors (Eberhart-Phillips et al. 1997). However, when Dean and Hunter (2012) pooled the data from this study with those from Few et al. (2009), Heyworth et al. (2006) and Saadi et al. (1995), they concluded that there was no additional health risk or benefit between the two water sources.

The QMRA methodology assumes a certain percentage of the cells found in tank water are viable and infective, a value that may or may not be representative of what is actually present. Additionally, the volume of water ingested, number of exposure events per year and other variables must be estimated to produce conclusions. The method also assumes that pathogens are present at the „range of dose" concentration for the entire exposure period, an assumption that may not be true in nature. Finally, the polymerase chain reaction (PCR) method of detecting the presence of pathogens in tank water is more sensitive than other analysis techniques, which may explain a higher number of pathogens reported than in other studies (Ahmed et al. 2009). Thus, Dean and Hunter (2012) assert that the application of QMRA methodology frequently overestimates risk.

Fry et al. (2010) applied WHO"s comparative risk assessment to estimate the potential reduction in diarrhea DALYs per month that could be achieved by supplementing or replacing existing water sources with domestic RWH. This assessment was conducted for 37 cities in West Africa using a variety of scenarios based upon daily per capita water use (Fry et al. 2010). It was found that implementing a 400L RWH system could reduce DALYs for all cities by 36,700, a total of 9%. If the RWH system was implemented in conjunction with point-of-use treatment, this number increases to 68,500 (16%) (Fry et al. (2010). Implementing a 10,000L RWH system with or without point-of-use treatment, DALYs could be reduced by 97,200and 71,100, respectfully (Fry et al. 2010).

2.10 Sources of nutrients and heavy metals in rainwater harvesting systems

Although many ancient forms of RWH employed watershed-scale basins and dams to collect runoff, present-day RWH is often employed where a roof serves as the source of runoff (Hamdan 2009). This is most likely due to the fact that rooftops are comparatively cleaner than parking lots, sidewalks and other impervious surfaces; however, it is well documented that even runoff from roof surfaces can contain substantial amounts of heavy metals and nutrients (Yaziz et al. 1989; Melidis et al. 2007; Chang and Crowley 1993). There are several sources that can contribute these pollutants to rooftop runoff: the precipitation (i.e. wet deposition), atmospheric deposition that has accumulated on the roof surface (i.e. dry deposition) and materials used in the construction of the roof (Abbasi and Abbasi 2011).

The quality of rainfall falling onto a given surface is the key factor determining the quality of runoff leaving the surface (Hamdan 2009). Numerous studies have been conducted on the quality of rainwater prior to its contact with a surface and results vary substantially (Tables 1a and 1b). This is to be expected, as the chemical composition of rainwater is influenced by a multitude of factors, such as geographic location and influences, prevailing meteorological conditions and anthropogenic activities (agriculture, industry, motor vehicle emissions, etc.) and thus varies greatly by location, season, and even storm type (Adeniyi and Olabanji 2005; Chang et al. 2004; Lee et al. 2010; Avila and Alarcon 1999).

As rain droplets descend through the atmosphere, they dissolve gases, absorb aerosols and collect other suspended particulates such as dust and ash (Zobrist et al. 2000; Hamdan 2009; Huston et al. 2009; Adeniyi and Olabanji 2005; Abbasi and Abbasi 2011). The composition of precipitation is influenced by the proximity and strength of emission sources, chemical reactions occurring in the atmosphere and scavenging mechanisms of moving air masses (Avila and Alarcon 1999). Perhaps the most well-known phenomenon that can be attributed to the scavenging of atmospheric particles by rainwater is that of acid rain. When rainwater absorbs sulfur and nitrogen oxides, the pH decreases and the rain becomes acidic (Lee et al. 2010; Hamdan 2009).

The presence of sulfur and nitrogen oxides can be attributed to fossil fuel combustion (specific sources include motor vehicle emissions, combustion in building heating systems and industrial processes); consequently, acid rain is prominent in regions characterized by high vehicle traffic volumes, high density residential development and industry (Olem and Berthouex 1989; Melidis et al. 2007; Lee et al. 2010; Hamdan 2009.

2.11 Effects of maintenance & design of Rain water harvesting system.

The material comprising the storage tank of a RWH system can impact the level of microbial contamination within the system. Dillaha and Zolan (1985) reported that ferrocement storage tanks resulted in the lowest TC and FC concentrations, while metal drums resulted in the highest.

Karim et al. (2010) reported that RCC and ferrocement tanks are more susceptible to microbial contamination when compared to plastic and brick. Schets et al. (2010) showed that die off of Aeromonas and EC occurred more rapidly in galvanized iron storage tanks than in PVC containers, indicating superior microbial quality (though this die off was thought to be due to toxic compounds in the tank material, which could possibly jeopardize other aspects of water quality).

The effect of storage tank material on microbial quality of harvested rainwater is not adequately characterized. More research is needed on this topic to aid designers in choosing a storage tank that minimizes microbial contamination. Furthermore, if an existing RWH system is made of a material linked with higher microbial levels, users can opt to incorporate additional treatment mechanisms to reduce risk of illness.

Other structures that would facilitate the perching of birds and other animals should also be avoided (Ahmed et al. 2011b). RWH systems with inlet screens, tank covers and other measures that prevent insects and animals from entering the storage tank have been shown to produce higher quality water than those without (Dillaha and Zolan 1985; Lye 1992; Pinfold 1993; Schets et al. 2010). The method of extraction and transport of harvested rainwater should minimize the introduction of contamination (Schets et al. 2010). Findings published by Pinfold (1993) suggest the dipping of containers into a storage tank can introduce pathogens into a RWH system and should be avoided if possible.

2.12 Modeling of rainwater harvesting systems

Due to the difficulties and expense associated with monitoring rainwater harvesting systems, models are often utilized to determine the feasibility of RWH at a given location, design the optimal storage tank volume, simulate the behavior of a theoretical or existing system and/or evaluate the benefits associated with a RWH system. This section discusses various modeling approaches, reviews models that have been developed for RWH including metrics that have been used to evaluate performance, summarizes modeling studies that have been conducted on RWH and presents implications for system design based up modeling results.

2.13 Modeling approaches

There are numerous approaches to modeling RWH systems, though those most commonly used include behavioral/simulation models, statistical methods and/or probability theories. A behavioral model "simulates operation of the reservoir with respect to time by routing simulated mass flows through an algorithm that describes the operation of the reservoir" (Fewkes and Warm 2000). This type of model imitates the physical behavior of a system, making it one of the most easily understood modeling approaches (Fewkes and Butler 2000; Palla et al. 2011). Behavioral models are often used with historical precipitation data to produce continuous mass balance simulations (Palla et al. 2011; Basinger et al. 2010). Although this approach may require a large amount of data and computation, it is suggested to be one of the most accurate modeling approaches for RWH (Kim et al. 2012). For maximum accuracy, the historical rainfall record used should be at least as long as the expected lifespan of the system and the amount of missing data should be minimized (Basinger et al. 2010).

Models that simulate the hydrologic behavior of RWH systems must use a method of estimating the filling, spilling and extracting of water from the storage tank. In natural conditions, these activities can occur simultaneously; however, it is impossible to accurately reflect that in a modeling environment (Mitchell et al. 2008). Two methods of estimation are commonly used: yield before spillage (YBS) and yield after spillage (YAS). In the YBS scenario water is extracted from the tank (due to demand) after rainfall is added and before the overflow volume is determined (Islam et al. 2010b; Liaw and Tsai 2004). Contrarily, in the YAS scenario demand is extracted from the storage tank after the overflow volume is calculated (Islam et al. 2010b; Liaw Tsai 2004).

Some models rely upon an underlying probability distribution to predict dependent variables within the system, such as overflow or storage volume (Kim et al. 2012). The selected probability distribution is based upon the hydrologic relationships between meteorological distribution functions and the variables within the system (Kim et al. 2012). The application of these models can be rather limited, as the precipitation characteristics of a given location must match the statistical assumptions of the model"s distribution to ensure accurate results (Basinger et al. 2010). While these models can be useful for preliminary design analyses and estimating parameter sensitivity, they lack the level of detail provided by continuous mass balance simulation models (Kim et al. 2012).

2.14 Using models to design RWH systems

There are countless models that can be used for RWH applications, some of which were specifically designed to simulate RWH systems while others have been adapted for this purpose. Though most models use the same general approach – behavioral simulation – the detailed processes and methods used within the model can vary substantially. Basinger et al. (2010) stochastically generates rainfall data from data inputs while other models simply use historical data input by the user. Water demands vary among the models, input and outputs differ and some incorporate a first flush allowance.

RWH models are often used during the design process to determine the optimal storage volume of a system given local rainfall conditions and water demands. Performance variables are typically used to evaluate the relative performance of systems with varying design parameters. Examples of these variables include reliability (time-based and volumetric), water savings efficiency, runoff reduction, economic efficiency, payback period, annual overflow volume, rainwater use efficiency, dry cistern frequency, detention time and failure probability (Palla et al. 2011; Basinger et al. 2010; Mitchell et al. 2008; Briggs and Reidy 2010; Ghisi 2010; Jones and Hunt 2010; Su et al. 2009; Kim and Yoo 2009; Zhang et al. 2010b; Zhang et al. 2009b; Ghisi et al. 2007a; Imteaz et al. 2012; Fewkes and Warm 2000; Farreny et al. 2011b; Fewkes and Butler 2000; Guo and Beatz 2007; Gires and de Gouvello 2009; Imteaz et al. 2011a; Liaw and Tsai 2004; Lee et al. 2000; Mun and Han 2011; Palla et al. 2012).The design and operational parameters used to describe the behavior of RWH systems. Multiple models may use the same term to describe a given variable but calculate it in different ways; thus, when comparing the performance of multiple RWH systems one must ensure the variables are defined in the same manner.

2.15 Evaluating RWH system performance.

There is a plethora of studies that employ models to evaluate the benefits of existing or hypothetical RWH systems. Several of these studies investigate the relationship between model inputs and system performance; however, the results are somewhat contradictory as to which factors are most influential. Many studies have emphasized the importance of water demand, storage volume and contributing drainage area on system efficiency (Ghisi 2010; Zhou et al. 2010; Fewkes and Butler 2000), while others list climate and design parameters as factors impacting system performance (Coombes and Barry 2007; Islam et al. 2010b; Mun and Han 2011).

Palla et al. (2011) asserts that design and operational aspects of a system influence performance more than climatic characteristics; however, substantial differences in system performance have been attributed to variations in climate and rainfall characteristics in other studies (Zhang et al. 2009b; Eroksuz and Rahman 2010; Imteaz et al. 2011b; Palla et al. 2012).

Many models use historical precipitation data for simulations, though the length of the record used has varied. Gires and de Gouvello (2009) used 5 years of data while Su et al. (2009) and Rahmen et al. (2010) used a 50- and 60-year record, respectively. Liaw and Tsai (2004) analyzed the relationship between the length of the rainfall record used and the resulting reliability and concluded that the variability associated with the estimated reliability decreased as the length of record increased. Palla et al. (2011) stated that rainfall records of at least 30 years should be used to ensure accurate estimates of performance while Su et al. (2009) recommends a minimum of 50 years to accurately reflect long-term trends.

Fewkes and Butler (2000) demonstrated that the accuracy with which a model predicted water savings efficiency decreased as the time interval increased from hourly to daily to monthly.

Liaw and Tsai (2004) also reported more accurate results with smaller time intervals, and showed that the impact of longer time intervals increased as storage volumes decreased; therefore, it is especially important to use shorter time intervals when modeling smaller RWH systems. While sub-hourly data may not be available, it is apparent that the highest resolution precipitation data should be used when available to maximize model accuracy.

2.16 Reducing potable water consumption via rainwater harvesting

As one of the primary goals of RWH implementation is to decrease consumption of potable water, many studies have been conducted on the potential potable water savings that can theoretically be achieved via RWH. The use of a detailed behavioral model is not always required or utilized when a study is simply investigating the potential reduction in potable water usage, as opposed to the relationship between design parameters and system performance.

2.17 Site-scale analyses

Gardner and Vieritz (2010) conducted case studies on two RWH systems in Gold Coast and Brisbane, Australia. A single household was equipped with a 25kL storage tank that was connected to all household taps and appliances. Four years of monitoring data indicated that the RWH system, on average, was able to meet 45% of water demands without a backup supply. As 3 of the 4 years monitored were significantly drier than the Gold Coast"s average annual rainfall, it was expected that this value would increase under normal rainfall conditions..

Coombes et al. (1999) conducted a similar study on a residential development in Newcastle, Australia. Figtree Place, a 27-lot development, incorporated many low impact development (LID) practices, including community RWH systems. Each 9-15kL underground system services 4-8 houses and collected rainwater is used for hot water systems and toilet flushing. Based upon preliminary monitoring results, potable water savings of approximately 45% and 65% are expected for internal and total potable water usage, respectively, when compared to development without LID practices. (Coombes et al. 1999).

2.18 Municipal-scale analyses

Abdulla and Al-Shareef (2009) conducted a study to evaluate the potential potable water savings if RWH was implemented in the residential portions of each of Jordan"s 12 governorates. Data were collected for the following variables: rainfall, sources of potable water, annual water demand, population numbers, number and type of dwellings within each governorate and average area of each dwelling type. The volume of rainwater that could be potentially harvested annually was estimated by multiplying the annual rainfall depth by the total roof area within the municipality. A runoff coefficient of 0.8 was applied to the total volume, as it was assumed 20% of the rainwater was not conveyed to the storage tank. Potential water savings for the 12 governorates in Jordan ranged from 0.27% to 19.7%. The lowest savings potential was associated with the Aqaba governorate, which experiences the lowest annual rainfall and highest per capita demand for water.

A study performed by Kim and Furumai (2012) investigated the potential water savings in a residential district of Chiba City, Japan. Chiba City has a total area of 562,000□ □ and a population of 5.518 x□□□. Rainfall data were available for the city in 5-minute intervals for a total of 30 years and GIS data were 129 used to classify buildings within the city based on their water usage. A basic mass-balance flow model, InfoWorks™CS, was used to model rainfall/runoff processes. RWH systems were assumed to have storage volumes equivalent to 30mm of rainfall, or 2.1m3, 4.2m3, 3.9m3, 2.1m3 and 18m3 for residential houses, offices, commercial buildings, restaurants and public buildings, respectively

Domènech and Saurí (2011) used a similar approach to evaluate potential water savings in Sant Cugat del Vallès, a suburb of Barcelona, Spain. GIS data were used to estimate the total area of rooftop surface available for collected rainwater.

Comparable analyses were conducted by Ghisi et al. (2007) in the southeast region of Brazil. A total of 195 cities were analyzed to determine the potential water savings associated with widespread RWH implementation. Rainfall, potable water demand, population numbers, number of dwellings, and roof area data were acquired for each city, and the total volume of rainwater was estimated using the same techniques as

Abdulla and Al-Shareef (2009). The overall average potential water savings for the south east region was 41%, with average monthly savings for individual cities ranging from 12%-79%. Higher savings potential generally occurred between October and March when temperatures were warm and rainfall was greater. Furthermore, cities with lower potable water demands usually had a higher potential savings than those cities with higher demands, indicating that average potable water demand is not a good indicator of potential water savings via RWH (Ghisi et al. 2007).

2.19 Economic and social aspects of rainwater harvesting

The implementation and operation of RWH systems are not just controlled by physical and environmental parameters; economic and social aspects of these systems play a major role in their adoption and use. This section discusses the economic implications of RWH implementation at both the site- and regional-scale, social perceptions of RWH and how they impact implementation and use, and the environmental and energy impacts of constructing and using these systems.

The majority of issues hindering RWH implementation involve the economic viability and public perception of RWH systems (Fewkes and Warm 2000). In a survey of Canadian residents, most participants felt that an overall indifference to water conservation was a substantial impediment to RWH use (Leidl et al. 2010). Ward et al. (2010) cited the lack of information regarding system design and sizing and cost effectiveness of systems as the primary reasons for people choosing not to implement

RWH. Abdel-Shafy et al. (2010) stated that a lack of public awareness and professional marketing have caused RWH opportunities in Egypt to be neglected. High capital costs, liability concerns, restrictions on end uses of harvested water and lack of environmental commitment among citizens have also been noted as barriers to RWH adoption (Leidl et al. 2010). It is apparent that the economic and social aspects of RWH systems are crucial components of implementation and must be understood and addressed appropriately.

2.20 Economic considerations

The majority of studies conducted on the economic aspects of RWH concluded that it is not economically advantageous when compared to existing potable water supplies (Kim and Yoo 2009; Islam et al. 2010b; Gardner and Vieritz 2010; Mikkelsen et al. 1999). Farreny et al. (2011b) performed a thorough economic analysis on 4 theoretical scenarios involving building- and neighborhood-scale RWH systems, both as new and retrofit construction (Table 24). It was concluded from this study that under current public water prices, none of the 4 scenarios considered were economically advantageous. Building-scale RWH systems were the least cost-effective (for both new and retrofit construction), as financial benefits from the systems never offset the costs. Farreny et al. (2011b) also determined that the neighborhood-scale/new construction scenario was most cost efficient of the 4 scenarios due to a relatively low payback period (27 years), though this conclusion was strongly dependent upon the condition of a small catchment area per dwelling.

Domènech and Saurí (2011) also found that the financial benefits associated with single-family houses never offset the costs of a RWH system under a low-consumption water rate scenario, verifying conclusions drawn by Farreny et al. (2011b). Higher potable water price scenarios resulted in decreased payback periods (the time it takes for a project"s net revenue to equal the capital cost), making community-scale RWH systems economically viable for all water demands except landscape irrigation. A high-consumption water rate scenario improved the cost effectiveness of the building-scale RWH scenario as well, but still yielded rather long payback periods (33-43 years, depending on them storage volume).

Mikkelsen et al. (1999) compared the cost of RWH to the costs associated with potable water supplies in Denmark. Costs for RWH were estimated to be DKK 26-83/m3 for apartment buildings. RWH costs for detached dwellings could potentially be as low as DKK 10/m3, but only if the collection system was homemade. Compared to the production and total costs (including taxes and wastewater fees) of DKK 1-10/m3 and DKK 35/m3 for potable water, RWH was not an economically attractive alternative to public water supplies (Mikkelsen et al. 1999). Gardner and Vieritz (2010) also found that the cost of RWH was consistently higher than current public water sources. Optimizing storage volumes, decreasing capital costs (ex. not using a pump) or increasing potable water yields from RWH systems would decrease the costs per kL, though it is still unlikely to make RWH a competitive alternative with current potable water prices. RWH was, however, found to be economically competitive with newer urban supply options, such as desalination, potable reuse or dual reticulation and new dam construction (Gardner and Vieritz 2010).

Khastigir and Jayasuriya (2011) did not compare the cost of RWH to public water supplies; however, they did investigate relationships between economic and design variables for RWH systems. The price of potable water, discount rate, inflation rate and amount of rainfall were found to influence the payback period of a RWH system. As the rainfall amount increased, the payback period decreased, as less potable water was utilized; thus, RWH may be more economically feasible in areas with greater rainfall. Furthermore, the payback period for a given system decreased as the public water price increased, the inflation rate decreased, or the discount rate increased. These results highlight the important of selecting the optimal storage volume when designing RWH systems (especially in areas with low rainfall), as this will maximize the use of rainwater and minimize costs associated with the system, thus increasing its economic viability (Khastigir and Jayasuriya 2011).

Findings by Alam et al. (2012) and Herrmann and Hasse (1997) contradicted those previously discussed. Alam et al. (2012) compared the price of water supplied by RWH, conventional public water supplies and private water supplies in Sylhet City, Bangladesh. The conventional and private sources of water were found to be 3 and 4.5 times more expensive than RWH, leading to the conclusion that RWH was an economically advantageous alternative to other water supply sources. It is anticipated that these results are applicable only to the unique site and situation described in the Alam et al. (2012) study. Hermann and Hasse (1997) concluded that local RWH systems were a more economically efficient method of solving the Oberfranken, Germany water crisis than the establishment of a long-distance water supply, though this is the only study found that compared RWH to the construction of a long distance, high-capacity pipeline.

2.21 Social perceptions

While economic aspects of RWH systems might be the primary issue influencing implementation, social attitudes and acceptability is an important factor as well (Tam et al. 2010, Gardiner 2010). Gardiner (2010) identified and interviewed a total of 1,050 residents of South East Queensland, Australia. The residents belonged to 1 of 5 groups: 1) rural areas with RWH as sole source of water, 2) rebate subsidized, retrofit RWH in urban areas, 3) development where RWH was required as part of new construction, 4) development that required retrofit systems to be installed for toilet flushing and laundry, and 5) development that required retrofit systems with optional internal connections.

Citizens that were required to install RWH systems possessed an attitude of indifference towards the system, while voluntary users viewed the system as a valuable resource. Consequently, owners of regulatory-required systems were less engaged with the system and less knowledgeable of its operational aspects than voluntary users. Usage patterns differed among systems with internal plumbing connections and those without, even if both groups were required to install the systems. Usage patterns of systems without internal connections were similar to those of voluntarily-installed systems, where collected water was more often used for discretionary purposes such as irrigation and car washing. Users of internally connected systems were also less likely to have an intimate knowledge of the system"s operation and design, and often viewed the system as part of the overall plumbing infrastructure of the house (as opposed to an independent supply of water). (Gardiner 2010)

2.22 Energy consumption and environmental impacts

Kenway et al. (2008) reported potable water specific energy rates of 0.07kWh/kL and 1.9kWh/kL for Brisbane and Adelaide, Australia, respectively. Contrarily, estimated energy rates for a community-scale RWH system with UV disinfection in Brisbane were 5kWh/kL. Hood et al. (2010) found energy rates for a sustainable development in the Gold Coast, to be 1.3 kWh/kL. Note that this development employed numerous water and energy conservation measures and did not include disinfection in the RWH systems, resulting rates lower than the Brisbane system (Hood et al. 2010).

Based upon these results, it is apparent that the energy consumption associated with RWH implementation is greater than that of existing public water supplies; however, in areas using more energy-intensive methods of water production, it is possible that RWH may be more energy efficient. For example, Hall et al. (2009) found the rate for widespread implementation of household-scale RWH systems in South East Queensland to be comparable to that of a nearby reverse osmosis desalination plant.

2.23 Storm water management and rainwater harvesting

RWH systems can be effective tools for managing storm water runoff. They can reduce the volume and rate of storm water entering the storm sewer network by intercepting and storing runoff from catchment areas (Basinger et al. 2010; Zhang et al. 2009a; Zhang et al. 2009b; Ahmed et al. 2011a; Fewkes and Warm 2000; Guo and Baetz 2007; Kim et al. 2012). This section discusses models for RWH systems that incorporate stormwater management components and design modifications that may improve the mitigation potential of these systems.

2.24 Storm water modeling tool

Graddon et al. (2011) combined two modeling environments, urban Cycle and urban Net, to create a powerful model capable of simulating water quality, various supply/demand scenarios, storage and treatment requirements, water recycling and effects of usage restrictions, to name a few. The urbanCycle portion of the model utilizes hierarchal networks that can simulate RWH implementation at the building- or neighborhood-scale. Urban Net balances supply and demands and simulates storage behavior through the use of linear programming. Together, these two models can simulate an infinite number of RWH scenarios (including multiple spatial scales, non-rooftop catchment areas, prioritized demand and supply, wastewater incorporation and many more) and allow designers to optimize system design based upon various user-defined goals). (Graddon et al. 2011)

2.25 Using legislation and incentive programs to promote rainwater harvesting

The implementation of subsidies, rebates and legislation has been shown to significantly increase RWH adoption in many countries (Gardiner 2010). This section discusses the benefits and challenges associated with RWH policy implementation and summarize the policies that have been successful in promoting RWH implementation around the world.

2.26 Policy approaches

There are essentially two approaches to RWH policies: voluntary, incentive-based programs and mandated regulations. Government subsidies and rebate programs can be particularly effective in promoting RWH implementation. As opposed to regulations that require compliance, subsidies target individuals with an appreciation for RWH and provide an incentive for them to pursue adoption of RWH practices (Domènech and Saurí 2011). These people may be more likely to adequately maintain and operate RWH systems, thus maximizing the water savings benefits provided by the system. As subsidy recipients may be more environmentally conscious than other citizens, advertisements, workshops and awareness campaigns may be necessary to reach populations not as involved with water conservation issues (Domènech and Saurí 2011).

Baguma and Loiskandl (2010) found citizens were more likely to implement RWH when subsidies were awarded for specific aspects of the installation, such as hardware, excavation or storage tanks, than if cash subsidies were offered.

2.27 Challenges to policy implementation

Public health and liability are major concerns for entities considering policy implementation and agencies often opt for conservative legislation (Leidl et al. 2010). For example, RWH systems in Australia have not been utilized for drinking purposes as much as they could be due to a lack of understanding about microbial and chemical contamination risks and management practices (Ahmed et al. 2011a).

This was the case in France as well where, until 2008, French citizens were not allowed to use harvested rainwater for any indoor demands (Gires and de Gouvello 2009). Policies restricting end uses of harvested rainwater limit the water savings potential and economic efficiency of these systems; thus, it is important for policies to address the health risks associated with RWH while still allowing maximum use of the system (Ahmed et al. 2011a). This requires the integration of public education, engineering and public health research (Fry et al. 2010).

CHAPTER 3

METHODOLOGY

3.1 Materials and methods.

Chapter three discusses the quality and quantity approaches to rainwater harvesting system as the qualitative approach talked about subjecting the rain water samples collected to some physical, chemical and bacteriological test to see if it met national standard for house hold usages, while for the qualitative analysis was assessed using survey questionnaires for different household at different locations in Ikole. But firstly this chapter gives a brief description about the study area of which will be followed by the material used for the study.

3.2 Description of study area.

This section gives a brief description of the district in terms of location, demography, climate, soil and vegetation, and water resources.

3.3 Location and size

Ikole lies within the longitude $7°48'0$ North and latitude 5° $31'0East$.The mean annual rainfall is 1313mm.The rainfall starts from march to October/November. The daily temperature is between $22.2°c\ and\ 26.5°c$.The land form is high lying. covers a land area of about $321km^2$of the Ekiti state. Figure 3.1 shows clearly the Map of NigeriaWhile Figure 3.2 shows its location of on Ekiti state Map.

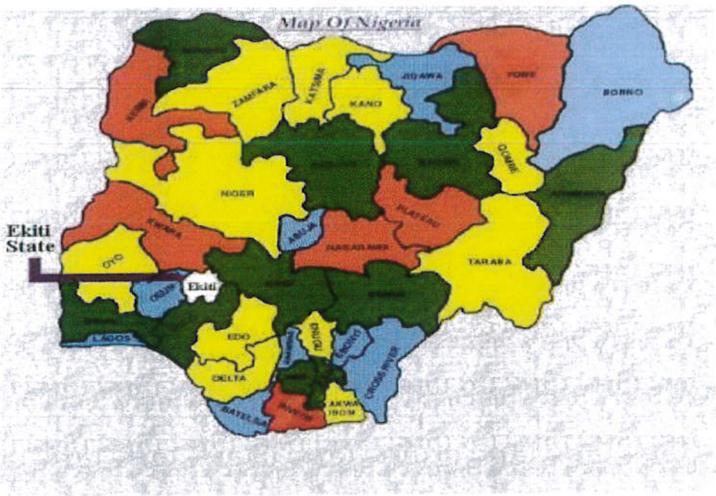

Figure 3.1: Map of Nigeria.

Figure 3.2: The location of Ikole- Ekiti on Ekiti state Map

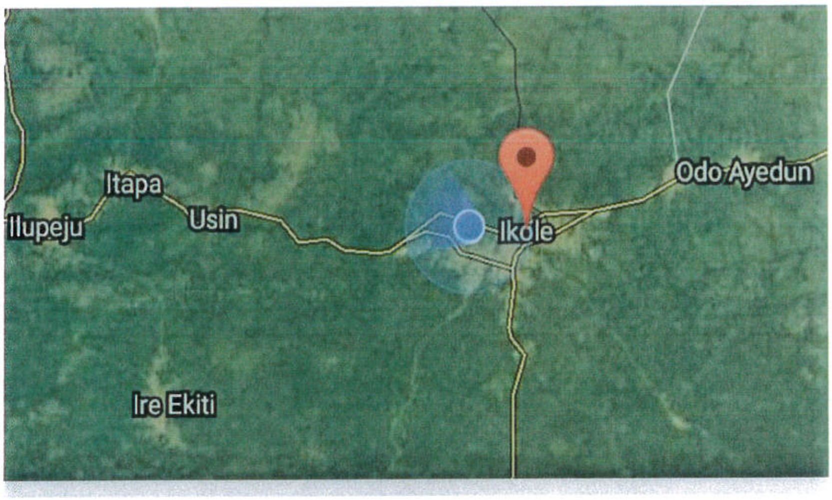

Figure 3.3: Location of Ikole - Ekiti

3.4 Demography and house hold characteristics

The district has about 230,000 people in 2016 projected based on 2006 population census.

3.5 Climate and Topography

The climate here at Ikole Ekiti is being classified as tropical, there is much more rainfall from April to September/October than the beginning of the year. The average annual normal temperature here in Ikole is $24.2°C$.Precipitation here averages between 1313mm.For the topography at Ikole Ekiti the town is 250m above sea level.

3.6 Materials

The materials for this study included water bottle containers to get water sample, 10 meters measuring tape, a Mobile phone to take pictures, a personal computer with Microsoft excel software for data entry and storage.

3.7 Methodology

In this paper, a case study was made to check for the viability of harvesting rain water making use of quality and quantity assessment of the water for domestic use. So as it was mentioned earlier on in this research study, two assessments were considered to check for the feasibility of rainwater harvesting here in Ikole-Ekiti which is the quality and quantity assessment. The method included the field measurement of roof catchments areas of the houses, household interviews using pre-designed questionnaires during quantitative assessments and laboratory analysis of water samples for quality when doing qualitative assessment of the water

3.7.1 Quality assessment.

For the rainwater quality assessment, water samples were collected from rooftops of some selected household which taken was at four locations which included Ootunja, Asin, Usin and Odi-olowo and Ilotin. Also in comparison to rain water samples collected, samples collected from hand dug well and borehole were checked to see to ascertain if the quality of rain water were far better than the other samples are. This all together comprised of 12 samples all together as they were collected into 5 litre kegs because there was a quite much number of test to be done. Samples were be analyzed using standardized physiochemical and bacteriological methods for water quality which included test like:

1. Turbidity.
2. Color.
3. Electrical conductivity.
4. Total hardness.
5. Total alkalinity.
6. Nitrate.
7. Fluoride.
8. Water PH.
9. Coliform count.
11. Total dissolved.
12. BOD
13. Chlorine.
14. Magnesium.
15. Lead.

10. Temperature

COLLECTION OF WATER SAMPLE.

Table 3.1 Details of Sample Source

Sample No	Types of source	Location	Latitude(N)	Longitude (E)	Comment
Sample 1	Rainwater	Mpado Hostel	7.798909 N7^{0}47’56’’	5.492716 E5^{0}29’33’’	Colourless Odourless
Sample 2	Rain water	Ootunja	7.79202 N7^{0}47’31’’	5.48745 E5^{0}29’14’’	Colourless Odourless
Sample 3	Rainwater	Usin	7.79669 N7^{0}47’48’’	5.48843 E5^{0}29’18’’	Colourless Odourless
Sample 4	Rainwater	Ilotin	7.79601 N7^{0}47’45’’	5.49236 E5^{0}29’32’’	Colourless Odourless
Sample 1	Hand dug well	Mpado hostel	7.798909 N7^{0}47’56’’	5.492716 E5^{0}29’33’’	Slightly Cloudy Unpleasant
Sample 2	Hand dug well	Gigonu House	7.798909 N7^{0}47’50’’	5.492716 E5^{0}29’33’’	Slightly Cloudy Unpleasant
Sample 3	Hand dug well	Olamide House	7.797449 N7^{0}47’56’’	5.501307 E5^{0}30’04’’	Slightly Cloudy Unpleasant
Sample 4	Hand dug well	CAC Ibudo	7.798909 N7^{0}47’56’’	5.492716 E5^{0}29’33’’	Slightly Cloudy Unpleasant
Sample 1	Hand Pump	Iya-Ibo House	7.798909 N7^{0}47’56’’	5.492716 E5^{0}29’33’’	Colourless Odourless
Sample 2	Hand Pump	Alayerogun	7.79202 N7^{0}47’31’’	5.48745 E5^{0}29’14’’	Colourless Odourless
Sample 3	Hand Pump	Ayeni Villa	7.79810 N7^{0}47’53’’	5.48778 E5^{0}29’15’’	Colourless Odourless
Sample 4	Hand Pump	Coded Villa	7.79776 N7^{0}47’51’’	5.48843 E5^{0}29’18’’	Colourless Odourless

Table 3.2: Physical, Chemical and Biological Parameters of Drinking Water

Parameters Health	Unit	NSDWQ	WHO	Health
Temperature	°C	Ambient	Ambient	None.
Appearance	-	Clear	Clear	None.
Odour	-	Odourless	Odourless	None.
Total Solids	Mg/l	Ambient	Ambient	None.
Turbidity	NTU	5	6	None.
Electrical Conductivity	µS/cm	1000	1200	None
PH	-	6.5-8.5	6.5-8.5	None
Nitrate (NO3)	Mg/l	50	50	Cyanosis, and asphyxia (blue-baby Syndrome) in infants under 3 month.
Total Alkalinity	Mg/l	250	250	None
Chloride (CL)	Mg/l	250	100	Consumer acceptability
Magnesium (Mg2+)	Mg/l	50	50	Consumer acceptability
Calcium(Ca2+)	Mg/l	50	50	None
Iron	Mg/l	0.3	0.3	None
Sulphate(S□□□	Mg/l	100	200	None
Dissolved Oxygen	Mg/l	-	-	None
BOD	Mg/l	5	5	Stagnant water (outbreak of
Bacterial Count	Cfu/ml	0	0	Urinary tract infections, bacteremia, meningitis, diarrhea, (one of the main course of mobidity and mortality among children) acute renal failure and hemolytic anaemia

3.7.1.1 Analysis of water samples.

The physicochemical and biological parameters were determined according to procedures and protocols outlined in the Standard Methods for the Examination of Water and Wastewater (APHA, 1992).

Temperature.

It was measured at the time of sample collection with a good mercury filled Celsius thermometer, having a scale marked for every 0.1°C.

Turbidity.

The method used was based on a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard Reference suspension. Samples were allowed to come to room temperature before the analysis. The samples were mixed thoroughly to disperse the solids. After air bubbles have disappeared, the samples were poured into the turbid meter tube. The turbidity value was read directly from the scale in Nephelometric Turbidity Units (NTU).

Water pH

The pH of water samples was determined immediately after sampling using Fisher brand Hydrus 100 pH Meter. The CALCULATE key was pressed to calibrate and the automatic calibration procedure was followed. The pH of the samples was measured by reading the values that displayed on the screen after the READY signal has disappeared.

Electrical conductivity

The Hi 9032 Microprocessor Bench Conductivity Meter was calibrated before the measurements were taken (By pressing the TDS key the display will show □TDS□ to confirm the measurement mode). Once the measurement reading stabilizes, the conductivity button on the instrument was pressed to display its value which was recorded on the data sheet.

Total alkalinity

A 50 ml sample was measured into a conical flask. Two drops of methyl orange indicator was added and the resulting mixture titrated against the standard 0.1 M HCl solution to the first permanent pink colour at pH 4.5. A reagent blank was performed without the sample

Calculation;

$$\text{Total alkalinity (CaCO3)} = \frac{A \times N \times 50{,}000}{V_s}$$

Where; VS =Sample volume (liters), A = Vo9lume of acid used, (liters) and N = Normality of acid.

Total Dissolved Solids

It was calculated indirectly from electrical conductivity values in μS. Total dissolved solids = 0.64 x EC (μS/cm)

Total hardness

Twenty-five (25) ml of the well-mixed water sample was measured into a conical flask. Two (2) ml of buffer solution and a pinch of Eriochrome black were added. If the sample turned into wine red in color, magnesium and calcium was present. The solution was titrated against 0.01 M EDTA until the wine red color turned to blue. A blank titration was also carried using distilled water.

Calculation;

$$\text{Total hardness} = \frac{(A-B) \times 1000}{C}$$

Where; A = volume of EDTA consumed for sample (ml), B = volume of EDTA Consumed for blank (ml) and C is the volume of the water sample (ml)

Magnesium

It was determined as the difference between total hardness and calcium as CaCO3.

Mg (mg/ l) = (Total hardness (as CaCO3mg / l) – Calcium hardness (as mg CaCO3/l)) x 0.243.

Chloride

It was determined by argentometric method. 1.0ml of 5% potassium chromate solution was added to 20.0ml of the sample and titrated with standard 0.014N AgNO3 solution till the colour changes to reddish brown.

Nitrate

An aliquot of 2 ml of 0.1 M NaOH solution and 1.0 ml of colour developing reagent was added to a sample. The mixture was allowed to stand for 20 minutes. The nitrate concentration was determined at wavelength 543 nm wavelength of absorbance using a 5500 photometer. A blank analysis was performed with all the reagents without sample for all the analysis.

Iron

A 250 ml of the samples was filtered through 0.45 µm cellulose membrane filter paper. The samples for iron determination were digested by adding 20 ml each of concentrated HN3 to 200 ml samples and heated on a mantle till the volume decreased to 50 ml. The samples were filtered and analyzed for iron using the flame Atomic Absorption Spectrophotometer (AAS). Triplicate determinations were made for the iron concentration determined.

Faecal coliform

The Coli scan medium was poured into a sterilized petri-dish, which was labeled with the code of sampling site and the quantity of sample water used from each site. A 250 ml of water from the sampling bottle was measured and transferred onto the petri-dish using a sterilized pipette. The water sample was swirled around the petri dish to ensure even distribution. The petri-dish was covered with lid and set aside at room temperature until the solution solidified. The procedure was repeated for all the samples, the petri-dishes were incubated at 44 °C for 24 hours. The petri-dishes were then taken out from the incubator, and all developed dark-blue and pink colonies were counted separately.

Calculation:

$$FC = \frac{\square_{\square}}{\square_{\square}} \square \; \square\square\square \frac{\square\square\square}{\square\square\square} \square \; \square$$

Where; FC= Fecal coliform, Coliform Faecal Unit (CFU) per 100 ml, CC = Colonies

Counted and $\square_{\square}$ = Volume of sample filtered (litres).

3.7.2 Quantity assessment

Quantitative analysis would include Data collection using quantitative data collection tools: a survey questionnaire would be used in other to access the types of rainwater collection method, type of storage used, amount of water collected, days of water usage after a particular rainfall activity, types of rooftop, the uses of water, do they treat their waters before usage, major problem faced when collecting water, and all other question that we will be included in it in other to access the quantity of water accessed by each household and how to sustain it for their daily usage.

CHAPTER 4

RESULT AND DISCUSSION.

This chapter presents the results and discusses the analyzed data from the field and laboratory. The survey data was reduced to means and percentages to facilitate easier interpretation.

4.0.1 Physical, chemical and biological analysis of rain water sample.

S/N	Parameters	UNIT	Raw sample ODI-OLOWO	Raw sample OOTUNJA	Raw sample USIN	Raw sample ILOTIN	W.H.O	NSDWQ
1	Temperature	^{O}C	24.2	25.4	22.4	22.7	25	25
2	Appearance	U	Clear	Clear	Clear	Clear	Clear	Clear
3	Odour	U	Odour Less	Odour Less	Odour less	Odour Less	Odourless	Odourless
4	Total Solid	Mg/l	4.50	3.20	14.20	3.20	500	500
5	Turbidity	NTU	0.00	1.00	0.00	0.00	6.0	0 - 5
6	E. Conductivity	υS/cm	400.00	500.00	400.00	700.00	1000	1200
7	pH Value		5.80	5.90	5.70	5.60	6.5	6.5 – 8.5
8	Nitrate (NO_4)	Mg/l	0.00	0.00	0.00	0.00	30	30
9	Total Alkalinity	Mg/l	73.20	48.8	73.2	73.2	250	250
10	Chloride Cl^{-2}	Mg/l	220.00	709.00	652.00	148.00	250	250
11	Magnesium Hardness Mg^{2+}	Mg/l	52.00	30.00	32.00	14.00	50	50
12	Calcium Hardness(Ca^{2+})	Mg/l	36.00	38.00	22.00	32.00	50	50
13	Iron (Fe^{2+})	Mg/l	0.04	0.01	0.04	0.03	0.3	0.3
14	Sulphate (SO_4)	Mg/l	0.00	0.00	0.00	0.00	200	300
15	Dissolved Oxygen	Mg/l	18.20	15.00	17.00	13.1	_	_
16	B.O.D	Mg/l	12.70	10.58	11.9	9.17	_	_
17	Bacterial Count	Cfu/l	0.00	0.00	0.00	0.00	0.00	0.00

4.0.2 Physical, Chemical and biological analysis of hand dug well.

S/N	Parameters	UNIT	Raw sample ODI-OLOWO	Raw sample OOTUNJA	Raw sample USIN	Raw sample ILOTIN	W.H.O	NSDWQ
1	Temperature	^{o}C	25.7	25.9	26.3	27.1	25	25
2	Appearance	U	Slightly Cloudy	Slightly Cloudy	Slightly Cloudy	Slightly Cloudy	Clear	Clear
3	Odour	U	Unpleasant	Odour Less	Unpleasant	Unpleasant	Odourless	Odourless
4	Total Solid	Mg/l	8.00	6.00	5.00	15.00	500	500
5	Turbidity	NTU	9.00	8.00	9.00	11.00	6.0	0 - 5
6	E. Conductivity	ʋS/cm	1600	1300.00	2100	1500	1000	1200
7	pH Value	-	6.0	6.80	6.10	6.40	6.5	6.5 – 8.5
8	Nitrate (NO_4)	Mg/l	4.25	6.30	0.45	0.33	30	30
9	Total Alkalinity	Mg/l	97.6	61.00	140.4	97.6	250	250
10	Chloride Cl^{-2}	Mg/l	453.76	652.28	581.26	446.7	250	250
11	Magnesium Hardness Mg^{2+}	Mg/l	50.00	84.00	42.00	92.00	50	50
12	Calcium Hardness(Ca^{2+})	Mg/l	30.00	136.00	156.00	75.00	50	50
13	Iron (Fe^{2+})	Mg/l	0.00	0.03	0.06	0.00	0.3	0.3
14	Sulphate ($SO_{4)}$	Mg/l	0.40	0.00	0.22	0.65	200	300
15	Dissolved Oxygen	Mg/l	7.50	15.00	11.15	8.5	–	–
16	B.O.D	Mg/l	5.70	10.58	8.05	5.95	–	–
17	Bacterial Count	Cfu/l	14.00	7.00	15.00	12.00	0.00	0.00

4.0.3 Physical, chemical and biological analysis of borehole sample.

S/N	Parameters	UNIT	Raw sample IYA-IBO HOUSE	Raw sample ALAYE ROGUN STREET	Raw sample AYENI VILLA	Raw sample CODED VILLA	W.H.O	NSDWQ
1	Temperature	^{O}C	24.2	25.1	24.5	26.2	25	25
2	Appearance	U	Clear	Clear	Clear	Clear	Clear	Clear
3	Odour	U	Odourless	Odour Less	Odour less	Odour less	Odourless	Odourless
4	Total Solid	Mg/l	2.50	5.00	6.00	3.00	500	500
5	Turbidity	NTU	0.00	1.00	9.00	4.50	6.0	0 – 5
6	E. Conductivity	ʋS/cm	1000	820.00	1400	460	1000	1200
7	pH Value		6.5	6.80	6.4	6.8	6.5	6.5 – 8.5
8	Nitrate (NO_4)	Mg/l	0.30	0.00	0.11	0.00	30	30
9	TotalAlkalinity	Mg/l	97.6	97.60	48.8	85.50	250	250
10	Chloride Cl^{-2}	Mg/l	354.5	860.5	194.0	194.00	250	250
11	Magnesium Hardness Mg^{2+}	Mg/l	42.0	84.00	60.00	52.00	50	50
12	Calcium Hardness(Ca^{2+})	Mg/l	61.00	32.00	56.00	52.00	50	50
13	Iron (Fe^{2+})	Mg/l	0.00	0.03	0.00	0.00	0.3	0.3
14	Sulphate (SO_4)	Mg/l	0.36	0.00	0.00	0.00	200	300
15	Dissolved Oxygen	Mg/l	9.20	15.00	16.20	10.20	_	_
16	B.O.D	Mg/l	6.43	10.58	11.63	7.13	_	_
17	Bacterial Count	Cfu/l	0.00	0.00	0.00	0.00	0.00	0.00

4.1 Analysis of result and discussion.

12 water samples were collected from boreholes, Hand dug well and rainwater sources during the rainy season. This section discusses the results from the laboratory analysis in terms of physicochemical and biological parameters to ascertain their quality for domestic purposes.

4.1.1 Temperature

The temperature of the rain water samples taken were the range of 22.7-25.4°C. While for the Hand dug well samples, the temperature of the samples taken, are in the range of 25.7-27.1°C as shown in figure 4.01, 4.02 and 4.03. Also, for the hand pump and borehole samples, the temperature of the samples was in the range of 24.2-26.2°C. The temperature of the samples taken were dependent on the environmental condition at the time of collection. It was observed that the rain water samples collected has the lowest temperature.

4.1.2 Appearance of Water Sample.

It was observed that the four samples gotten from the rain water, hand pump and borehole sources, have a clear appearance and they meet up with WHO and NSDWQ standard.

4.1.3 Odour of water sample

From rain water samples obtained from odi-olowo, usin ,Ilotin and ootunja were tested to be odourless which implies that the sample tested is devoid of bad smell which gives it an edge for safe drinking than other sources of that were at the other hand tested, while the raw sample obtained from the hand dug well had unpleasant smell except the sample 2 taken at odi-olowo, gigonu house for the hand pump borehole the 4 samples tested proved to be odourless in which the raw water and borehole sample met with the NSDWQ standard for testing water, but the hand dug well sample did not meet the standard due to it bad smell as this was caused by sulphate reducing bacteria and algal by product present in the hand dug well .Odour in water is due mainly to the presence of organic substances. Some odours are indicative of increased biological activity, while others may originate from industrial pollution. Sanitary surveys should include investigations of sources of odour when odour problems are identified.

4.1.4 Total solids

The values for the sample of rain water from 1 to 4 were 4.5, 3.20, 14.20 and 3.20 and according to WHO, the palatability of drinking water has been rated by panels of tasters in relation to its TDS level as follows: excellent, less than 300 mg/litre; good, between 300 and 600 mg/litre; fair, between 600 and 900 mg/litre; poor, between 900 and 1200 mg/litre; and unacceptable, greater than 1200 mg/litre Water with extremely low concentrations of TDS may also be unacceptable because of its flat, insipid taste, in which most of the samples of water were rated to be excellent for drinking in terms of total dissolved because it was less than 300mg/l which implies that it was devoid of Certain components of TDS, such as chlorides, sulfates, magnesium, calcium, and carbonates, affect corrosion or encrustation in water-distribution systems (sawyer and McCartey) 1967.

The total solid values for the hand dug well were 8.00mg/l, 6.00mg/l, 5.00mg/l and 15mg/l. Also, the borehole samples valued at 2.5mg/l, 5.00mg/l, 6.00mg/l and 3.00mg/l.

According to the WHO and NSDQW standard the Maximum allowable limits were for drinking water based on the concentration of total solids were not exceeded as shown in Figure 4.1.

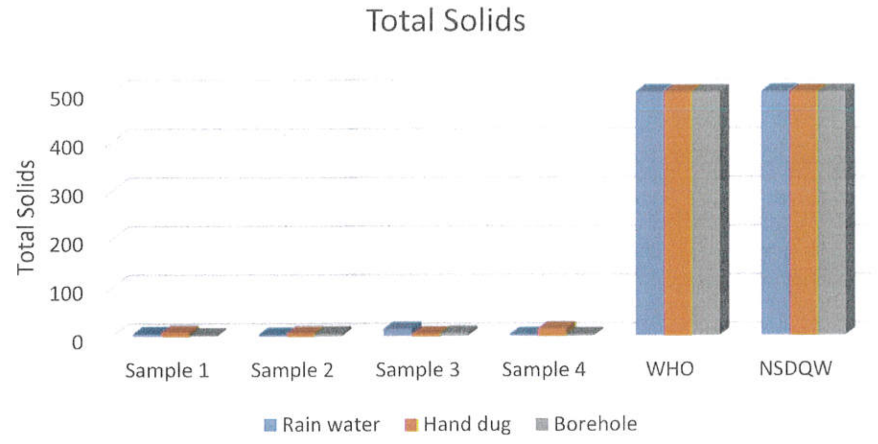

Figure 4.1 Total solid of all obtained sample with comparison to NSDQW and WHO standard.

4.1.5 Turbidity of water

The recommended value for turbidity is below 5.0 NTU for effective disinfection (WHO, 2006) and 6.0 NTU for NSDQW.The turbidity value for the rainwater of sample 1,2,3 and 4 were 0.00, 1.00, 0.00, 0.00 NTU respectively which abides with the WHO guideline for effective disinfection AND also makes it acceptable for drinking from its appearance to its consumer This is probably due to low levels of particulates such as smoke, dust, and soot suspended in the atmosphere which dissolved in the rain droplets as it falls from the sky. This may also be related to the presence of particles of clay, organic components and other microscopic substances (Ovrawah and Hymone, 2001). In addition, the low turbidity in the rainwater can be associated with frequent rainfalls during the sampling period. Appiah (2008) in the study of physicochemical analysis of roof run-off established that turbidity is affected by dry spell, and the longer the span of continuous rainfalls, the lower is the turbidity.

As shown in Table 4.0.3, the turbidity value of the hand dug well were 9.00, 8.00, 9.00 and 11.00 NTU in which fell short of the standard for WHO and NSDWQ in which they happened to be above 5.0 NTU for effective disintegration as it is not valid, this is due to the percolation of excessive of rainfall water into the ground which as a result disturbed the clarity of water and caused it to contain clay particles.

The turbidity of water for the borehole sample were 0.00, 1.00, 9.00 and 4.50 NTU as sample 3 appeared to be of higher value above the (WHO, 2006) guideline this could be the result of rainwater percolation in the soil that may have dissolved soil particles on its trip to recharge groundwater and for the low turbidity may be due to the fact that groundwater is naturally filtered by the soil and extracted by filter-aided mechanical pumps.

Generally, the borehole and rainwater had lower mean turbidity values below WHO (2006) guideline value of 5 NTU.The high turbidity levels in the hand dug well can cause problems during purification, possibility of micro-biological contamination, low dissolved oxygen, high temperature and decrease in the rate of photosynthesis in the study area.

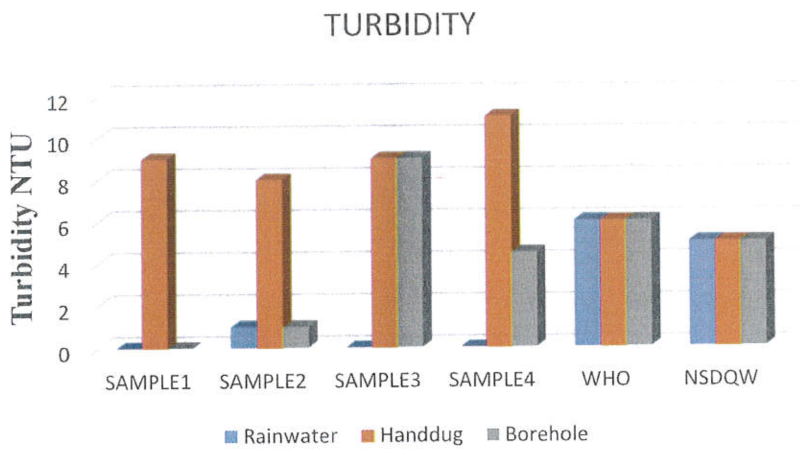

Figure 4.2 Total Solids (Mg/l) of all samples with comparison to NSDQW and WHO standard.

4.1.6 Electric Conductivity.

According to WHO (2006) electrical conductivity above 300 µS/cm can affect its suitability for domestic use, the WHO standard states that it should not be above 1200 µs/cm and as for NSDQW 1000 µS/cm.

The conductivity for the rainwater samples at Odi-Olowo, Ootunja, Usin and Ilotin are 400µs/cm, 500 µs/cm,400 µs/cm and 700 µs/cm respectively in which the latter sample happens to have the highest conductivity although there is no health impact when conductivity of samples of water exceeds the maximum limit of the water. low conductivity of rainwater may be due to low levels of organic and inorganic ions in the atmosphere. Further, the low conductivity of fresh rainwater isvalidated by frequent rainfalls combined with low temperature during the sampling period (wet season)

The conductivity of hand dug well for the 4 samples were 1600,1300,2100 and 1500 which happens to be above the allowable limit for the NSDQW(1000) and WHO (1200) which implies

The other 4 samples gotten from the borehole 1000,820 and 1400 and 460 all fell in the maximum allowable limit for NSDQW and WHO except for the 3rd sample with was 1400 µs/cm. The relatively low conductivity in the rainy season may be due low temperatures that reduce the mobility of the inorganic particles such as carbonate and bicarbonate ions in the aquifer. High temperatures might have enhanced the mobility of the inorganic particles in the aquifer. However, the presence of carbonates, for instance NaHCO3 in the aquifer may give salty taste to the borehole water leading to its rejection. The alkali carbonate resulted from meteoric water dissolving Na+ from sodium-bearing silicates (eg. Albite) or reverse cation exchange where Ca2+ is taken up from the groundwater, in return for Na+ helps to refresh the water quality and prevent it from having salty taste (Dickson and Benneh, 2004).

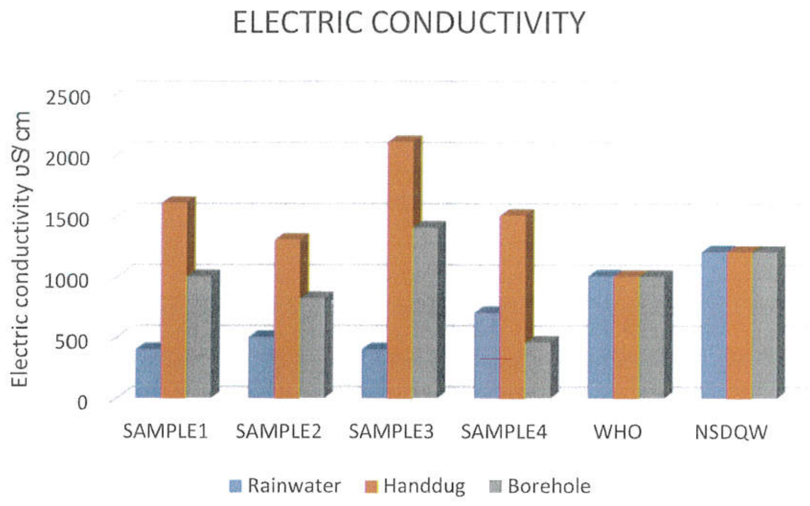

Figure 4.3: Electric Conductivity of all obtained Sample with comparison to NSDQW and WHO standard.

4.1.7 PH value

The acceptable range for the PH value of water as required by NSDQW is 6.5-8.5 while for WHO is 6.5.

The PH value of rain water sample at Odi-Olowo, Ootunja, Usin and Ilotin are 5.80,5.90,5.70 and 5.60 respectively in which the tested water was ranged to be acidic, corrosive and naturally soft as this low PH value can be attributed to wet atmospheric deposition of CO2, SO2 and NO2 produced by vehicular emissions including the slash and burn method of land preparation for farming in the study communities.

The PH value for the well sample stood at 6.0,6.80,6.10 and 6.40 respectively although this set of values fall below 7 but the stand s to be a little higher than the value of the samples for the rainwater, the only sample that fell within the range of drinking in terms of quality was the sample from Usin.

The PH value of the four borehole sample were within the range of 6.4-6.8, the sample from odi-olowo was valued at 6.50, Ootunja 6.80, Usin 6.40 and Ootunja 6.80 only the sample collected from usin fell out of the maximum allowable range of drinking water by WHO and the NSDQW as this might be due to the low mean pH in the dry season may have been caused by high temperatures that increased the concentration of H+ ions, hence decreasing the pH of the borehole water.

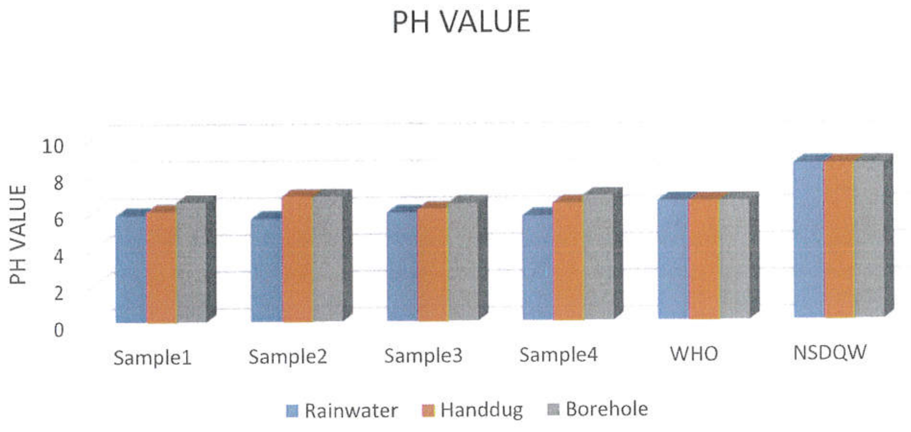

Figure 4.4: PH Value for all obtained Sample with comparison to NSDQW and WHO standard.

4.1.8 Nitrate

According to the WHO standard and NSDQW the suitability of water use for domestic usage should not exceed a limit of 30mg/l as*it* deleterious especially to babies due to the formation of methmoglobinamea (WHO, 2006).

The rainwater at the four locations had a nitrate concentration of 0.00 in all of the samples obtained. The absence of nitrates in the rainwater samples may be due no activity leasing to the dissolution and oxidation of NO2 to NO3- particles caused by the use of nitrogen fertilizers for crop cultivation in the study area.

The well water samples were 4.25, 6.30, 0.45 and 0.33 the sample from Odi-olowo and Ootunja had high nitrate concentration than the samples at gotten from Usin and Ilotin. The high nitrate concentration from the samples at Odi-olowo and Ootunja can be attributed to run-offs from nearby farms which carried nitrogen fertilizers through it percolating into the ground water which goes in to become part of the well water constituent.

The borehole samples had nitrate concentration of 0.30, 0.00, 0.11, 0.00 The low mean nitrate concentration in the borehole water may be due to the reduction of nitrate to nitrogen gas and ammonia by microbes (eg. Nitrobacteria). A study on the modeling of groundwater flow and quality by Konikow and Glynn (2005) found that the presence of organic carbon (present in the soil) in the soil may cause the reduction of NO3- to NO2 and sometimes to NH4+ ions in the phase of denitrifying microbes.

The entire sample obtained did not exceed the allowable limit for proper suitability for drinking water as prescribed by the WHO and the NSDQW.

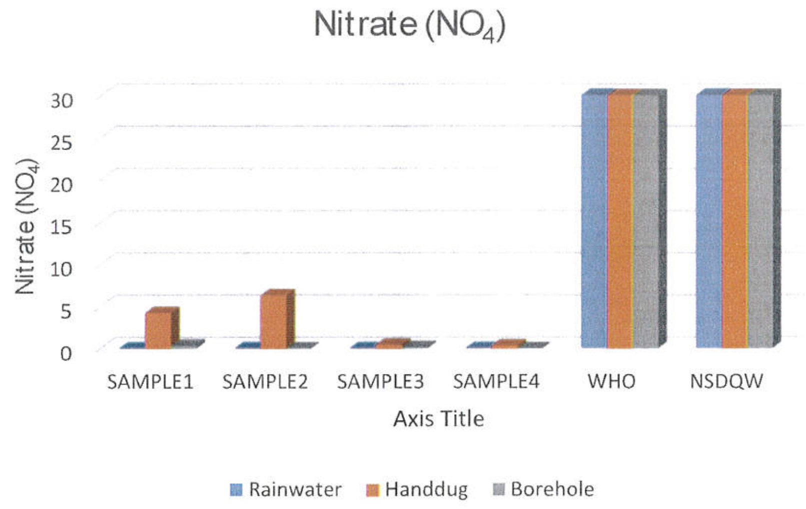

Figure 4.5: Nitrate (Mg/l) of all obtained sample with comparison to NSDQW and WHO standard.

4.1.9 Total alkalinity.

Rainwater from Odi-olowo, Ootunja, Usin and Ilotin had total alkalinity of 73.2mg/l, 48.8mg/l, 73.2 mg/l and 73.2mg/l in the rainy season respectively. The allowable limit of the for-drinking water as required by NSDQW and WHO were 250 mg/l and 250mg/l which none of the rainwater samples collected exceeded the limit.

Well water sample obtained from the four locations were valued at 97.6 mg/l, 61.0 mg/l, 140.4mg/l and 97.6 mg/l.

While the samples for the borehole were 97.6mg/l, 97.6mg/l, 48.8mg/l and 85.5mg/l. All the 12 samples fell within the acceptable range for quality water drinking as they did not exceed 250mg/l for the both requirements as stated above by WHO and NSDQW.

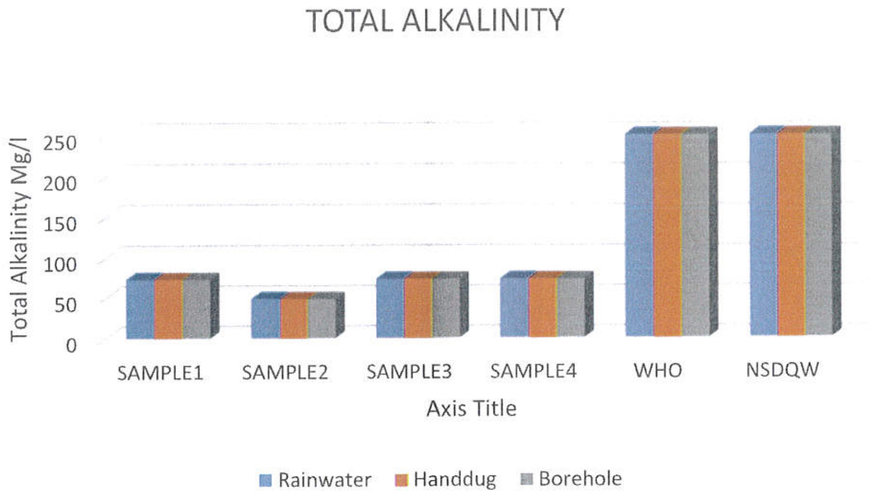

Figure 4.6: Total Alkalinity (Mg/l) of all Obtained Sample with comparison to NSDQW and WHO standard.

4.20 Chloride □□$^{□□}$.

The allowable limit for chloride concentration for drinking water as stated by the WHO and NSDQW is 250mg/l, Concentrations in excess of 250 mg/l are increasingly likely to be detected by taste, but some consumers may become accustomed to low levels of chloride-induced taste.

Rainwater sample had chloride concentration of 220.00 mg/l, 709.00 mg/l, 652.00mg/l, and 148.00mg/l in the four samples, of which sample 2 and 3 collected from Ootunja and Usin had very high concentration of chloride in them but there has been no confirmation traced to the adverse effect of excess of chloride in drinking water.

The hand dug well samples had chloride concentration of 453.76 mg/l, 652.28mg/l, 581.26mg/l and 446.7mg/l. All the four samples collected had very high concentration of chloride.

The borehole samples had chloride concentration of 354.5mg/l, 860.5mg/l, 194.00mg/l and 194.00mg/l. Of all the samples, sample three and four fell within the acceptable range for drinking water as prescribed by the two regulatory bodies.

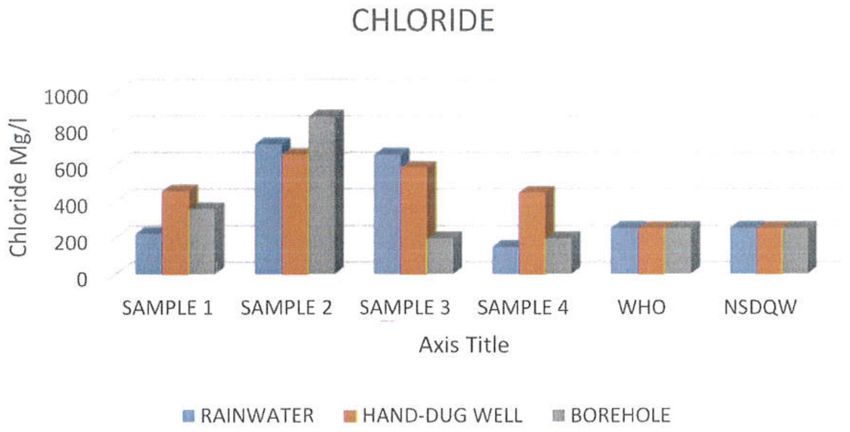

Figure 4.7 Chloride (Mg/l) of all obtained sample with comparison to NSDQW and WHO standard.

4.21 Magnesium hardnessMg^{+2}.

Depending on the interaction of other factors such as PH and Alkalinity, water with hardness above approximately 50mg/l may cause scale deposition in the treatment works, pipe work and tanks within the building.

Firstly, the rainwater samples were valued respectively at 52.00mg/l, 30.00mg/l, 32.00mg/l and 14.00mg/l.

The hand dug well sample had concentration of 50.00mg/l, 84.00mg/l, 42.00mg/l and 92.00mg/l in which three of the sample exceeded the WHO and NSDQW standard. A study by Olobaniyi (2007) of groundwater established that Mg+2 ions are usually released into groundwater by the dissolution of limestone, feldspars and micas which increases its hardness, as this as resulted to the increase of the magnesium hardness of the water.

The borehole sample contained 42.00mg/l, 84.00mg/l, 60.0mg/l and 52.00mg/l concentration of magnesium hardness in which three of the sample exceeded the WHO and NSDQW standard.

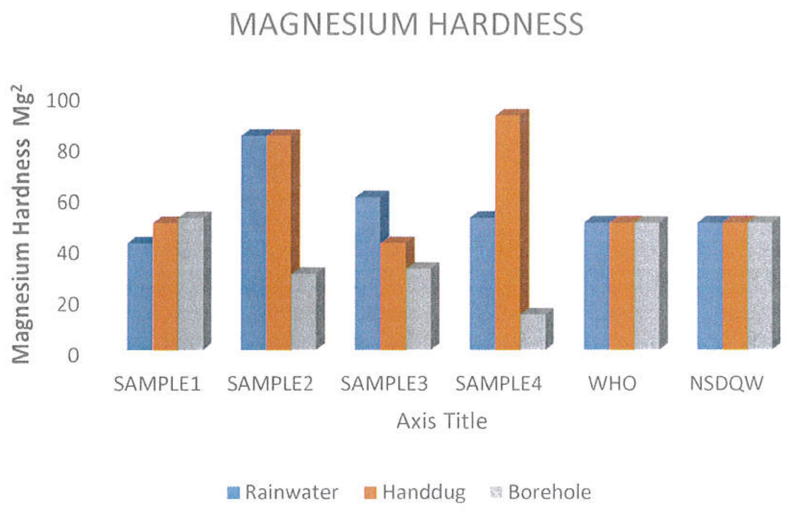

Figure 4.8 Magnesium Hardness (Mg/l) of all obtained sample with comparison to NSDQW and WHO standard.

4.22 Calcium hardness Ca^{+2}.

Water having calcium hardness at concentration below 60mg/l is generally considered as soft, 60mg/l-120mg/l as moderately hard and classified as more than hard when its concentration is around 180mg/l and above.

The rainwater samples had calcium hardness at 36mg/l, 38mg/l, 22.0mg/l and 32.00mg/l in which all samples of water were rated as soft provided that its concentration was not above 60mg/l. Calcium hardness of rainwater due to its concentration will allow scale formation on appliances at a reduced rate.

The hand dug well sample hardness were at 30mg/l, 136.00mg/l, 156mg/l and 75mg/l only sample 1 from Odi-olowo had lower concentration of calcium in it followed by sample 4 which was at the range of moderately had as the other had very high concentration of calcium of which they were being classified as more than hard.

The borehole samples had calcium hardness at 61mg/l, 32mg/l, 56mg/l and 52mg/l, as we can see sample one was the only one that fell out of the range of being classified as soft.

Moreover, as stated by NSDQW and WHO allowable limit for acceptability of the water sample should not exceed the limit of 50mg/l of which many of the samples obtained from the hand dug well exceeded those limits, owning to the reason being that samples have ions that have originated from run-offs that infiltrated into the soil, causing leaching and weathering of limestone and feldspars in the soil as this resulted into the precipitation of Ca+2 ions and other mineral constituents in the soil that can also increase the calcium hardness of groundwater.

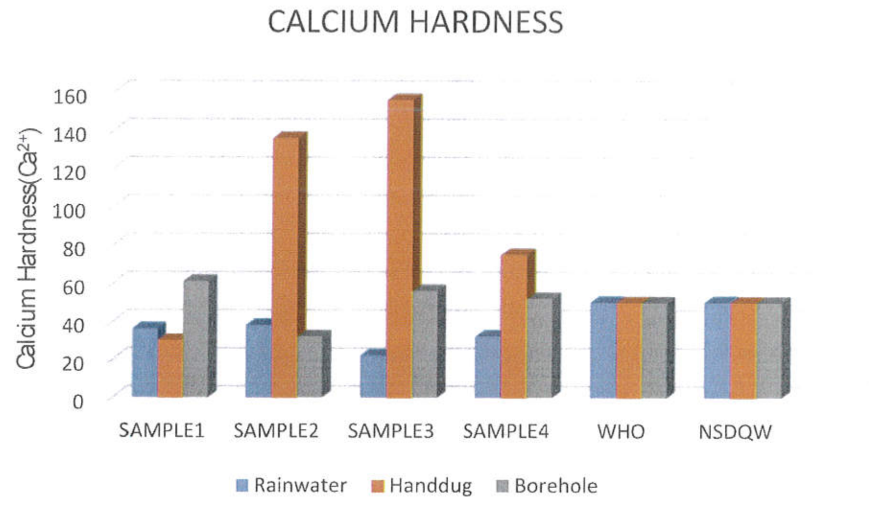

Figure 4.9 Calcium Hardness (Mg/l) of all obtained sample with comparison to NSDQW and WHO standard.

4.23 Iron.

Iron concentrations below 0.2 mg/l are safe, but the taste of water is affected when it exceeds 0.3 mg/l (WHO, 2006).

The rain water samples had iron concentration of 0.04mg/l, 0.01mg/l, 0.04mg/l and 0.03mg/l although it never meant that there was no iron concentration in the atmosphere but its presence in the atmosphere was at a very small amount.

The hand dug well had iron concentration at 0.00mg/l, 0.03mg/l, 0.06mg/l and 0.00mg/l. The samples had lower concentration of iron due to absence of rainwater percolation which led to the reduced amount of iron in the well.

The borehole sample had iron concentration at 0.00mg/l, 0.03mg/l, 0.00mg/l and 0.00mg/l respectively, all this samples also has their iron concentration at a reduced rate due to the. The low iron concentration in the wet season may suggest that very small amount of iron was dissolved by rainwater from lateritic soil into the groundwater. A study by Olobaniyi (2007) of the quality of groundwater and rainwater indicated that the occurrence of iron in the boreholes is due to the dissolution of iron from metallic wastes and scraps, and lateritic iron within the soil particles, but the dissolution of iron concentration was at a very low rate.

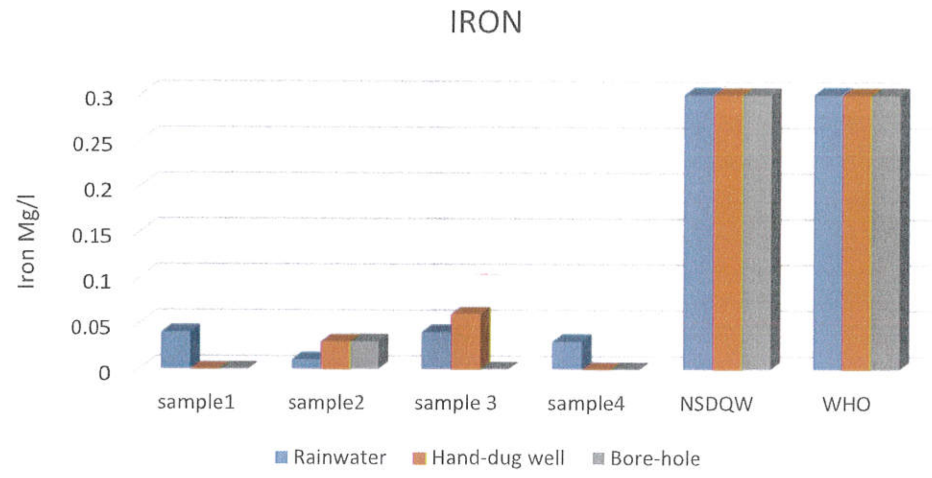

Figure 4.9 Iron (Mg/l) of all obtained Sample with comparison to NSDQW and WHO standard.

4.24 Sulphate.

The allowable limits for the concentration of sulphate in water as stated by WHO and NSDQW is 300mg/l and 200mg/l.

The rainwater samples had zero sulphate concentration in all of them that is from sample one to sample four were 0.00mg/l all through the samples at different locations.

The hand dug well samples had sulphate concentration of 0.4 mg/l, 0.00mg/l, 0.22mg/l and 0.65mg/l. This implies that the water sample for that location has low concentration of sulphate in them.

The borehole sample had 0.36mg/l, 0.00mg/l, 0.00mg/l and 0.00mg/l. As seen from the following result this implies that the location this samples were obtained from had negligible amount of sulphate in it.

But as seen from the result it had it highest concentrations in the ground water system which is the hand dug well which in which they are from natural sources.

Furthermore, the entire sample did not fallout of the WHO and NSDQW standard for drinking water.

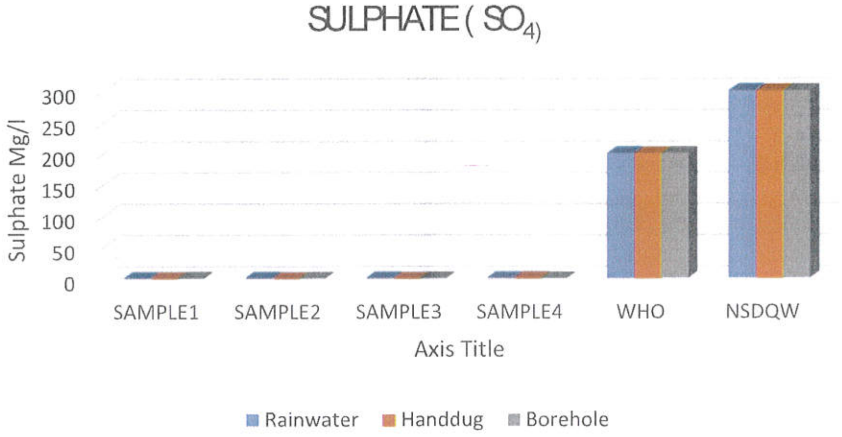

Figure 4.10: Sulphate Mg/l of all obtained sample with comparison to NSDQW and WHO standard.

4.25 Dissolved oxygen

The dissolved oxygen content of water is influenced by the source, raw water temperature, treatment and chemical or biological processes taking place in the distribution system. Although, no health-based guideline value is recommended. However, very high levels of dissolved oxygen may exacerbate corrosion of metal pipes.

The samples of rainwater had concentration of 18.20mg/l, 15.00mg/l, 17.00mg/l and 13.10mg/l, for the hand dug well samples it had 7.5mg/l, 15.00mg/l, 11.15mg/l and 8.5mg/l and for the borehole sample it has 9.2mg/l, 15.0mg/l, 16.20mg/l and 10.20mg/l.

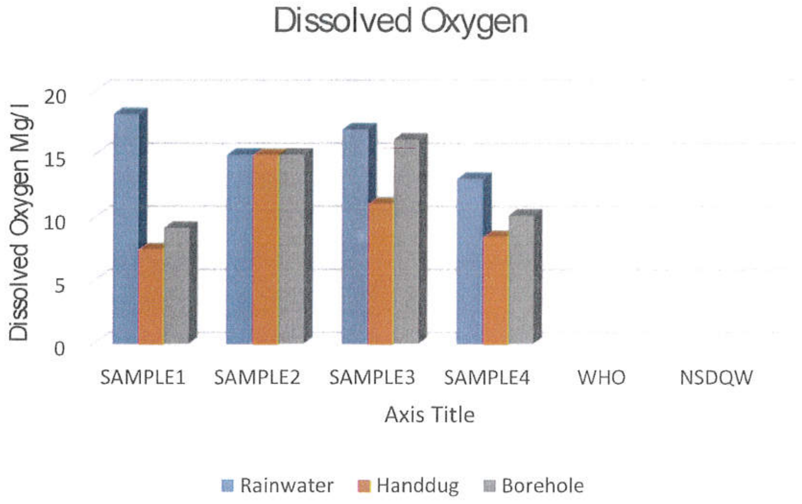

Figure 4.11: Dissolved Oxygen (Mg/l) of all obtained sample with comparison to NSDQW and WHO standard.

4.26 Biochemical oxygen demand

There is no health guideline for biochemical oxygen demand according to WHO and NSDQW. The rainwater samples tested gave the result as follows 12.70mg/l, 10.58mg/l,11.9mg/l and 9.11mg/l. The samples of hand dug well resulted to 5.70mg/l, 10.58mg/l, 8.05mg/l and 5.95mg/l. Lastly, the borehole samples gave 6.43mg/l, 10.58mg/l, 11.63mg/l and 7.13mg/l.

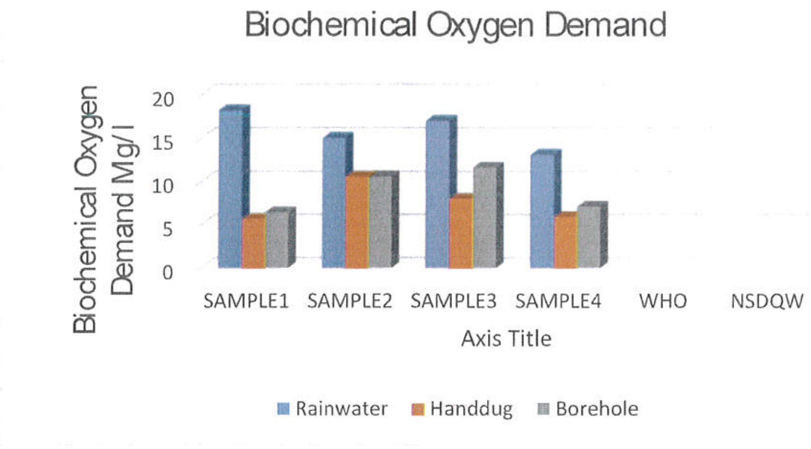

Figure 4.12: BOD (Mg/l) of all obtained sample with comparison to NSDQW and WHO standard.

4.27 Bacterial count

For water source to be considered as no risk to human health, the faecal coliform counts/100 ml should be Zero (WHO, 2006). The presence of bacteria suggests that it may be potentially harmful for human consumption, as it might cause urinary tract infections, bacteremia, meningitis, and diarrhea.

The rainwater sample had 0.00cfu/l, 0.00cfu/l, 0.00cfu/l and 0.00cfu/l in all the locations, as this result means that it is not harmful for household consumption.

The hand dug well sample had 14.00cfu/l, 7.00cfu/l, 15cfu/l and 12cfu/l in the four locations as this implies that the sample contained bacteria as this might be harmful for human consumption in terms of drinking.

The borehole sample also had 0.00cfu/l, 0.00cfu/l, 0.00cfu/l and 0.00cfu/l in the four location as this also give it fitness in terms of human consumption.

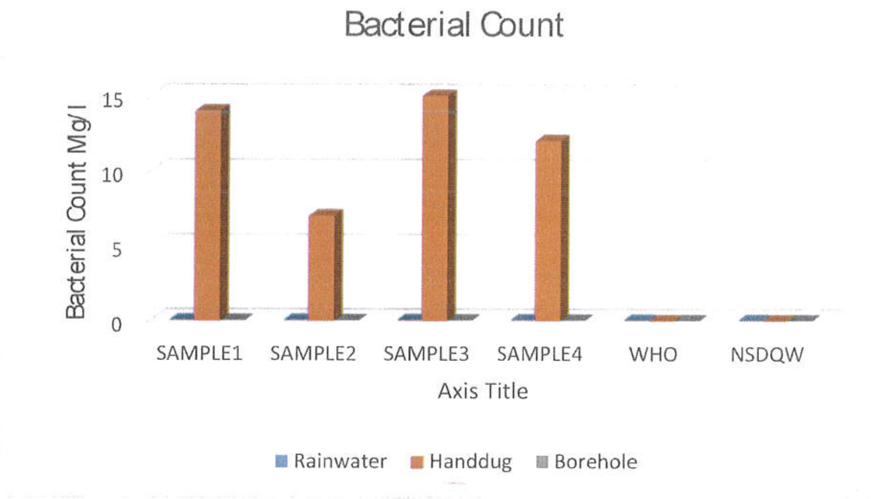

Figure 4.13: Bacterial Count (Cfu/l) of all obtained sample with comparison to NSDQW and WHO standard.

4.2 Response of survey Analysis

The results and discussions of analyzed statistical data are being presented below.

4.2.1 Household socio-economic characteristics

The size of household determines the quantity of water consumed in a household. The average household size was 6 persons per household in the 4 study communities. This excluded members who reside outside the household for more than six months. The relatively high household size can be attributed to the polygamous marriage practiced by the people in these communities. Eighty-four percent (22.5 %) of the respondents depended on agriculture as their main source of livelihood whilst 37.5 % relied on the non-agriculture sector which involved trading and the remaining percentages where 40% earned from activities like business, civil services, online business(This was obtainable from particularly students), bus drivers and tailoring.

4.2.2 Seasonal unreliability of the water sources

Hand dug wells, boreholes and rainwater harvesting were identified as water sources in the study areas in Ikole-Ekiti. These water sources were highly affected by seasonal variation especially in the dry season. In Odi-Olowo people relied on the rainwater, hand dug well and borehole water for their water supply, but sometimes due to long dry period between late January and early February they experience water shortage. The inhabitants of Ootunja, Usin and Ilotin also depend on the rivers, boreholes and hand-well for their water needs. However, heavy rainfall in the rainy season leaves the surface water such a river although was inhabitants of this communities hardly rely on this sources flooded, polluted and making it difficult to fetch water from such sources. And also for the hand-dug well, the water appearance is being disturbed when there is an occurrence of heavy rainfall which also rises the water level of the hand dug well.

4.2.3 Distance and time spent on water collection

Majority of the respondents (86 %) walked 300m returned trip on average to fetch water in the dry season. Such a distance is not too long to walk while carryingtheir 20 litres pail bucket, container head load of water. Respondents in Ootunjawalk 1 km per trip to collect water. This walking distance is very long as it is classified as „"NO ACCESS`` in service level description to obtain water, the respondent saidthey experienced this in the Ootunja community Owning to the rocky formation of that area, as this has hindered the digging of hand dug well in this area. All the respondents

collected water at an average distance < 0.1 km in the wet season, which may indicate that water from rainwater storage tanks is the main source for domestic needs during that period (rainy season). The World Health Organisation recommends 0.20 km (200 m) as a convenient distance fetching water (Sharma, 1996). Therefore, the distance covered by the people to fetch water is convenient considering WHO recommendation.

Time allocated to water collection differ among households and communities. Generally, households allocate more time walking long distances during the dry season than in the rainy seasons. More time is spent collecting water in the dry season than in the wet season. Women in Oyo State, Nigeria spent about one (1) hour daily to collect water at an average distance of 0.50 km (Sangodoyin, 1993).

4.2.4 Factors that affect the amount of water consumed by house hold per day.

Respondent gave factors influencing consumption of water like:

1. Variation in the number of people in the house-hold per day.
2. Changes in the weather.
3. The water scarcity.
4. Large queue of people fetching from the borehole and well point
5. Variation in the day to day use of water in each household.
6. For the church location at Ilotin the number of people attending the church at that particular time, they gave example of church their annual convention as a reason owning to the factor influencing the usage of water per day.

4.2.5 Household Water Consumption.

For the survey questionnaire allocated to the 40 households the average daily household water consumption was 232, 192, 216, and 220 litres in the rainy season for Odi-Olowo, Ootunja ,Usin and Ilotin areas respectively. In the dry season, the average daily household water consumption drops to 194, 162, 180 and 186 l/day for Odi-Olowo, Ootunja ,Usin and Ilotin areas respectively. The quantities of water consumed per activity showed little variation in all the four study locations. The quantity of water consumed by households in the dry season was lower because of water scarcity during this period, which makes households to adapt to lower water consumption strategies. Also, women and children can only carry small quantities for the long distance. The average per capita consumption of water in the dry season was 21, 18, 20, 22 l/day/p is correct taking into account 8 persons per household for, Odi-olowo, Ootunja, Usin and Ilotin respectively. Generally, the water quantities consumed daily exceeded the WHO minimum amount of 20 l/capita/dayof safe water needed for metabolic, hygienic and domestic purposes (WHO, 1996).And also it meets the requirement from Likely impact of service level in water demand and health from the basic access service level of description, but could not meet up with the rest due to the rural setting of that environment.

The reason for low consumptions levels may be due to inadequate water supply options, resulting in water consumption levels not matching-up with demand (London Economics, 1999). There was little variation in household water consumption between the four study locations. The relatively high household water Consumption in Odi-Olowo, Ootunja and Usin may suggest the absence of rocky terrain on their land settlement which made it easier for them to dig wells. However, the scarcity of hand dug well can be traced to the rocky land terrain in the Ootunja area, as this has caused women and children as the most likely individuals to travel longer distance in other to fetch water. This meant that households located nearer to the water source are likely to use water more than others located farther away.

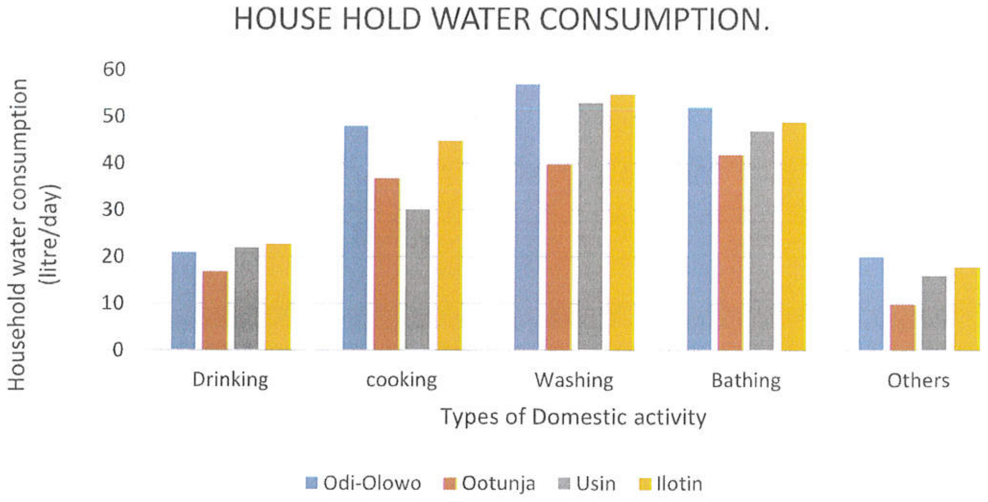

Fig 4.14: Average daily household water consumption and the type of domestic activity for rainy Season.

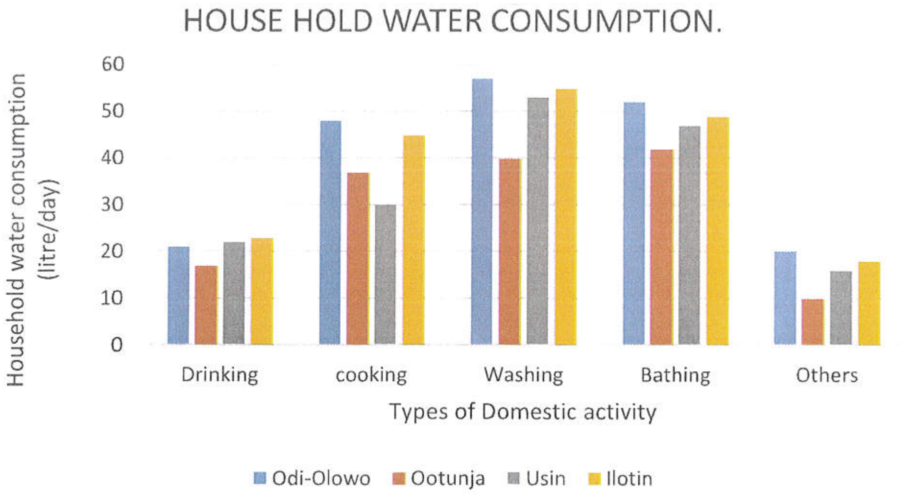

Fig 4.15: Average daily household water consumption and the type of domestic activity for dry Season.

Table 4.1 Likely impact of service Level in water demand and health table

Service Level Description	Distance/Time measured	Likely quantity collected	Level of Health concern.
No access	More than 1km or 30 minute walk	Very low often less than 5L/capita/day	Very high and consumption need not met.
Basic access	Between 100 m and 1000m (5-30) walk	Low about 20L/capita/day	Medium and not all requirements met.
Intermediate Access	One plot single tap in the yard	Medium About 50L/capita/day	Low and most basic and consumption need met
Optional Access	Water is piped through home through multiple taps	Very high 100L/capita/day to 300L/capita/day	Very Low and all use met.

4.2.6 Rain water Storage Capacity.

The water demand was compared to the mean rainwater supply to determine whether it is sufficient to meet the dry season mean water demand. In Ikole - Ekiti, mean rainwater supply was calculated as follows;

Table 4.2: Based on the estimation of annual water supply according to the mean roof size analyzed

Roof Area size	**R(Liters)**	**K**	**A(m^2)**	**S(l/year)**
Small roof ($35m^2$)	1200	0.9	35	37800
Medium Roof ($70m^2$)	1200	0.9	70	75600
Large Roof ($105m^2$)	1200	0.9	105	112400

Where S=R×K×A

Defining each parameter;

R= Rainfall.

K= Run off coefficient

S= Annual rainwater Supply

According to the demand of water per day from dry season The average per capita consumption of water in the dry season was 21, 18, 20, 22 l/capita/day taking into account 8 persons per household for, Odi-olowo, Ootunja, Usin and Ilotin respectively.

Table 4.3: Table showing the water demand for 5 months during rain fall in Ikole-Ekiti.

Study Location	**C(l/capita/day)**	**N**	**Water demand for 5 months.(150 days)**
Odi-Olowo	21	8	25200
Ootunja	18	8	21600
Usin	20	8	24000
Ilotin	22	8	26400

Where Water demand = C×n×N

C: Per capita water consumption

n: Average household size

N: Number of days in 5 months

From Table 4.3 it shows that in Ikole-Ekiti, the longest period of the dry season is from Early November to Late February. Thence, from this estimation it can be explained that annual rainwater supply from the roof catchment areas of the houses is greater than the annual water demand in all the four study locations. Therefore, the roof catchment areas of the houses are sustainable, as it is obvious that a storage capacity of 30,000 litres will be able to meet the annual household water demand in the dry season.

4.2.7 Water storage

For the 40 house-holds the rainwater tanks were surveyed with storage capacities ranging from 300 - 1500liters, although majority of the household do not make use of the obtainable storage tanks which ranged from 1500 litres to 3000 litres as only 6 households out of 40 of them made use of these storage tanks, other households in the other locations made use of buckets, barrels and bowls for storage of water. Based on the method of construction different materials such as concrete, plastic, and metal. Twenty-four (24) of the tanks were subsidized by the Ghana Presbyterian Church and 8 were financed by households. Plastic barrels (300 litres) were the most common water storage facility contributing 87.5 % of households whilst metal tanks and concrete tank constituted 10 % and 2.5 % respectively. Based on the duration on how hold the tanks are 50% ranged for the period of (0-3) years, while 32.5% has existed for a period of (4-10) years while 12.5% has existed for a period greater than 5years.The period of water supply in households varied from 1 week to 3 weeks, but the rainwater stored is used rapidly within a week to two weeks. Water collected were used for activities like drinking, cooking, bathing and washing.

Materials roofs were made up of included corrugated iron sheets (82.5%), Aluminum sheet (27.5%), thatched roof and others were not described.

4.2.8 Perception based on rainwater quality.

When respondents from the 40 house hold gave their ideas on how they ensure the quality of rainwater harvested most of them said they do wash the barrels before rain water storage as 42% constituted to this, whilst others 38% said they use ordinary eye inspection and the remaining 20% said they make use of filters from the entry point of the gutter into the storage tank, this implies that just small number of people make use of storage tanks.

Based on the response for diseases associated with collection of rainwater, 11 respondents 25% said they were being affected by disease from usage of rain water for consumption and drinking which includes tooth ache, typhoid and hepatitis.

For the frequency of illness during the rainy season 22% of respondent said they experience illness once in three months while the other 78% said they do not experience illness at all. For the frequency of illness during scarcity period the frequency of illness increased for the respondent as 44% said they experienced illness once in 3 months and 56% said they hardly experience illness.

4.2.9 Maintenance

Males in the family especially the heads had the responsibility for repairing the system which is usually two to three times in the rainy season. As they affirmed that their system was working well, only that they do check the gutter at entry point to see that there was no bird nest there to ensure they do not contaminate the rain water collected into the storage tanks with their excreta, they also said they check out for lizards.

Plate 4.14: Location of rain water harvesting system at Ilotin ACCF.

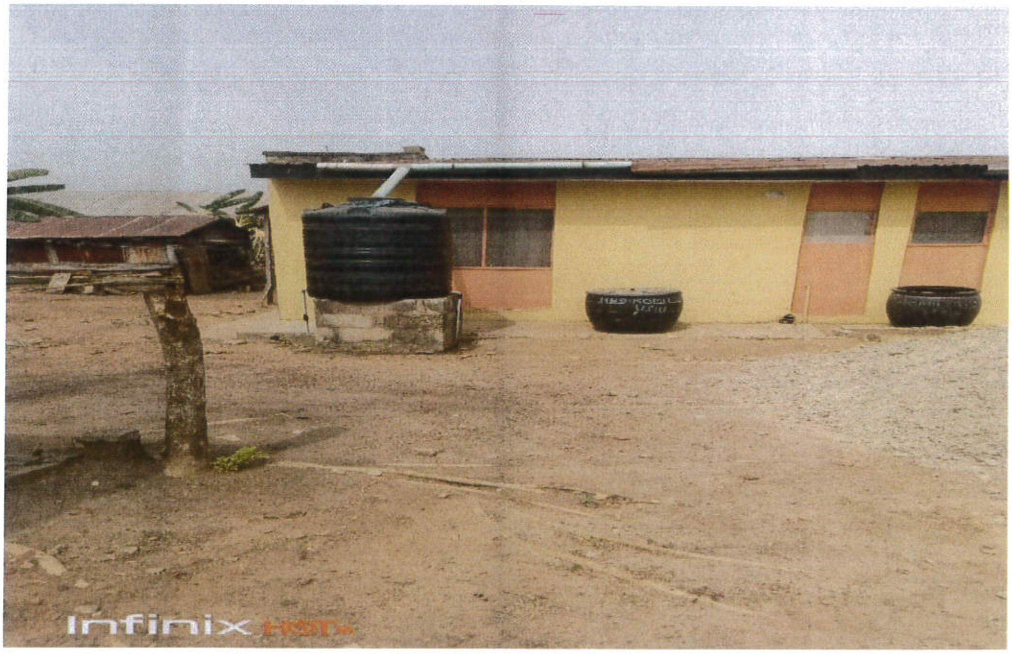

Plate 4.15: Location of Rain water harvesting system at Usin

Plate 4.16: Location of Rain water harvesting storage tank at Ootunja.

Plate 4.17: Location of Rain water harvesting storage tank at Odi-Olowo.

CHAPTER 5

5.0 CONCLUSION AND RECOMMENDATION.

5.1 Conclusion.

This study focused on the feasibility of rainwater harvesting system for domestic water usage as a focus on quality and quantity in Ikole-Ekiti. The appearance of the water for the four sample of rain water was clear, but the samples for the hand dug well had a poor appearance in which every of it sample was slightly cloudy. Based on the WHO guidelines that the quality of water at acceptable range should be very clear the samples of hand dug well faulted in its result. The results obtained from the turbidity of rainwater was acceptable, compared with the WHO and NSDWQ standard, but all samples of hand dug well fell out of the acceptable range having its turbidity at 9.00NTU, 8.00NTU, 9.00NTU, 11.00NTU.The result of electric conductivity for the rain water was within the acceptable range according to WHO and NSDWQ standard, all the 4 sample for the hand dug well did not meet the WHO and NSDWQ standard.

Furthermore, all samples obtained from hand dug well, borehole and rainwater fell within the acceptable range for the Total alkalinity result. Based on the chloride test the whole water sample obtained were out of the acceptable limit as stated by the two bodies. All samples tested for iron and Sulphate fell within the acceptable range for WHO and NSDQW standards for drinking water.

Based on the test result obtained for Bacterial count samples from the rainwater and borehole, results obtained fell within the acceptable range of WHO and NSDQW in which states that the bacterial count should be at 0.00cfu/l and 0.00cfu/l respectively.

5.2 Recommendation.

1. Domestic rainwater harvesting should be encouraged on large-scale to prevent the use of from the unsafe water sources.
2. Plastic and concrete reservoirs should be installed for storing harvested rainwater to meet the domestic water demand during the dry season.
3. The use of filters should be promoted and incorporated in storage tanks. The filters could be used to treat the supplementary contaminated water supplies as well.
4. Use of disinfectant such as chlorine should be engaged in the purification of water obtained from rain.

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APPENDICES

APPENDIX 1: QUESTIONNAIRE SURVEY FOR HOUSEHOLDS

QUESTIONNIARE.

SECTION 1: LOCATION AND BACKGROUND

1. Name of community……………………………………………

2. Sex of respondent. (i) Male [ ] (ii) Female [ ]

3. What is your educational level?
(i) None [ ]
(ii) Primary [ ]
(iii)Secondary [ ]
(iv) Post-secondary [ ]
(v) Others [ ] (specify)………………………………

4 a) How many persons live in your household? ……………………
b) How many of them are:
(i) Children (Below 18 years) …………
(ii) Adults (Above 18 years) ………….

5. a) What are the main sources of income in your household?
(i) Farming [ ]
(ii) Trading [ ]
(iii) Fishing [ ]
(iv) Others [ ] (specify)......................................

b) Does your household regularly receive any remittances from others (e.g. members of the family working outside the home)? (i) Yes [ ] (ii) No [ ]

SECTION 2: COLLECTION AND USE OF WATER

6. a) What sources of water do you have in your community?

(i) River [ ]

(ii) Borehole [ ]

(iii) Dam [ ]

(iv) Others [ ] (specify).......................................

b) What is the distance from your house to the source of water in km?

(i) River ....

(ii) Borehole ....

(iii) Dam..................................

c) How reliable is the source of water supply e.g. during dry seasons?

(i) Not reliable at all [ ]

(ii) Quite reliable [ ]

(iii) Very reliable [ ]

d) If not reliable enough where do you go to collect water for household consumption?

e) Is it easy to collect water from that alternative source? ....

7. a) Who is responsible for collecting water in your household? ....

b) What time is taken for daily water collection in your household?

(i) During wet season...................

(ii) During dry season.....................

c) What do youlike/dislike about water collection?

....

d) Are you ever short of water? (i) Yes [ ] (ii) No [ ]

e) If *yes*, which months? ....

f) How do you cope during periods of shortage?..

8. a) How much water do you use in your household on the following activities? Please Specify in gallons per day.

Activity Wet season (gal/day) Dry season (gal/day)	Wet season (litres/day)	Dry season (litres/day)
i) Drinking		
ii) Cooking		
iii) Washing		
iv) Bathing		
v) Others (specify)		

b) What factors influence the amount of water consumed by your household per day?
....

SECTION 3: DOMESTIC RAINWATER HARVESTING

9. a) Do you harvest rainwater for domestic activities? (i) Yes [ ] (ii) No [ ]

b) If *yes*, why did you decide to harvest rainwater..?

c) What type of storage container do you use to harvest rainwater?

(i) Metal tank [ ]

(ii) Plastic tank [ ]

(iii)Concrete tank [ ]

(iv) Others [ ] (specify)..........................

d) What type of material is your storage tank made of?

(i) Metal [ ]

(ii) Polyethylene [ ]

(iii) Cement and sand [ ]
(iv) Others [ ] (specify).......................................

e) How old is your tank?
(i) 0 – 3 years [ ]
(ii) 4 – 10 [ ]
(iii) > 10 years [ ]
(iv) Unknown [ ]

f) What is the capacity of your storage tank (measure and record in m...............................?

g) Have your tank ever been completely full? (i) Yes [ ] (ii) No [ ]

h) If *yes*, for how long could the tank serve your household with water? ....
(Days/weeks/months).

i) What do you use the rainwater collected for? ....

10. a)What type of material is the roof of your house made of?

(i) Corrugated iron sheet [ ]

(ii) Aluminum sheet [ ]

(iii) Thatched [ ]

(iv) Others [ ] (specify) ....

b) Area of roof guttered (measure and record in m) ....

c) Total roof area (measure and record in m) ....

12. What type of material is the gutter made of?
(i) PVC pipe [ ]
(ii) Galvanized steel sheet [ ]

(iii) Bent zinc roofing sheet [ ]

(iv) Others [ ] specify.................................

SECTION 4: KNOWLEDGE/PERCEPTION OF RAINWATER QUALITY

13. a) How do you ensure quality rainwater harvested ....?

b) Are there any common diseases associated with water consumption in this community?

(i) Yes [ ] (ii) No [ ]

c) If *yes,* describe any of the diseases you know of...

d) How would you describe your frequency of illness?

(i) Once in two weeks [ ]

(ii) Once a month [ ]

(iii) Once in 3 months [ ]

(iv) Rarely [ ]

e) How would you describe your frequency of illness during water scarcity periods?

(i) Once in two weeks [ ]

(ii) Once a month [ ]

(iii)Once in 3 months [ ]

(iv) Rarely [ ]

Thank you so much for your time and ideas for completing this form. I am happy to answer any questions you may have relating to this study.