QUALITY OF RAINWATER HARVESTED IN CISTERNS IN ONICHA-UGBO, ANIOCHA-NORTH LOCAL GOVERNMENT AREA OF DELTA STATE, NIGERIA

BY

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(MSC/SCI/00253/2011-2012)

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (MSC) DEGREE IN ENVIRONMENTAL MANAGEMENT

SEPTEMBER, 2015

DECLARATION

I declare that the work in thisdissertation titled “Quality of rainwater harvested in cisterns in Onicha-Ugbo, Aniocha-north local government area of Delta state, Nigeria” has been carried out by me in the Department of Geography, Ahmadu Bello University, Zaria under the supervision of Dr. A.E. Ubogu and Dr. J.O. Folorunsho. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any university or institution of higher learning.

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CERTIFICATION

This dissertationtitled Quality of rainwater harvested in cisterns in Onicha-Ugbo, Aniocha-North local government area, Delta state, Nigeriaby Chinonso EdwinUDEMEZUE, meets the regulations governing the award of the degree of Master of Science (M.Sc) Environmental Management in Ahmadu Bello University, Zaria and is approved for its contributions to knowledge and literary presentation.

Dr. A.E. Ubogu Chairman, Supervisory Committee	________________ Signature	________________ Date
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DEDICATION

Thisdissertation is dedicated to GOD ALMIGHTY, the source and giver of knowledge and wisdom, my parents, my wife, my loved ones and all aspiring students for the successful completion of this Master's programme.

ACKNOWLEDGEMENT

My greatest gratitude goes to the Almighty God for granting me the enablement not only to embark on this program, but to also conclude it successfully. The completion of this research work owes much to the encouragement, prayers and support of many individuals.I am full of gratitude to my supervisors, Dr. A.E. Ubogu and Dr. J.O. Folorunsho for their insightful criticisms, suggestions and patience throughout the course of this research work. I also acknowledge the contributions of Prof. I.A.Jaiyeoba, Prof. J.G.Laah, Dr. R.O.Yusuf, Dr.Y.Y. Obadaki, Dr.Sawaand Dr.BenedineAkpu amongst others.May God's favour never cease in your lives.

I am most grateful to my parents, Mr.&Mrs. Augustine Udemezue for their support and encouragement. To my dear wife Mrs.OnyinyechiUdemezuewhose added prayers and support was a great motivation to me, I say thank you. The prayers and support of my siblings; Mr.Chinedu, Mrs.ChinweEmodi, Mrs.BlessingOkafor, Mr.Gozie and Nwachukwuis acknowledged and most appreciated. May God's mercies never cease in your lives.I also offer my regards and appreciation to Mrs.Patricia Mbamali, Mr. Joseph Emodi, Mr. JosephYisa andMr. Clement Abraham for their encouragement and guidance.

I would like to seize this opportunity to thank the HOD of Geography department, Dr. I.J Musa, as well as all the academic and non-academic staff of Geography department for their mentorship and encouragement. I am indeed grateful to you all. I would most sincerely wish to express my profound appreciation to the bursar, FCE (T) Omoku, Mr. Christian OnyinkuroGoin for his support, understanding and encouragement. May the Lord almighty bless and reward you richly. To all my friends and classmates particularly, Emmanuel Aruya, Matthew Habila, Ariko Joseph, Naomi Eseuwa, MainaMamman, Edna Uwayeme, Favour Ezerioha and others too numerous to mention, for their contribution academically, morally and financially towards the success of this thesis.

To those whose names could not be mentioned, I know that all your contributions have been acknowledged by the Almighty God, which is more important than that of a mortal being like me. There is no gainsaying the fact that the collective good will, prayers, encouragement and support of everyone acknowledged here have been instrumental in giving me a success in this program. May God richly bless and reward you all. Amen.

ABSTRACT

Rainwater harvesting despite being an ancient practice in many parts of the world has very limited use as a source of potable water, primarily because the quality of stored rainwater in domestic tanks (cisterns) is not believed to meet drinking water quality standards. This study was aimed at assessing the level of potability of harvested rainwater in rainwater harvesting cisterns in Onicha-Ugbo, Aniocha-North Local Government Area, Delta State, Nigeria. The main objectives were to determine the concentrations of turbidity, pH, colour, TDS, TSS, COD, BOD, DO and total coliform count in the harvested rainwater samples and to compare them with the World Health Organization (WHO) and Nigerian Standards for Drinking Water Quality (NSDWQ) prescribed guidelines. Harvested rainwater samples were collected from twenty (20) different cisterns across the four quarters of the study area in the months of February (dry season sampling) and April (rainy season sampling) respectively. The harvested rainwater samples were analyzed with the most appropriate equipment and analytical techniques as recommended by the WHO and the NSDWQ in Nigeria. Simple descriptive statistic was employed to ascertain whether differences exist amongst the harvested rainwater samples collected during the dry and rainy seasons respectively. Results obtained indicated the following: most of the physico-chemical characteristics of the harvested rainwater samples were generally within the WHO (2010) and NSDWQ (2007) acceptable limits for drinking water. As such, the harvested rainwater characteristics showed satisfactory physicochemical levels in the study area. However, pH levels of the harvested rainwater samples were below the minimum acceptable limits of 6.5 as prescribed by the WHO and NSDWQ, hence treatment is needed in terms of the pH. Also, coliform bacteria were observed in all the harvested rainwater samples in the study. Although the levels of coliform bacteria didn’t meet the WHO drinking water specifications of 0cfu/100ml, it

fell within the 10cfu/100ml permissible limit as prescribed by the NSDWQ. Similarly, the Pollution index (pi) of the physicochemical and bacteriological water quality parameters reveals a ‘no significant degree of pollution’ for all the harvested rainwater samples in the study area using the water quality specifications by the NSDWQ. However, it indicates a significant degree of pollution for total coliform when making reference to the WHO water quality guidelines. Consequently, it is recommended that harvested rainwater in cisterns in the study area should undergo simple purification/disinfection techniques such as boiling and liming before consumption.

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CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Water is an indispensible substance to man and all life processes; it is the essence of life, without which human beings cannot live for more than a few days (Eletta and Oyeyipo, 2008). It plays a vital role in nearly every function of the body, protecting the immune system, the body's natural defenses and helping to remove waste matter. It is essential in maintaining and sustaining human, animal and plant life (Patil and Patil, 2010). Undoubtedly, water represents a unique and significant feature in any settlement: for drinking, sanitation, washing, planting, fishing, recreation, industrial process, etc. Succinctly, water is greatly important and is in great demand in all sectors of human endeavour and in every human settlement (Aderogba, 2005).

Water that is easily available and affordable is a prerequisite to good hygiene, sanitation and is central to the general welfare of all living things (UN, 2008). It is a prerequisite for all socio-economic development and for maintaining healthy ecological systems. Water is of great importance for domestic, industrial, agricultural, religious and recreational uses (Folorunsho, 2010); hence, it is very critical for the socio-economic survival of the human race without which life as it exists on our planet is impossible (Asthana and Asthana, 2001).

According to Cummingham, Cummingham and Siago (2003) and Duggal (2004), of all the elements essential for the existence, survival and sustenance of human beings and animals, water is rated as the greatest. Water plays a vital role in the development of a stable community, since human beings can exist for days without food but absence of water for a few days may lead to death. Water is an essential pre-requisite for the establishment of a stable community. In the absence of which nomadic lifestyle becomes necessary and communities move from one area to another as demand for water exceed its availability.

Globally, the demand for water for agricultural, industrial, domestic and other purposes will continue to increase with increasing world population as a contributory factor, such that an estimated additional 5,600km^3/year of water may be required to cope with population growth and nutrition in 2050 (Rockstrom, 2002). Similarly, the global water situation is so precarious that without immediate action, it is estimated that by 2025, two-thirds of the world population will have difficulty surviving in water stressed areas (Mendidia Exclusive, 2008).

The need for clean water for drinking, cooking, bathing and other household needs had long been recognized. It is estimated that over one billion people still lack safe domestic water supplies, while 2.4 billion lack adequate sanitation (Meinzen-Dick and Rosegrant, 2001). The resulting human toll is roughly 3.3 billion cases of illness and 2 million deaths per year. Moreover, even as the world's population grows, the limited easily accessible freshwater resources in rivers, lakes and groundwater aquifers are dwindling as a result of over-exploitation and water quality degradation (IAEA, 2004). This statistics, no doubt holds true mostly in the developing economies of Asia, Latin America and Africa, where poverty has assumed an endemic root. Understanding water risk in developing countries implies coming to terms with issues of unsafe drinking water and scarcity, which varies in time and space, water related threats, as well as quality and quantity issues (Emmanuel and Ekanem, 2009).

The World Bank (2002) stated that one of the key issues emerging in our time is access to clean water. It is established that just 12% of the global population consumes 86% of the available water while 1.1 billion people (one-sixth of the world's population) have no access to adequate water supplies, where access is defined as the availability of at least 20 litres of water per person per day from an improved water source within a distance of one (1) km (Bates, Kundzewicz, Hu and Palutikof, 2008). As global demand for clean water is increasing, changes in climate and population are reducing potable water. While the resources available to cater for the demand are shrinking, the potentials for large scale water resource development in poor countries are overshadowed by financial constraints and changing donor policies. This leads to an emerging interest in improving safe water access (Rafee and Hassan, 2010).

Access to safe water supply is fundamental to life and health. By extension, it is a prerequisite for realizing other basic human rights (WHO and UNICEF, 2000). The vital importance of water for development is reflected in one of the Millennium Development Goals (MDGs) which requires halving the proportion of people without access to safe drinking water and adequate sanitation by 2015 (WHO and UNICEF, 2000). It is documented that less than ten countries have about 60% of globally accessible water, suggesting inequitable distribution of water globally and nationally (Swaminathan, 2001).

Water as one of the most valuable resources that is widely distributed all over the world is available to mankind for sustenance and survival. However, many of Nigeria's major cities and urban centres face shortage of safe and potable water supply, with existing storages unable to meet increasing demands (Lamikanra, 1999). The provision of improved water to millions of households in Nigerian rural communities with no access to it remains one of the greatest challenges for sustainable development. The lack of access to safe water supply is a precursor to waterborne diseases, with the children and the elderly mostly affected especially within poor rural communities in developing countries (Rafee and Hassan, 2010).

The provision of potable water for domestic and other uses in rural and urban centres is one of the most intractable problems in Nigeria today, with 52% of Nigerians lacking access to improved drinking water supply (Lekwot*et al*., 2012; Orebiyi*et al*., 2010). One reason the provision of safe drinking water is of paramount concern is that 75% of all diseases in developing countries arise from polluted drinking water (TWAS, 2007). Moreso, 25,000 people die each day from the use of contaminated water borne illnesses (Mason, 1996). In addition, about half of the people that live in developing countries do not have access to safe drinking water and 73% have no sanitation. Some of their wastes eventually contaminate their drinking water supply leading to a high level of suffering. Furthermore, more than five million people die annually from water borne diseases. Of these, about four million deaths (400 deaths per hour) are of children below the age of five. Consequently, the lack of safe drinking water also stunts the growth of 60 million children per year (WHO-UNICEF, 2000).

The lack of public water system in the rural areas and the inability of water facilities to function effectively in the towns and cities of Nigeria have made it impossible for most of her population to have access to potable water (Orebiyi*et al*., 2010). Sources such as rivers, boreholes, streams, wells, ponds and rainwater are still very much depended upon for water needs. In the developed countries of the world, the average domestic use of water including that for all purposes per person is 180-230litres per day while in Nigeria, the average domestic consumption by individuals is 2.25 litres per day as against 115 litres per head per day by the World Health Organization (Chima, Nkemdirim and Iroegbu, 2009). Given the fact that the publicly operated water supply systems have not been able to cope with the increasing demand, there is a need for a paradigm shift from the public monopoly of water supply to an innovative approach. Rainwater harvesting technology appears to be one of such alternative approaches.

Rainwater harvesting is the method by which rainwater that falls upon a roof surface is collected and routed to a storage facility for later use (Lye, 2009). It is an economical small-scale technology that has the potential to augment safe water supply with least disturbance to the environment, especially in the drier regions (Ishakul, Rafee, Ajayi and Haruna, 2011). The conscious collection and storage of rainwater to cater for demands of water, for drinking, domestic purposes and irrigation are termed "harvesting". Rainwater harvesting is a technology used to collect, convey and store rainwater from relatively clean surfaces such as roof, land surfaces or rock catchments for later use. It captures, diverts and stores rain water for later use. The collected water is generally stored in a rainwater tank (cistern) or directed into mechanisms that can recharge groundwater (Krishna and Hari, 2009).

A cistern (storage tank) is a receptacle built to catch and store rainwater (Pacey and Cullis, 1986). Cisterns can be either above or below ground; however, they are usually built underground and come in range of sizes and shapes with varying features. Most large cisterns are underground tanks, while smaller models can be purchased and placed above ground. They range in capacity from a few litres to thousands of cubic meters. Many people in dry or rural areas have cisterns to back up their regular water supply, and in some cases, a cistern is used as the primary source of water for households (Camilli, 2000).

1.2 STATEMENT OF THE RESEARCH PROBLEM

Poor quality of water has been principally associated with public health concerns through transmission of waterborne diseases that are still major problems in Africa and in many developing world (Ongley, 1999). The World Health Organization (2000) estimates that four billion cases of diarrhoea are reported each year around the world, in addition to millions of other cases of illness associated with lack of access to clean water. Gleick (2002) estimated global deaths arising from water- related diseases at between 2 - 5 million yearly. Although there are no accurate data on water related cases and deaths in Nigeria, studies have however shown that cases of typhoid, cholera and other water related disease and deaths have been on the increase in recent times (Ojeifo, 2011).

The quality of rainwater collected depends on when it is collected, how it is stored as well as method of use (Ariyananda, 2003). The quality of rainwater also depends on the atmospheric pollution of the individual area, the proximity to pollution sources and the level of cleaning and attendance (Zhu *et al*., 2004). Microbial contamination and other water quality problems associated with rainwater harvesting systems are most often derived from the catchment area, conveyance or storage components (Lye, 2009). Public health risks associated with microbial pathogens remains the most significant issue in relation to using untreated harvested rainwater for drinking or other potable purposes (Muhammad and Mooyoung, 2008); hence the quality of rainwater in tanks has been the subject of much controversy.

Although rainwater harvesting has been receiving increased attention worldwide, as an alternative source of water, its use as potable water supply is very limited and the main reason is obviously the quality of stored rain water in domestic tanks believed not to meet the drinking water quality standards (Amin and Alazba, 2011). Also, despite having some clear advantages over other sources, rainwater use has frequently been rejected on the grounds of its limited capacity or due to water quality concerns (Regab*et al*., 2003).

It has also been reported that, due to geographical difference and anthropogenic activities, rainfall in various regions have their special characters. Even in the same region, synoptic situations and air-borne pollution scattering vary seasonally, resulting in large chemical components in rainfalls (Changling*et al.*, 2005). Atmospheric deposition have also been considered to be a major source of toxic metals such as Mercury (Hg), Cadmium (Cd), Lead (Pb) and several other trace metals to our ecological system and poses great risks to people who depend on this source of water resources (Chukwuma*et al.*, 2012).

Previous studies on the quality of water resources in the tropical African environment have largely been restricted to surface and groundwater to the negligence of rainwater (Olobaniyi and Owoyemi, 2006). This is predicated by the assumption that rainwater was pure and could be consumed without pre-treatment. While this may be true in some areas that are relatively unpolluted, rainwater collected in many locations contains impurities (Bankole, 2010). The vulnerability of rainwater and groundwater to quality degradation from human activities makes a periodic assessment of their qualities necessary (Ige and Olasehinde, 2010).

According to Moe, Sobsey, Samsa and Mesolo(1991) the incidence of diarrheoa in children was significantly related to drinking water containing high levels of bacterial contamination (>1000 *Escherichia coli* per 100ml) but little difference was observed between illness rates of children using either good quality drinking water (<1 *E. coli/*100ml) or moderately contaminated drinking water (2 - 100 *E. coli* per 100 ml). Cancer, arthritis, skin irritation and eruption, heart disease, central nervous system pathology, skin rashes, kidney problems and bronchitis are the diseases associated with water pollution by chemicals. The amounts of concentration that can cause sickness to its consumers depend on concentration and composition of its contaminant chemicals (Eja, 2012).

Kalia (2006) in an assessment of rooftop rainwater harvesting in Nagpur, India stated that contrary to the widely held theoretical view of rainwater being one of the purest forms of water, the quality of rainwater maybe affected during harvesting, storage and household use. The study revealed that the quality of water collected in a rainwater harvesting system can be affected by numerous factors, including dry periods (Sazakli and Leotsinidis, 2007), the type of catchment (Nair, Gibbs and Ho, 2001), and the storage conditions (Chang, Matthew and Beasley, 2004). Weather patterns can also significantly influence the bacterial load in roof run-off. The catchment surfaces can significantly degrade the quality of rainwater and are often viewed as potential sources of contamination for rainwater (Evans, Coombes and Dunstan, 2006).

Achadu, Ako and Dalla (2013) in their study on quality assessment of stored harvested rainwater in Wukari, North-Eastern Nigeria: Impact of storage media revealed that all stored rainwater samples tested positive to faecal coliform and the counts were above the WHO standards for drinking water. Although, the trace and heavy metals in the water samples were relatively within the WHO standards, copper and iron levels were high. They concluded that harvested rainwater may not be suitable for direct drinking without treatment but could be used for other domestic purposes.

Furthermore, Tobin, Ediagbonya, Ehidiamen and Asogun (2013) in their assessment of rainwater harvesting systems in a rural community of Edo state, Nigeria showed that majority of the thirty (30) water samples tested had unacceptable levels of total coliform, while one sample had Escherichia coli.

Also, Ushurhe and Origho (2013) in a comparative assessment of the quality of harvested rainwater, underground water and surface water for domestic purposes in Ughelli, SouthernNigeria revealed that pH mean values were generally low (5.90 – 6.97) for rainwater. Moreso, all the dissolved oxygen (DO) values were above the world health organization (WHO, 2010)acceptable threshold for drinking water, thereby making the water unsafe. The high value of the dissolved oxygen in the rainwater (7.44mg/l) shows the presence of bacteria and activities. This implies that there is a strong indication of a reducing agent in the water and if such water is consumed without further purification, it may cause instant death in the living organisms. Biological oxygen demand (BOD) was also slightly low in harvested rainwater (1.07mg/l). This implies that the concentration of soluble organics reaching the rainwater is generally low.

Although several research works have been carried out on harvested rainwater quality, none of such works has been conducted in Onicha-Ugbo, Aniocha-North Local Government Area of Delta state, Nigeria to the best of the researcher's knowledge. Thus, it is against this background that this study aims atassessing the level of potability of rainwater harvested in rainwater harvesting cisterns in Onicha-Ugbo, Aniocha-North Local Government Area, Delta state, Nigeria. The research will attempt to address the following questions:

i. What are the forms of rainwater harvesting cisterns employed in the study area?
ii. What are the levels of turbidity, colour, temperature, pH, total dissolved solids (TDS), total suspended solids (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD), dissolve oxygen (DO) and totalcoliform count in the study area?
iii. In comparison with national and internationally recommended standards for drinking water, is the level of turbidity, colour, temperature, pH, total dissolved solids, total suspended solids, chemical oxygen demand, biological oxygen demand, dissolve oxygen and total coliform count within the approved permissible limit for drinking water?
iv. What is the pollution index of turbidity, colour, temperature, pH, total dissolved solids (TDS), total suspended solids (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD), dissolve oxygen (DO) and total coliform count in the study area?

1.3 AIM AND OBJECTIVES OF THE STUDY

The aim of this research work is to assess the level of potability of harvested rainwater in rainwater harvesting cisterns in Onicha-Ugbo, Aniocha-North Local Government Area of Delta state, Nigeria. The specific objectives are to:

i. identify the forms of rainwater harvesting cisterns in the study area.
ii. examine the levels of turbidity, colour, temperature, pH, total dissolved solids (TDS), total suspended solids (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD), dissolve oxygen (DO) and total coliform count of rainwater samples harvested in rainwater harvesting cisterns in the study area.
iii. compare results in objective (ii) above with the World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) recommended standards for potable water.
iv. determine the pollution index (Pi) of individual water quality parameters from the sampled rainwater harvested in rainwater harvesting cisterns in the study area.

1.4JUSTIFICATIONOF THE STUDY

The Poor quality of water has been principally associated with public health concerns through transmission of water borne diseases that are still major problems in Africa and in many other parts of the developing world (Ongley, 1999). Nevertheless, SIWI/WHO (2005) believes that almost one-tenth of the global disease burden could be prevented by improving water supply, sanitation, hygiene and management of water resources. It is concluded that such improvements reduce child mortality and improve health and nutritional status in a sustainable way (Vilane and Mwendera, 2011).

While rainwater harvesting technology has been adopted in many areas of the world where conventional water supply systems are not available or have failed to meet the needs and expectations of the people, the use of harvested rainwater especially for potable purposes is limited especially because the quality of stored rainwater in domestic tanks and rainwater harvesting cisterns is perceived as failing to meet drinking water quality standards (Amin and Han, 2009).

Presently in Onicha-Ugbo, the provision of pipe-borne water has not been realized. Consequently, rainwater harvesting has become the major source of water supply in Onicha-Ugbo for drinking, cooking, bathing and other domestic activities. However, the question that occasionally agitates the mind of the inhabitants of this growing rural community is that, is the rainwater collected from rainwater harvesting cisterns in the area good for human consumption and other domestic uses ?. It is on the premise of the aforementioned problems and questions that this study on the quality of rainwater harvested in cisterns in Onicha-Ugbo, Aniocha North Local Government Area, Delta state, Nigeria when achieved will contribute to the management of the water resources of the area and Nigeria in general.

1.5SCOPE OF THE STUDY

In terms of spatial extent, the investigation covered the entire community of Onicha-Ugbo, which is made up of four villages otherwise called “Ogbeor quarter in English language” namely; Ogbe-Obi,Ogbe-kenu, Ishiekpe and Umuolo. Harvested rainwater samples from rainwater harvesting cisterns were collected across these four (4) quarters for the purpose of adequate representation.

Temporally, Samples of harvested rainwater from rainwater harvesting cisterns were collected between two (2) sampling periods: in February (dry season harvesting) and April (rainy season harvesting). Each harvested rainwater samples collected was analysed for physico-chemical and microbiological water quality parameters, namely: pH, turbidity, colour, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Dissolved Oxygen (DO) and total coliform counts.

However, given the enormous cost oflaboratory analysis for water quality parameters in the area, this study did not investigate the metallic content of the harvested rainwater samples. Consequently, this is recommended as a gap for further study.

CHAPTER TWO: LITERATURE REVIEW

2.1 RURAL WATER SUPPLY IN DEVELOPING COUNTRIES

Access to safe water has been recognized as a basic human need. Significance of safe water was recognized in the World Summit held at Johannesburg, South Africa in 2002 and later in the 3rdWorld water Forum held at Kyoto, Japan by mentioning that without safe water; sustainable poverty reduction in the third countries is not possible (Rana, 2007).The issue of access to potable water supply has been a topical issue of high interest to several individuals, communities, organizations and governments in the last three decades (Amori and Makinde, 2012).

In developing countries, women and girls spend hour's everyday walking many kilometres to collect water from different sources. As reported by UNPF (2001), women in developing countries walk average of 6 kilometres per day to collect drinking water. On the whole, the average time lost by children and women in a day has been put at 200 million hours in search of water in developing countries daily (Ifabiyi*et al*., 2010).

According to the Millennium Developmental Goals report 2012, 783 million people, or 11% of the global population remain without access to an improved source of water. Such sources include; household convections, public standpipes, boreholes, protected dug wells, protected springs and rainwater collection. Even though water is one of the most precious gift to mankind, lack of access to safe drinking water and basic sanitation is one of the problems affecting billions of people and the world (Hesperian Foundation, 2005).

Antonio (2005) states that more than 1.2 billion people in the world still lack access to safe drinking water and 2.6 billion lack access to even basic sanitation. This is particularly so in the developing countries where level of access to water and water related facilities are said to be very low. Consequently, when the provision of clean water is inadequate, people are compelled to use contaminated water that later result into water related diseases and also the outbreak of these diseases (Mwendera, 2006).

Recent survey by Majuru*et al*., (2011) estimates that 65 million Nigerians had no access to safe water. The situation is worse in the rural areas where only 24% of the population have access to safe water supply. Therefore, the provision of clean, reliable and potable water in rural areas still remains a challenge considering the fact that a larger percentage of the population live in the rural areas. In the face of the dwindling and depleting water resources, there is the general concern of how people will have unhindered access to potable water supply, rainwater harvesting is a valuable tool that may be used to fulfil this need; however, the lack of knowledge regarding the quality of harvested rainwater has prevented widespread use of this practice (Lye, 2009).

2.2 RAINWATER HARVESTING

The term 'rainwater harvesting' appears to have originated from the word 'harvesting', used to cover all agricultural activities involving cutting, reaping, picking and gathering of grain of value from any fully-grown crop (Mylaram, 2011). It may be defined as any human activity involving collection and storage of rainwater in some natural or artificial container either for immediate use or use before the onset of the next rainy season (Mylaram, 2011).

Rainwater harvesting is also described as a method for collecting, storing and conserving rainwater from roof tops, land surfaces or rock catchments using simple techniques such as jars and pots as well as more complex techniques such as underground check dams for future use (Critchley and Siegert, 1991). This old technology is gaining new popularity these days especially in areas of prolonged periods of little or no rainfall or areas where public water works and distributing systems has completely broken down or areas where hydrogeological conditions does not favour the drilling of bore-holes (Rim-Rukeh*et al*., 2007).

Three main forms of rainwater harvesting system exist namely; Water collection, Rooftop harvesting and Micro-catchments.

a. Water Collection: This form of rainwater harvesting is also known as water conservation. Water collection is essentially the prevention of runoff from a given area by retaining rainwater and prolonging the time for infiltration (Mbilinyi*et al*., 2005). This practice employs a number of different techniques to "catch the water where it falls". These techniques are often a product of local ingenuity and varying cultural practices (Mylaram, 2011).
b. Rooftop harvesting: In rooftop rainwater harvesting system, rainwater from rooftops, rock catchments and other surfaces is collected using simple technologies, such as storage tanks, pipes and gutters (Appan, 1999). A simple rooftop rainwater harvesting system consists of its catchment area, a treatment facility, a storage tank, a supply facility and piping (Han and Mun, 2008). Also, the roof of houses, stores, green houses and animal shelters which are covered with metal, plastic, thatch or mud, channel rainwater into storage tanks.

   This technique has the best chance where houses already have good roofs. According to Thomas (1998), roof catchment provides safe water for domestic use. However, during the dry season, debris builds up on roofs resulting in initial runoff during the first rainfall being full of sediment and highly turbid. To minimize contamination of the harvested rainwater, flush diverters can be incorporated in the delivery system to divert the runoff to waste during the initial few minutes at the beginning of each rain event.

Plate 2.1: Rooftop harvesting in Ogbe-Obi, Onicha-Ugbo

a. Micro-Catchment:Micro-catchmentinvolves a runoff generating catchment area or a cultivated area where runoff is concentrated and stored in the root zone and used by plants. The advantages of this water harvesting system relative to the others, in that the design is simple and cheap, there is higher runoff efficiency than larger-scale water harvesting systems. They often prevent or reduce erosion and can be implemented on almost any slope or level planes (Prinz, 1999). Micro-catchments vary in sizes and technique from region to region.

Plate 2.2: Run-off catchment area to the Micro-catchment RWH system

Plate 2.3: Micro-catchment rainwater harvesting system

Rainwater harvesting is both simple and ancient and varies from small and basic, such as the attachment of a water butt to a rainwater downspout, to large and complex, such as those that collect water from many hectares and serve large numbers of people (Leggett *et al*, 2001). In its broadest sense, it is a technology used for collecting and storing rainwater for human use from rooftops, land surfaces, steep slopes, road surfaces or rock catchments using simple techniques such as pots, tanks and cisterns as well as more complex techniques such as underground check dams (Makoto, 1999). It primarily consists of the collection, storage and subsequent use of captured rainwater as either the principal or as a supplementary source of water (Roebuck and Ashley, 2006).

Rainwater harvesting is one of the most promising alternatives for supplying water in the face of increasing water scarcity and escalating demand. The pressure on water supplies, increased environmental impact from large projects and deteriorating water quality, constrain the ability to meet the demand for freshwater from traditional sources. Rainwater harvesting presents an opportunity for the augmentation of water supplies allowing at the same time for self-reliance and sustainability (Khoury- Nolde, 2008).

Many rural communities in developing countries use roof-harvested rainwater as their primary water source for drinking. Traditionally, this was the major option to people in water-scarce regions where people had to manage to fulfil drinking-water and household water needs by rainwater harvesting. However, due to the ubiquitous contamination of surface and ground water resources by microbial and chemical contaminants, rainwater harvesting has become more relevant now even in areas which enjoy high rainfall (Meera and Ahammed, 2011).

2.3 HISTORY OF RAINWATER HARVESTING

Rainwater collection is one of the oldest means of collecting water for domestic purposes. This has been a common technique throughout the Mediterranean and Middle East, being used by Egyptians, Palestinians, Iranians, Iraqis, Yemenis, Greeks and Romans. Water was collected from roofs and other surfaces and stored in underground tanks or excavated reservoirs (cisterns) with masonry domes (Gnadlinger, 2000). In some parts of the Middle East, rainwater was collected on the surfaces and channelled through vertical shafts to horizontal tunnels (qanars) that in turn led the water to underground reservoirs. In sub-Saharan Africa, the collection of rainwater was (and is) practised using containers and tanks of various sizes (Gould and Nissen-Petersen, 1999).

Rainwater harvesting has been practiced for more than 4,000 years, owing to the temporal and spatial variability of rainfall. It is an important water source in many areas with significant rainfall but lacking any kind of conventional, centralised supply system. It is also a good option in areas where good quality fresh surface or ground water is lacking. The application of appropriate rainwater harvesting technology is important for the utilisation of rainwater as a water resource (UN-HABITAT, 2005).

Rainwater capture and utilization is an ancient tradition which dates back to similar techniques used in today's Iraq around 5000 years ago. Modern methods usually represent improvements with respect to technical variations (Mbilinyi, 2005). According to Bankole (2010), the collection of rainfall from roof run-off is an ancient practice that dates back over 3000 years ago. In China, archaeological evidence attests to the capture of rain water as far back as 4,000 years ago, and the concept of rainwater harvesting may date back 6,000 years, while in Israel, ruins of cisterns built as early as 2000BC for storing runoff from hillsides for agricultural and domestic purposes are still standing (Gould and Nisssen-Petersen, 1999).

Gould andNissen-Petersen (1999) stated that rainwater harvesting is an ancient technology that has been used throughout history to supply water to human settlements and, more recently, to buildings in urbanised areas. He also mentioned that whilst the exact origin of rainwater harvesting has not been determined, the oldest known examples date back several thousand years and are associated with the early civilisations of the Middle East and Asia. In India, evidence has been found of simple stone-rubble structures for impounding water that date back to the third millennium BC (AgarwalandNarain, 1997).

In the Negev desert in Israel, runoff from hillsides has been collected and stored in cisterns to be used for agricultural and domestic purposes even before 2000 BC (Evenari, 1961). There is evidence in the Mediterranean region of a sophisticated rainwater collection and storage system at the palace of Knossos which is believed to have been in use as early as 1700 BC (Hasse, 1989). In Sardinia, from the 6th century BC onwards, many settlements collected and used roof runoff as their main source of water (Crasta*et al*, 1982). Many Roman villas and cities are known to have used rainwater as the primary source of drinking water and for domestic purposes (Kovacs, 1979).

Also, there is evidence of the past utilisation of harvested rainwater in many areas around the world, including Australia (Kenyon, 1929), sub-Saharan Africa (Parker, 1973), North Africa (Shata, 1982), East andSouth-East Asia (PrempridiandChatuthasry, 1982), Pakistan and much of the Islamic world (Pacey andCullis, 1986), South Pacific (Marjoram, 1987), Turkey (Hasse, 1989), North and South America (Gnadlinger, 1995), the Indian sub-continent (Pakianathan, 1989), Japan, China (Gould and Nissen-Petersen, 1999) and Western Europe (Leggett *et al*,, 2001).

Before the latter half of the twentieth century, rainwater harvesting systems were used predominantly in areas lacking alternative forms of water supply, such as coral islands (Krishna, 1989) and remote, arid locations lacking suitable surface or groundwater resources (Perrens, 1975). During the twentieth century, the use of rainwater harvesting techniques declined around the world, partly due to the provision of large, centralised water supply schemes such as dam building projects, groundwater development and piped distribution systems. However, in the last few decades there has been an increasing interest in the use of harvested water (Gould andNissen-Petersen, 1999) with an estimated one hundred million people worldwide currently utilising a rainwater system of some description (Heggen, 2000).

Rainwater harvesting is far from being a novel practice, as its use has been documented in ancient Greek and Roman civilizations (Abdulla and Al-shareef, 2009). Traditionally, rainwater harvesting had been practiced in arid and semi-arid areas as well as areas with limited access to water resources; it has become an integral part of societies in remote areas where potable water and reliance on shallow wells is not an option (Ishakul*et al*., 2011). Rainwater harvesting has provided drinking water, domestic water and water for livestock, water for small irrigation and a way to replenish ground water levels in many communities ofthe world, especially in Coimbatore Erode, Salem Districts of Tamil Nadu, India where water is becoming a scarce commodity and is considered as a liquid gold (Sivanappan, 2006).

Consequently, many countries have begun to show a resurgent interest in the use of rainwater harvesting techniques, driven by environmental concerns (particularly the increasing strain on other sources of water) and by renewed interest in small scale and appropriate technologies of all kinds (Gould and Nisssen-Petersen, 1999). Although not a panacea in itself, it is widely believed that these systems can form part of a new urban water management paradigm that is more sustainable than the traditional methods (Villarreal and Dixon, 2005).

2.4 TYPES AND CONFIGURATIONS OF RAINWATER HARVESTING SYSTEMS

Three basic types of system for supplying potable or non-potable water to buildings for internal and external uses are identified by Leggett *et al* (2001): directly pumped, Indirectly Pumped and gravity fed. In all cases, water is collected from a catchment surface and held in a sealed storage structure until needed.

2.4.1 Directly Pumped Systems

In a Directly Pumped System (sometimes also referred to as a pressurisedsystem) rainwater is initially held in a storage tank and then pumped directly to the point of use when required. There is no header tank with a direct system and mains top-up occurs within the storage tank. Mains top-up does not completely fill the tank but maintains a minimum level that is able to meet short-term demand. If the storage tank is full, any additional incoming water will exit via an overflow and will normally be disposed of either to a soak-away or an infiltration device or sewer. Plate 2.4 shows a schematic of a directly pumped rainwater harvesting system.

The main advantages of directly pumped systems are that water is provided at mains pressure which is ideal for garden hoses and washing machines, and that they do not require a header tank. However, the main disadvantages are that if the pump fails (e.g. due to mechanical or electrical failure or power loss) then no water can be supplied. Water cisterns would have to be flushed manually (e.g. using a bucket of water) and washing machines would not function (Environment Agency, 2007).

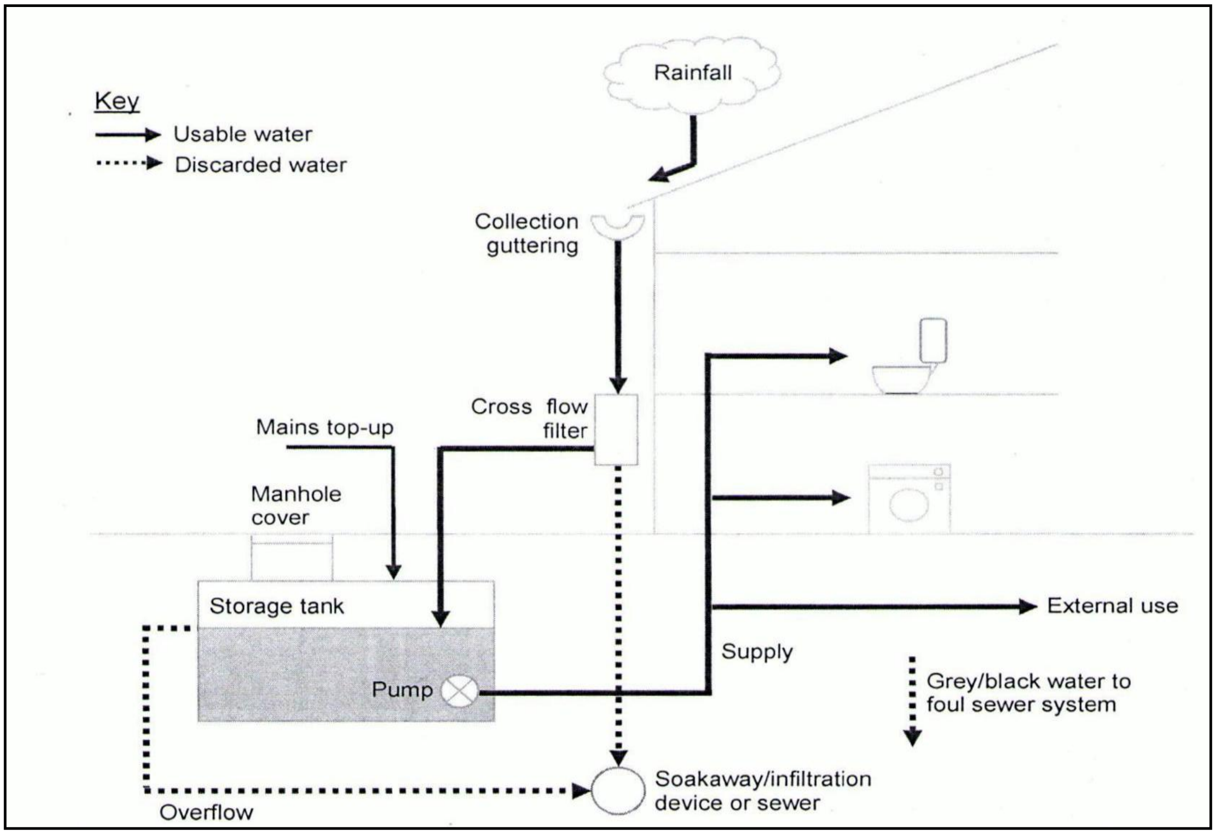


Plate 2.4: Schematic representation of a Directly Pumped Rainwater Harvesting System (Adapted from Leggett *et al*, 2001).

2.4.2 Indirectly Pumped Systems

In Indirectly Pumped system, rainwater is initially held in a storage tank and then pumped to a header tank within the building, which is usually located within the roof void. Water is delivered to appliances via gravity and the header tank should be at least one metre above the supply points. If the storage tank runs dry, the header tank is supplied with top-up water from the mains. If the storage tank is full, any additional incoming water will exit via an overflow and will normally be disposed of either to a soak-away or to an infiltration device or sewer. See Plate 2.5 for a schematic of an Indirectly Pumped rainwater harvesting system.

The main advantages of Indirectly Pumped systems are that if the pump fails (e.g. due to mechanical/electrical failure or power loss) then water will still be supplied to the associated fixtures and fittings via the mains top-up function. Low cost pumps and simple controls are possible and systems tend to be energy efficient as the pump runs at full flow (Environment Agency, 2007). On the other hand, the main disadvantages of Indirectly Pumped systems are that they tend to deliver water at low pressures. This can lead to slow filling of water cisterns and the system may not provide enough pressure to work with some appliances. Although, some proprietary units solve the low pressure problem by using a hybrid system. Indirect systems also require the use of a header tank which adds to the overall cost of a system. Also, there may not always be sufficient space in the roof void to site the tank (Environment Agency, 2007).

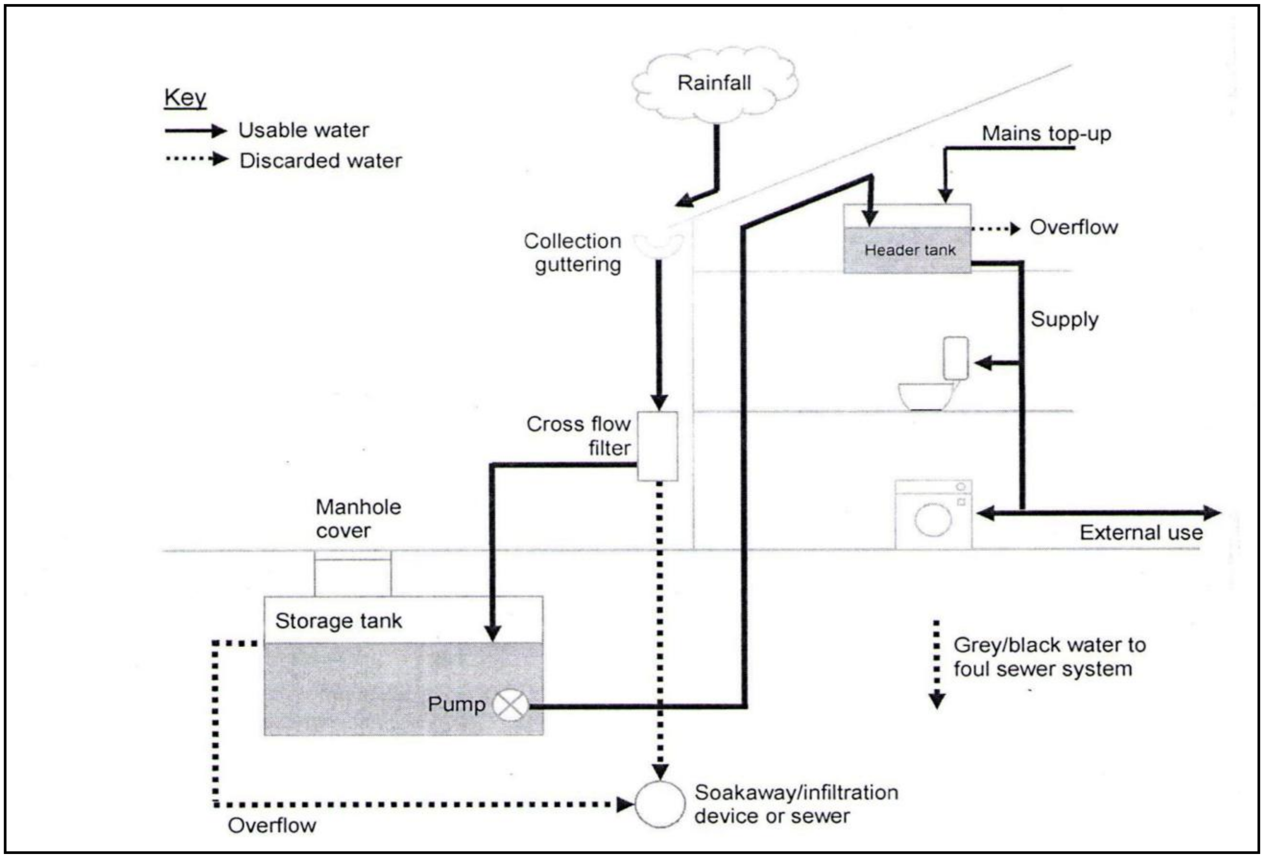


Plate 2.5:Schematic representation of an Indirectly Pumped Rainwater Harvesting System **(**Adapted from Leggett *et al*, 2001).

2.4.3 Gravity-Fed Systems

Gravity fed systems differs from the Direct and Indirect variants primarily in that the main storage tank is located within the roof void of the building. Rainwater is collected from the roof, filtered and then piped directly to the storage (header) tank. Water is delivered to appliances via gravity and the storage tank should be at least one metre above the supply points (See Plate 2.6). Mains top-up water is supplied directly to the tank if it runs dry. If the tank is full, any additional incoming water will exit via an overflow and will normally be disposed of either to a soak-away/infiltration device or sewer.

The main advantages of gravity fed systems are that they do not require a pump or electrical supply as is the case with the direct and indirect versions (Fewkes, 2006). Also, since there is no pump, there is no risk of pump-associated supply failure. However, the main disadvantages are that the water pressure is likely to be less than that of the mains supply. This can result in poor performance of some appliances, e.g. slow filling of water cisterns, and some appliances such as some modern washing machines may stop working altogether. In this case a pump may be required to boost the water pressure (Leggett *et al*, 2001).

There may also be issues with high structural loads, damage from leaking components and water quality issues due to fluctuating temperatures in the stored water (Fewkes, 2006). It also has to be possible to collect runoff from the roof, filter it and deliver it to the tank under the action of gravity. In this case the relative levels of the various components (roof, filter and tank) are critical and it may not be possible to find an arrangement that functions hydraulically (Fewkes, 1989).

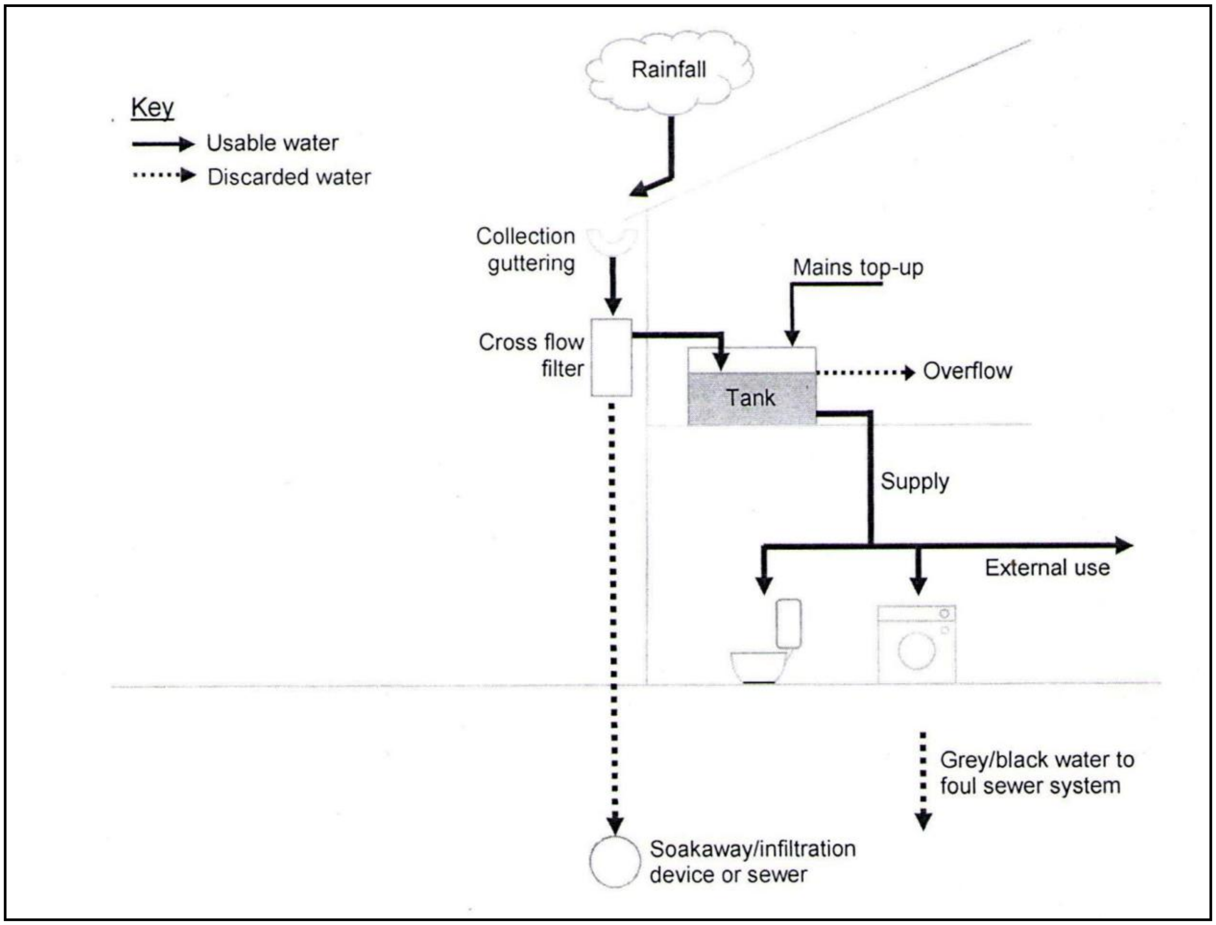


Plate 2.6: Schematic representation of a Gravity-Fed Rainwater Harvesting System **(**Adapted from Leggett *et al*, 2001)

2.5 COMPONENTS OF RAINWATER HARVESTING SYSTEMS

Rainwater harvesting systems can consist of a number of different components, some specific to the rainwater harvesting aspects and some which are part of the building but are utilised as part of the rainwater system (auxiliary components). A list of typical rainwater harvesting system specific components (See Plate 2.7) could include some or all of the following items:

2.5.1 First flush diverters

During dry periods roofs become contaminated with a variety of pollutants such as atmospheric particulates, bird droppings, leaves and other debris (Fewkes, 2006). When it rains, some of the contaminants are washed off the catchment surface and transported in the runoff flow. The rainfall intensity and number of dry days preceding a rainfall event significantly affects the quality of the runoff, with long dry periods resulting in higher pollutant loads for a given catchment (Gould andNissen-Petersen, 1999). Therefore, diverting the initial portion of runoff generated by a storm away from the storage device will mean that the quality of water entering storage is improved and the need for subsequent treatment reduced or even eliminated altogether (Martinson and Thomas, 2005).

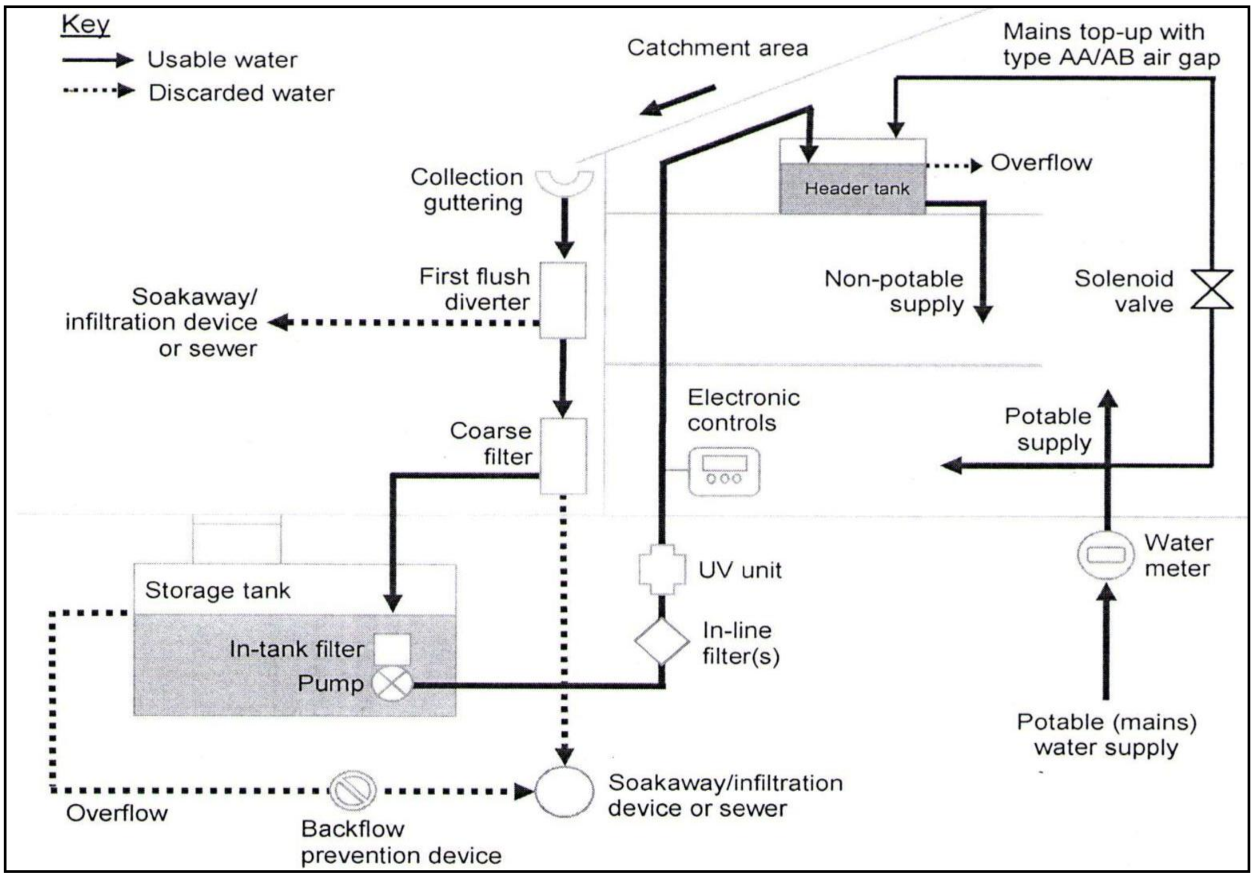


Plate 2.7:Schematic diagram showing range of common Rainwater Harvesting System components

Gould andNissen-Peterson (1999) state that the use of first flush diverters tends to be limited and when they are used they often suffer from a lack of maintenance. As a result of this neglect, many function incorrectly or have simply been disconnected by the building occupiers. However, Mustow*et al.*,(1997) state that the inclusion of such a device can increase the cost and complexity of a system without providing any significant benefit.

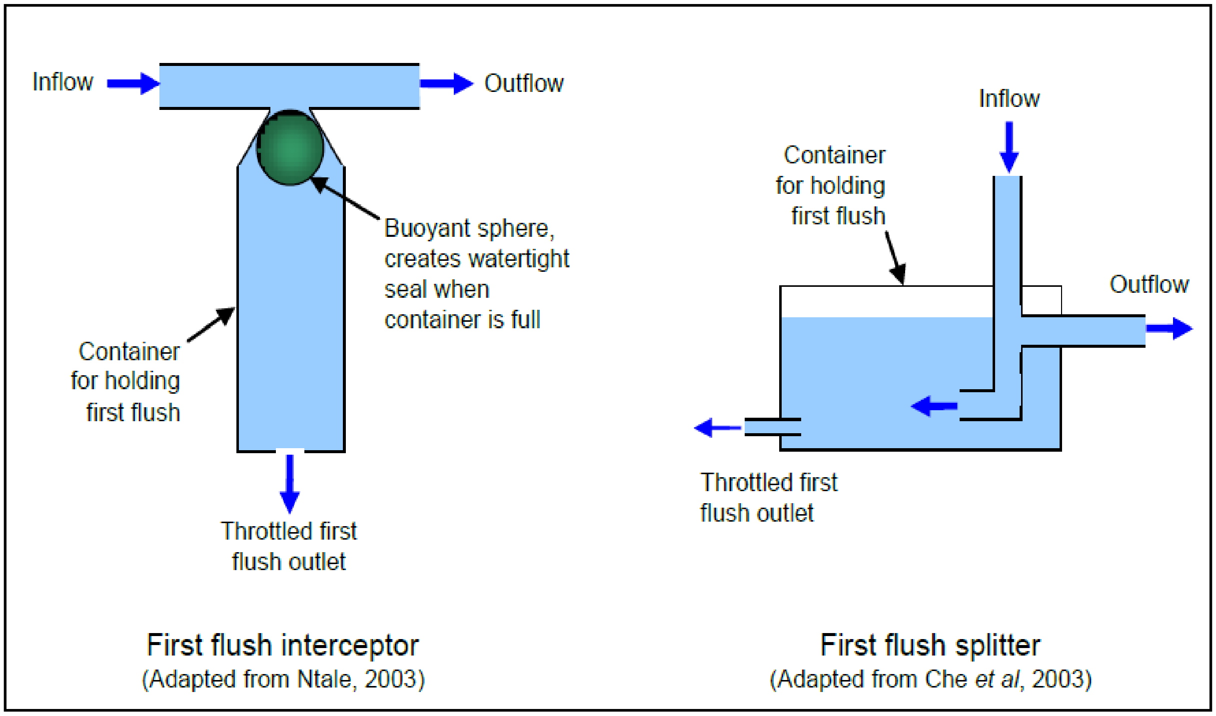


Plate 2.8 (a): Cross-sectional sketches of typical first flush diverters

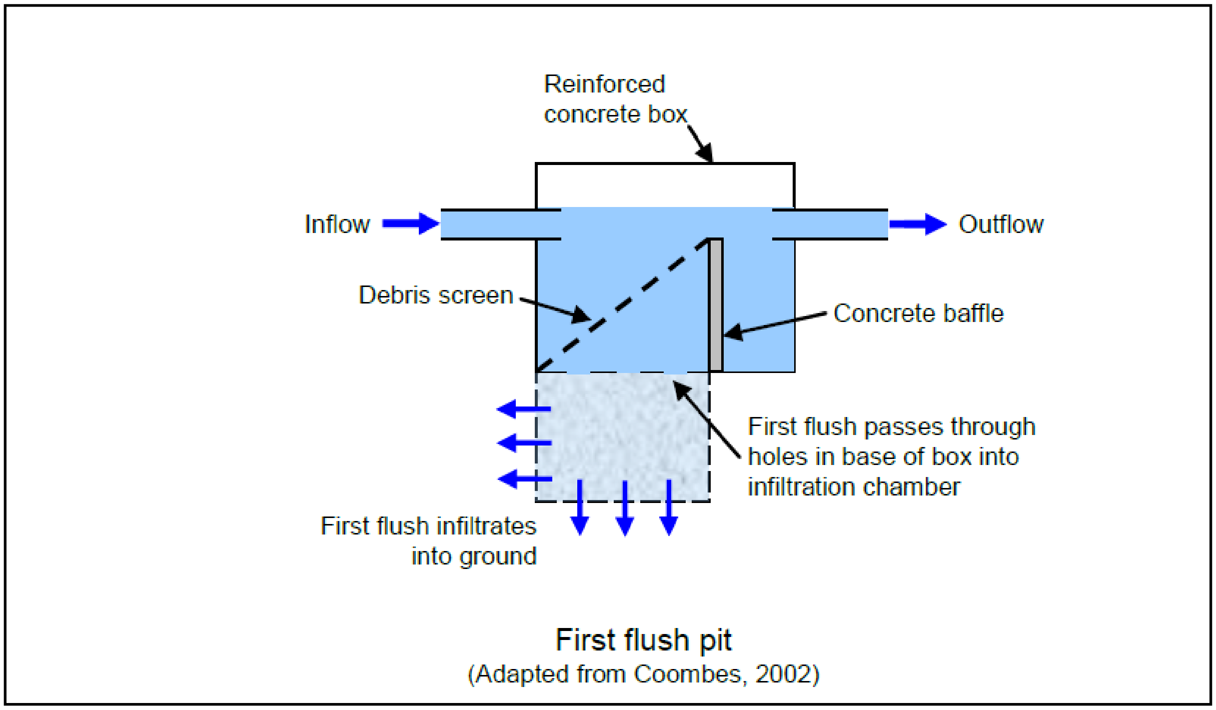


Plate 2.8 (b): Cross-sectional sketches of typical first flush diverters

2.5.2 Filters

It is recommended that rainwater be filtered before entry into the storage tank in order to remove debris such as leaves, grit, moss and soil. Filters should be easy to clean (or self-cleansing) and should not block easily (Martinson and Thomas, 2003). Leggett *et al.*,(2001) identify a range of filter types and sub-types namely;

- Crossflow filters: Crossflow filters contain a mesh screen which water flows across (hence the name) and that separates the flow into two fractions. The portion that passes through the mesh is cleaned of all debris larger than the mesh size (typically 0.2mm – 1.0mm) and passes to the storage tank. The residual debris is washed from the mesh by the remaining fraction of water and diverted away from the tank, e.g. to the sewer system or an infiltration device. Crossflow filters are considered to be self-cleansing since debris is automatically washed from the mesh screen. Self-cleansing filters are preferred as they require less maintenance and reduce the cost of consumables (Leggett *et al*, 2001).
- Cartridge filters: Cartridge filters are usually placed after the storage tank and require that water be passed through them under pressure. They are most often used in systems that require a high degree of water quality and low turbidity, such as those that include a ultra-violet unit or for potable applications. It is common practice to have several arranged in series with the unit that has the largest porosity first in line and subsequent units arranged according to diminishing pore size, e.g. 25μm followed by 5μm. Cartridge filters tend to have small porosities and so pre-filtration is required, for example by the prior use of a screen or crossflow device. If this is not done then they will rapidly clog. They are not self-cleansing and so require replacement at regular intervals, typically every 3 months or thereabouts (Leggett *et al*, 2001).Leggett *et al* (2001) also describe a

number of other filter types including in-tank floating, screen, slow sand, rapid gravity, reed beds, membrane and activated carbon. Chemical disinfection is also mentioned as another option for improving water quality.

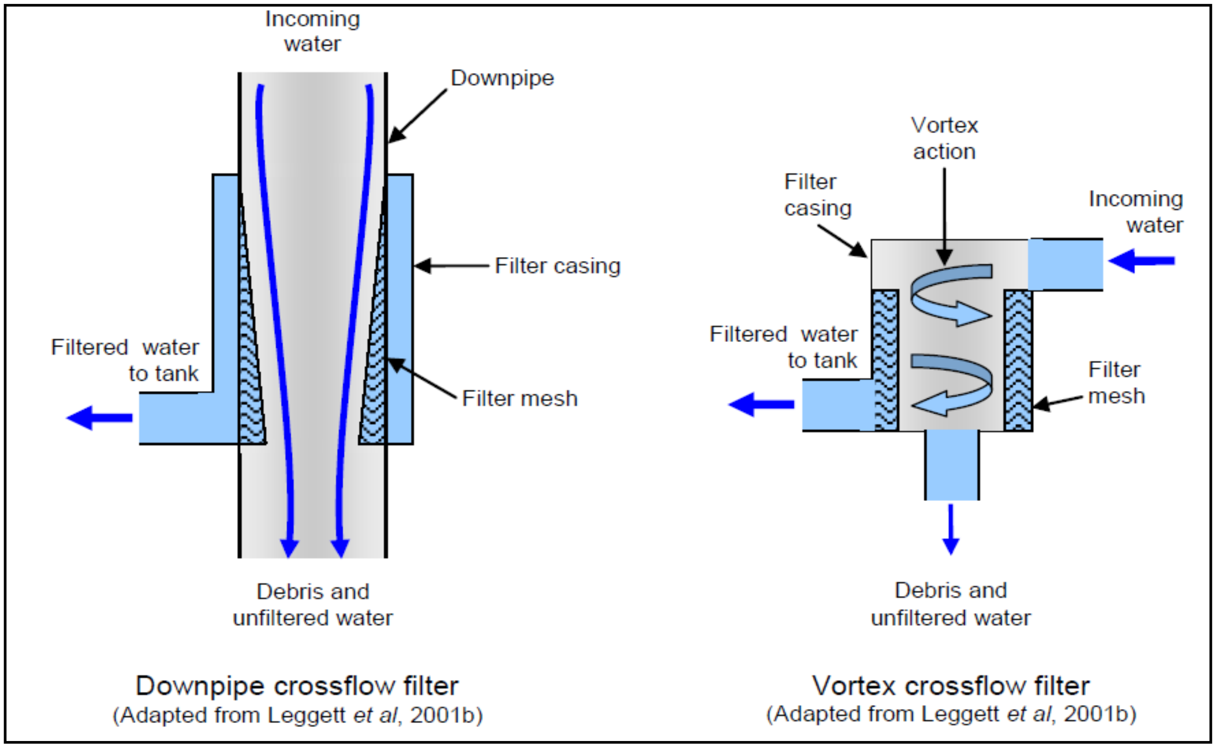


Plate 2.9: cross-sectional sketches of typical cross-flow filters

2.5.3 Rainwater Storage Devices

A storage device is required to collect and hold catchment runoff because rainfall eventsoccur more erratically than system demand (Fewkes, 2006). Water storage capacity is required in order to balance out the difference between supply and demand (Gould andNissen-Petersen, 1999). In the developed world the most commonly used storage device is the underground tank (Hassell, 2005). Other types of reservoir structures exist, such as above ground tanks and ponds (Woods-Ballard *et al.*, 2007), the gravel sub-base of permeable driveways and pavements (Leggett *et al.*, 2001), covered flat roofs (Mustow*et al.*, 1997), the void space beneath garages (Jones, 2002), geo-cellular structures (Stephenson, 2002) and small local aquifers (Coombes *et al*, 2000; Gardner *et al.*, 2001).

Storage tanks come in a variety of shapes and sizes and can be constructed from a range of materials including concrete, ferro-cement, bricks, steel and plastics such as glass reinforced plastic (GRP) or high-density polyethylene (Fewkes, 2006). Some are relatively basic in design whilst others are essentially complete systems that incorporate the tank, filters, pump and mains top-up arrangement in a single integrated unit.

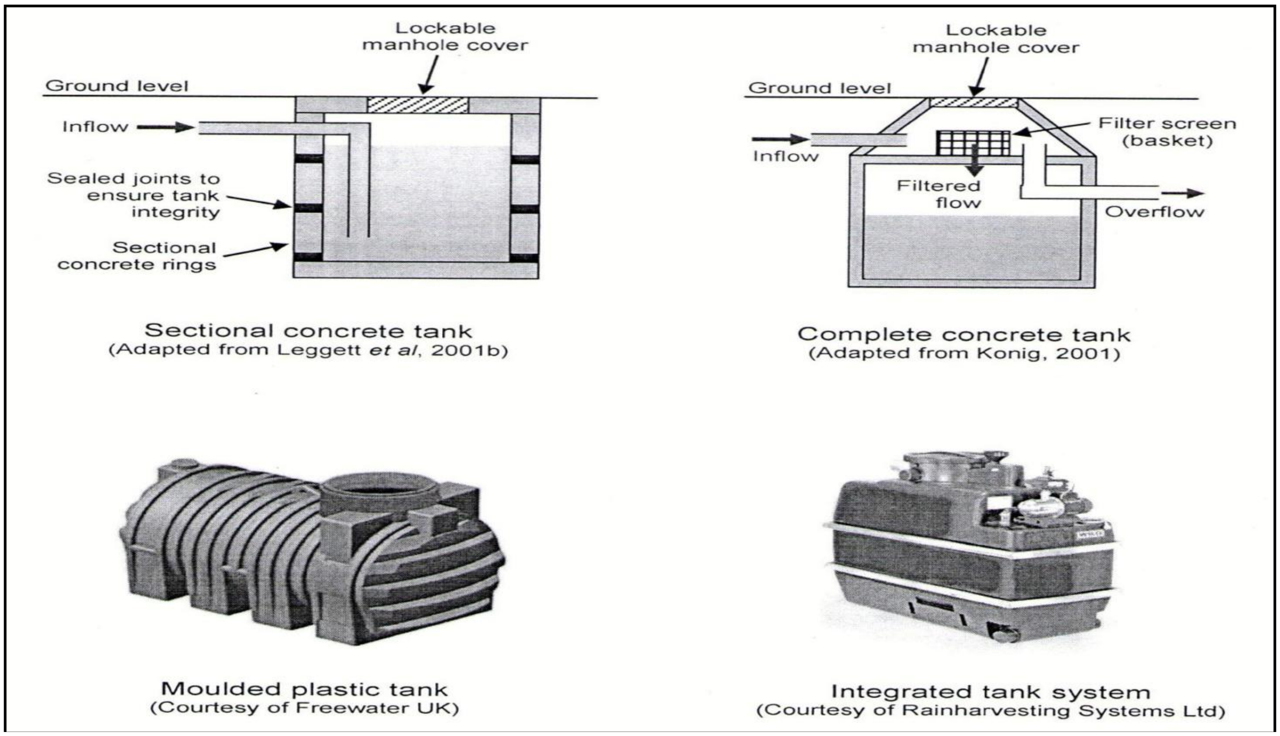


Plate 2.10: Examples of storage tanks

Tanks for domestic systems generally have storage volumes in the 1-10m3 range. While those for commercial systems are available in a wider range of sizes and can be tens or hundreds of cubic metres in size. Whichever tank is selected, current best practice recommends that it should be sized such that it overflows at least twice per year in order to facilitate the removal of any floating debris (Fewkes, 2006).

2.5.4 Storage device overflow arrangement

Modern rainwater tanks have an overflow arrangement in order to prevent localised flooding if the capacity of the tank is exceeded, and also to help avoid stagnation of stored water and remove floating debris (Leggett *et al*, 2001). Overflows are predominantly unrestricted (no throttle) and water passes through them via gravity flow although pumped overflows are also available.

Plate 2.11: Storage device overflow at Ogbe-obi, Onicha-Ugbo

2.5.5 Pumps

Rainwater harvesting systems require that stored rainwater be pumped either to the point of use (direct systems) or to a header tank located at least 1m above the point of use (indirect systems). In general, gravity fed systems do not require a pump since water is fed straight from the catchment surface to a high-level storage tank. However, they are sometimes used with gravity systems in order to increase the water pressure which may otherwise be too low to work with certain appliances, e.g. some modern washing machines.

Pumps have a finite lifespan and will require repair/replacement at some point, typically after 5-10 years of use. It is also recommended that they are checked at least once per year in order to ensure that they are functioning correctly (Leggett *et al.*, 2001).

Plate 2.12: Water pump at Ogbe-kenu, Onicha-Ugbo

2.5.6 Ultraviolet units

Ultraviolet (UV) radiation is effective at killing a wide range of waterborne bacteria and viruses. Ultraviolet disinfection has a number of advantages: ease of use, requires no chemicals, short retention time, no effect on the chemical characteristics, taste or odour of the water, maintenance is not onerous, and there is no risk from excessive use as might be the case with chemical treatments (McGhee, 1991). Ultraviolet disinfection of potable water supplies has been shown to be sufficient for the inactivation of 99.9% of most microorganisms (Hall *et al.*, 1997).

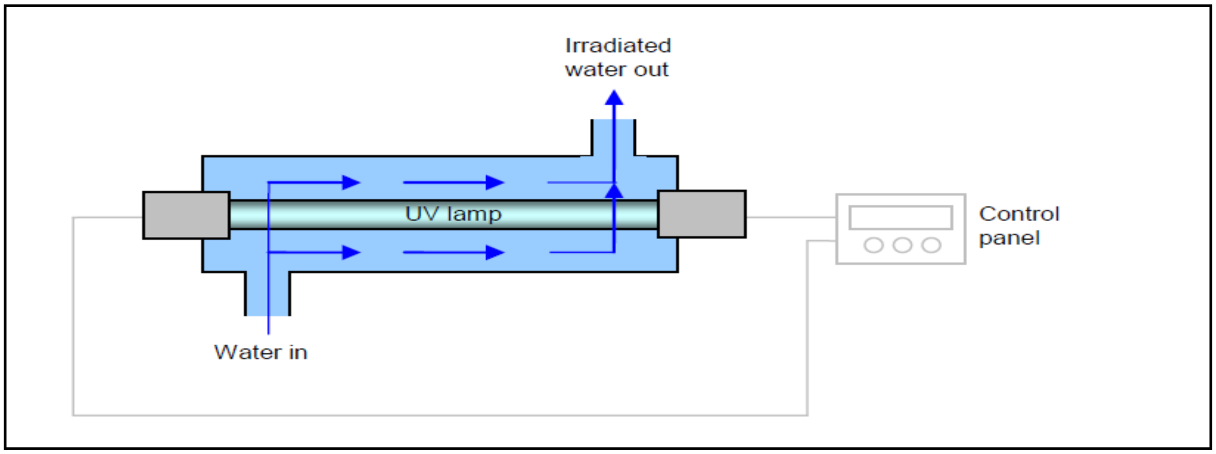


Plate 2.13: Schematic representation of an Ultraviolet disinfection unit (Adapted from Leggett *et al*, 2001)

Ultraviolet units can be fitted to rainwater harvesting systems in order to safeguard water quality. However, in order for an Ultraviolet unit to effectively kill microorganisms the water has to have a low turbidity, necessitating the use of fine filters (e.g. a 25µm filter followed by a 5µm filter, located in series before the Ultraviolet unit). If this is not done, suspended solids in the water can effectively shield harmful pathogens from Ultraviolet light and they may not be destroyed (Parsons & Jefferson, 2006).

The Ultraviolet bulb consumes electricity and also has a finite lifespan, generally requiring replacement after about six months of use (Shaffer *et al.*, 2004). Ultraviolet units fitted to rainwater harvesting systems tend to be passive, i.e. they do not control the rate of flow through them. Rather, the capacity of the pump should be matched to the treatment flow rate of the Ultraviolet unit. The use of anUltraviolet unit will add to the capital and running costs of a system. Extra filters are required and these need replacing every six months or so.

2.5.7 Electronic control and management units

Many contemporary rainwater harvesting systems have the option of including an electronic control and management unit. This is not essential and some systems can be controlled using simple mechanical float valves and a low-level switch to trigger the pump. However, more sophisticated controls allow for the use of float switches, pressure sensors and electrically actuated valves which can result in better overall performance (Leggett *et al*, 2001). Controls can also have visual readouts of systems status, such as the level of water in the tank, or report if there is a problem such as pump failure, disinfection failure or filter blockage (Konig, 2001).

2.5.8 Header tank

Indirect systems require the use of a header tank. This is normally located in the roof void of the building and should be at least 1m above the point of supply. High and low level switches are used to signal the storage tank pump when to activate and when to disengage. If mains top-up occurs in the header tank then this is usually controlled by a low level switch in conjunction with a solenoid or float valve (Leggett *et al*, 2001).

Plate 2.14: Header tank at Umuolo, OnichaUgbo.

2.5.9 Mains top-up arrangement

Given the intermittent nature of rainfall, it is rare that a rainwater harvesting system can be designed such that a constant supply of harvested water can be guaranteed. In times of shortfall it is advisable to have a top-up arrangement which can supply enough mains water to meet short-term demand. Top-up can be provided in a number of locations; in an indirect system it most commonly occurs in the header tank, although it can also be in the storage tank. Direct systems normally have mains top-up in the storage tank although a variation exists known as a "centralised" system in which the pump and mains top-up are integrated into a single unit located inside the building (Leggett *et al*, 2001).

If the main storage tank runs empty, mains water is fed into the suction pipe of the pump and from there water is transferred directly to the point of use (Woods-Ballard *et al*, 2007). Top-up controls can consist of simple mechanical valves controlled by flotation devices or more complicated systems involving float activated switches coupled with solenoid valves.

2.5.10 Solenoid valves

Solenoid valves are typically used to start/stop the mains top-up function. A float activated switch, located either in the header tank (for indirect and gravity fed systems) or primary storage tank (for direct systems), triggers the valve if the water volume falls below a predetermined level. This activates the mains top-up function, ensuring that a minimum amount of water is available at all times. Once the minimum water level has been restored, the float activated switch closes the valve, shutting off the flow of mains top-up water.Solenoid valves have a typical life expectancy of between 5 and 10 years (Leggett *et al*, 2001).

2.5.11 Distribution pipework

A pipe distribution network is required to transport water from the storage tank to the point of use and a wide selection of pipes are available that are suitable for this task. Plastic pipes are commonly used. These are durable and, if installed correctly, have a long service life although they will require replacement at some point, typically after about 20 years of use (Leggett *et al*, 2001).

2.5.12 Guttering and collection pipework

Rainwater run-off from the catchment surface needs to be collected and diverted to the rainwater storage device. If the catchment surface is a roof then collection is generally via a system of gutters feeding into one or more downpipes and from there into the storage device (WRAS, 1999).

Plate 2.15: Guttering and collection pipeworkat Ishiekpe, Onicha-Ugbo

2.5.13 Catchment surface

The catchment surface can be described as the area on which the rainfall is collected. Depending on the type of rainwater harvesting system, several catchment surfaces can be defined, i.e. roofs, paved or unpaved surfaces, dry sandy river beds (RAIN, 2008). In urban locations the most commonly utilised catchment areas are roofs (Hassell, 2005) although runoff can also be collected from other impermeable areas such as pavements, roads and car parks (Environment Agency, 1999).

Not all of the rain falling on a catchment area can be collected as some is lost from the system due to processes such as depression storage and evaporation (Butler and Davies, 2004). Other factors that also influence the amount of lost water include the rainfall depth and intensity, antecedent conditions, the material the catchment is made from and the catchment slope (Li, Xieand Yan, 2004).

2.6 FACTORSDETERMINING HARVESTED RAINWATERQUALITY

The quality of water is a powerful environmental determinant of health (UNICEF, 2008). It is determined by the amount and level of physicochemical, microbial and heavy metals found in it. Water quality also refers to the physical, chemical and biological characteristics of water and its general composition. The quality of water is a measure of the condition of water relative to the requirements of one or more biotic species and to any human need or purpose and it is frequently used by reference to a set of standards against which compliance can be assessed (Chapeon, 1992).

According to Itah, AkpanandDre(2005), quality water must be free from high concentrations of chemicals or ions such as leads, sulphate, low pH, high turbidity etc. Water must possess the characteristics of being aesthetically wholesome, chemically tolerable and bacteriological safe before it meets up with the requirements of the World Health Organization (WHO) as a potable water. Good quality drinking water is water free from disease causing organisms, harmful chemical substances and radioactive matter; it is aesthetically appealing and is free from objectionable colour or odour (Life Water Canada, 2007).

Water quality is determined by the composition of water as affected by natural processes and human activities. Water quality depends on the constituents dissolved or contained within the water. It is often presumed that the chemical composition of water is the only factor involved. However, especially (micro) biological factors are of main importance when considering water quality. Next to this there are also physical factors such as sand, silt, clay, dust and plant material (RAIN, 2008). This is illustrated in Figure 2.1

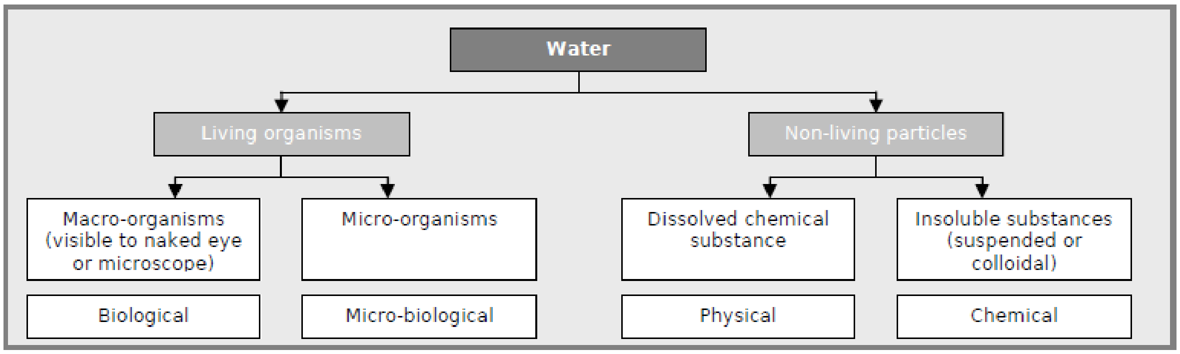


Figure 2.1: Factors determining water quality(RAIN, 2008).

According to RAIN (2008), it is not possible to find completely pure water in nature, since water droplets already begin to dissolve a whole range of substances in the atmosphere, such as gases, airborne dust particles and salt from sea spray. Atmospheric pollution can have a major effect on the composition of rainwater. Water that reaches the earth as rain, acquires other substances from processes such as leaching, weathering, and dissolution. Living organisms may enter the water. All these processes affect the composition of the water.

Depending on the source of the contamination, three types can be distinguished: (Micro) biological contamination, Chemical contamination, Physical contamination

- **(Micro) Biological Contamination:** The most common hazard in water sources obtained from roof or surface catchments is microbial (biological and microbiological) contamination, especially enteric pathogens. Enteric pathogens are micro-organisms (bacteria, viruses, and protozoa) that cause gastrointestinal illness. These organisms are introduced into drinking water supplies by contamination with faecal material (from human or animal origin) or dead animals and insects (enHealth, 2004). The most important indicator of micro-biological contamination is *Escherichia coli*(enHealth, 2004).

- **Chemical Contamination:** Chemical contamination results from air pollution (industrial and traffic emissions), runoff and leaching of chemical substances (agricultural and human activities) and toxic material use. All these factors can pose a serious health threat. However, in rural areas of developing countries, these activities are mostly absent or are present in a very small-scale (for example: fireplaces near a roof or having a chimney can cause soot to settle on the roof), and are therefore unlikely to cause significant impacts on the quality of the collected rainwater (enHealth, 2004).
- **Physical Contamination:** Physical contamination includes inorganic and organic sediments like sand, silt, clay, or plant material. Physical contamination affects the colour, odour or taste of the water, but it poses no direct health risk. Users can however object to water if its colour, odour and taste are found less attractive.

Besides these contamination hazards, another significant health risk is the breeding of mosquitoes in or near RWH systems. Mosquitoes can breed in a storage tank, but also in blocked rainwater collection gutters, drains, puddles and pools around a storage system, due to inappropriate operation of the RWH system or poor construction. Of particular concern are species of mosquitoes that can be a vector for viruses, for instance dengue virus (enHealth, 2004). Malaria, yellow fever and filariasis diseases. A clear link exists between the presence of mosquito larvae and rainwater storage containers lacking secure covers or screens (Kolsky, 1997).

Factors determining the water quality of harvested rainwater have also been classified into three (3) by other schools of thought namely: Particulate matter, Roof catchment and Storage tanks

- **Particulate Matter:** Particulate matter refers to smoke, dust, and soot suspended in the air. As rainwater falls through the atmosphere, it can incorporate these contaminants. Rainwater harvested from roofs can contain animal and bird faeces, mosses and lichens, dust, pesticides, and inorganic ions from industrial emissions (Kohler, SausenandReinberger,1997). In agricultural areas, rainwater could have higher concentration of nitrates due to fertilizer residue in the atmosphere (Thomas and Grenne, 1993). In industrial areas, rainwater can have slightly higher values of suspended solids concentration and turbidity due to the greater amount of particulate matter in the atmosphere (Foester, 1999).

- **Roof Catchment:** When rainwater comes in contact with a catchment surface, it can wash bacteria, dust, particularly during the dry and harmattan period as it contains high levels of metals, which can be toxic to plants, animals and humans. Some of these metals, especially trace metals, are bioavailable and can accumulate in the tissues of living organisms (Pelig-Ba, 2001). However, the longer the span of continuous number of dry days, the more debris are washed-off the roof by rainfall (Vasudevan, 2002). The inclination and direction of the roof also affects the run-off quality. Flat and gentle sloping roofs result in a slow flow of water over the roof surface when compared to roofs with steep inclines (Odnevall*et al*., 2000). Roofs facing the prevailing wind are affected more by the climatic conditions. This in turn will increase the rate of corrosion and weathering of the roof material (Pringle, 1998).

- **Storage Tanks:** The more filtering of rainwater prior to storage, the less sedimentation and introduction of organic matter will occur within the tank (Abdul-Hammed, 2008). Sedimentation reduces the capacity of tanks, and the breakdown of plant and animal matter may affect the colour and taste of water, in addition to providing nutrients for the growth of microorganisms. If a tank is completely covered and organic debris is prevented from entering the water by means of a filter, any bacteria or parasites carried by water flowing into the tank will die-off. Thus water drawn from tanks several days after the last rainfall will usually be of better bacteriological quality than fresh rainwater (Thomas, 1998).

2.7 WATER QUALITY PARAMETERS

2.7.1 Turbidity: Turbidity refers to water clarity. Turbidity is of a fluid caused by individual particles (suspended solids) that are generally invisible to the naked eye, the cloudiness or haziness similar to smoke in air. The measurement of turbidity is a key test of quality. The greater the amount of suspended solids in the water, the murkier it appears, and the higher the measured turbidity. The source of these sediments includes natural and anthropogenic (human) activities in the watershed, such as natural or excessive soil erosion from agriculture, forestry or construction, urban runoff, industrial effluents, or excess phytoplankton growth. Turbidity is often expressed as total suspended solids (TSS).

2.7.2 pH:pH is a measure of the activity of the (solvated) hydrogen ion. It can be defined as the decimal logarithm of the reciprocal of the hydrogen ionactivity in a solution. The pH of pure water decreases with increasing temperatures. For example, the pH of pure water at

50 °C is 6.55, but at 25°C it has a pH very close to 7. Note, however, that water that has been exposed to air is mildly acidic. This is because water absorbs carbon dioxide from the air, which is then slowly converted into bicarbonate and hydrogen ions. Solutions with a pH less than 7 are said to be acidic and solutions with a pH greater than 7 are basic or alkaline. Measurement of pH for aqueous solutions can be done with a glass electrode and a pH meter, or using indicators (Bates, 1973).

2.7.3 Total Suspended Solid: Suspended solids refer to small solid particles which remain in suspension in water as a colloid or due to the motion of the water. It is used as one indicator of water quality. Suspended solids are important as pollutants and pathogens are carried on the surface of particles. The smaller the particle size, the greater the total surface area per unit mass of particle, and so the higher the pollutant load that is likely to be carried.

2.7.4 Total Dissolved Solids: Total Dissolved Solids (TDS) is a measure of the combined content of all inorganic and organic substances contained in a liquid in: molecular, ionized or micro-granular (colloidal sol) suspended form. Generally the operational definition is that the solids must be small enough to survive filtration through a sieve the size of two micrometer. Primary sources for TDS in receiving waters are agricultural and residential runoff, leaching of soil contamination and point sourcewater pollution discharge from industrial or sewage treatment plants. However, certain naturally occurring total dissolved solids arise from the weathering and dissolution of rocks and soils. High TDS levels generally indicate hard water, which can cause scale build-up in pipes, valves, and filters, reducing performance and adding to system maintenance costs (DeZuane, 1997).

2.7.5 Dissolved Oxygen (DO): The amount of dissolved oxygen is a measure of the biological activity of the water masse. Dissolved Oxygen (DO) is widely used in water quality studies and routine operation of water reclamation facilities. The amount of dissolved oxygen gas depends highly on temperature and somewhat on atmospheric pressure. Salinity also influences dissolved oxygen concentrations, such that oxygen is low in highly saline waters and vice versa. The amount of any gas, including oxygen, dissolved in water is inversely proportional to the temperature of the water; as temperature increases, the amount of dissolved oxygen (gas) decreases.

2.7.6 Biochemical Oxygen Demand (BOD): This isthe amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. The term also refers to the amount of oxygen required for microbial metabolism of organic compounds in water. The BOD value is most commonly expressed in milligrams of oxygen consumed per litre of sample during 5 days of incubation at 20 °C and is often used as a robust surrogate of the degree of organic pollution of water. The difference between the physical concentration of oxygen in the water (or the theoretical concentration if there were no living organisms) and the actual concentration of oxygen is called the biochemical demand in oxygen (Clair *et al*., 2003).

2.7.7 Chemical Oxygen Demand (COD): This is a measure of the oxygen equivalent of the organic matter in a water sample that is susceptible to oxidation by a strong chemical oxidant, such as dichromate (Eludoyin, 2010). In environmental chemistry, CODtest is commonly used to indirectly measure the amount of organic compounds in water. Most applications of COD determine the amount of organicpollutants found in surface water(e.g. lakes and rivers) or wastewater, makingCOD a useful measure of water quality. It is expressed in milligrams per litre (mg/l) also referred to as ppm (parts per million), which indicates the mass of oxygen consumed per litre of solution (Clair *et al*., 2003).

2.8 PREVIOUSSTUDIES ON RAINWATER QUALITY

Over the years, several research works on Harvested Rainwater quality in Nigeria, Africa and the world at large have produced contradictory conclusions, with some claiming harvested rainwater was severely polluted while others concluded that it was unpolluted (Sazakli*et al*., 2001; Abdulla and Al-shareef, 2009; Zhang *et al*., 2010). Ebong*et al.*, (2012) in their study on the levels of inorganic contaminants in rainwater samples harvested from different rooftops in Uyo metropolis, AkwaIbom state, Nigeria stated that rainwater samples harvested from aluminium coated roof recorded levels of zinc and aluminium higher than their recommended limits for drinking water in Nigeria while the concentrations of other metals were within the acceptable limits. Samples obtained from asbestos roof recorded concentrations of Cd and Pb above the Nigerian standards for drinking water whereas the levels of Fe, Zn, Al and Cu recorded were within the acceptable limits. Moreso, concentrations of zinc recorded in rainwater samples harvested from zinc galvanized iron roof and zinc roofs were two and three times respectively higher than the Nigerian standard for Zn in drinking water.

However, concentrations of other elements analyzed for in samples from both roofs were within their limits for drinking water. Copper roof samples recorded concentrations of Al and Cu above their recommended limits for drinking water while other metals under investigation recorded concentrations within the acceptable standards. Rainwater harvested from ceramic tiles roof recorded concentrations of these metals within the permissible limits in drinking water by

Nigerian standards. Results obtained in this study indicated that roofing materials may contribute substantial amounts of toxic metals to rainwater harvested from them and their concentrations could be influenced by where they are located. These results also indicated that drinking of rainwater harvested from metallic roofs might pose serious health risks to human (Ebong*et al.*, 2012).

Efe(2006) in a similar research work titled 'Quality of rainwater harvesting for rural communities of Delta state, Nigeria assessed the level of potability of rainwater samples harvested from catchments roof in six (6) rural communities of Delta state, Nigeria. He employed the Kruskal-wallis H' test statistical techniques to ascertain whether differences exist amongst the rainwater samples collected from thatch, aluminium, asbestos and corrugated iron roofing sheet, and open surfaces. The result revealed that most of physiochemical and biological characteristics of rainwater samples were generally below World Health Organization (WHO) threshold, as such the rainwater characteristics showed satisfactory concentration in these rural communities. Thus, he concluded that rainwater from the rural communities should be harvested, stored for human consumption and for other uses by the inhabitants. However, Efe (2006) concluded that treatment is needed in terms of the total suspended solids, pH, iron and colour.

In the same vein, Ojeifo (2011) carried out a study which he titled "Assessment of rainwater harvesting facilities in Esanland of Edo state, Nigeria. He examined the structural and environmental aspects of the use of underground wells in the study area. The structural aspects dealt with the structural condition of wells which was observed to be poor because many wells had cracks and leakages, surface peelings, bad channels and coverings. The environmental aspects described the conditions of dust, smoke, household effluents, waste dumps, bushy surroundings, flooding and erosion affecting the wells. The study identified and analyzed the physical, chemical and microbiological constituent of the water and the results revealed that 68.6 percent of the wells are suitable for drinking while 31.3 percent of the wells are unsuitable for drinking.

At the Africa scene, Hammad, Ali and Ahmed(2008) studied the quality of drinking water in storage tanks in Khartoum state. Out of 92 storage tank samples analysed, 51 tanks showed the presence of thermo-tolerant coliform and *Escherichia coli*. The degree of microbial contamination of water stored in iron tanks was greater than that stored in fibreglass tanks. Contamination in public tanks was greater than that in household tanks. Turbidity ranged between 7.4 and 8 NTU. The pH was between 7.7 and 7.9. Iron and copper were found to increase in water stored in tanks compared to that from taps. Iron and copper were also common in water stored in metal tanks. Covered tanks showed less degree of contamination compared with uncovered ones.

Mayo and Mashauri (1991) studied the bacteriological (faecal coliform and faecal streptococci), chemical (pH and total hardness) and physical (turbidity and colour) analyses from rainwater cisterns at the University of Dares' Salaam in Tanzania. The results showed that 86 % of the samples were free from faecal coliform. Faecal streptococci were obtained in 53 % of the samples and 45 % of the samples tested for total coliforms were positive. The pH was 9.3 - 11.7 which is above the World Health Organization (WHO) recommended permissible limits for drinking water. In addition, fifty four percent (54%) of the consumers raised objections over the taste of water.

Barnes (2009) assessed rainwater harvesting cisterns in northern Ghana. Rainwater samples were taken from cisterns at 24 visited sites. The samples showed better bacteriological quality over alternative sources, including dug-out water and even piped water. All the tanks provided by the Presbyterian Church had *Escherichia coli* ≤ 10 CFU/100ml, which is low in terms of risk level. Other water sources showed a higher level of contamination.

In the same vein, Appiah (2008) analysed the physico-chemical properties of roof run-off in Obuasi, Ghana. Seventy-five roof run-offs were sampled in Wawasi, Ramia and Antobuasi from aluminium, Aluminium-zinc, asbestos, clay tiles and one collected directly from the skies. Aluminium roofs had high pH values making the run-off more basic. Water from aluminium analysed for pH, alkalinity, EC, turbidity, TDS, TSS, nitrites, phosphates, chloride and sulphate, 31 % were above the WHO permissible limit for drinking water, whilst 69 % were below. For asbestos roofs, 25 % of the samples analysed were above the WHO guidelines whilst 75 % of the sample were below. However, clay tiles recorded lower values of pH, turbidity, sulphate and iron in the roof run-offs when compared with control samples. The pH had a good correlation within iron and zinc but had a poor correlation with lead, aluminium, chromium and cadmium. The orders in which the roofs are liable of releasing metals into the run-off are: Cr (ceramic > asbestos > metal sheet), and Zinc and Aluminium (metal sheet > asbestos > ceramic tiles). Asbestos and clay tiles pose more environmental risk than other roofs investigated in this study.

In Palestine, Adel, Issan and Hassan (2011) in their study on Sustainable water quality: management of rainwater harvesting cisterns in Southern Palestine, analyzed pH, temperature, conductivity, nitrates, ammonium, chloride, hardness, alkalinity, calcium, magnesium, salinity, TDS, turbidity, total coliforms and faecal coliforms. Their findings showed that most of the tested physiochemical parameters were within the acceptable limits of WHO and Palestinian standards except turbidity, calcium and magnesium where 24%, 47% and 32% of the samples were nonconforming, respectively. The pH values of the collected rainwater ranged from 7.32 to

8.97 with a mean value of 8.16. The nitrate analysis results range from 1.5 to 7.0mg/L, with a mean value of 4.2mg/L. High percentage of cisterns were found to be contaminated with total coliforms (TC) and faecal coliforms (FC) with percentages of 95% and 57%, respectively, rendering the cistern water unacceptable for drinking purposes.

However, none of this previous research works focused on the quality of rainwater harvested in cisterns in OnichaUgbo, Aniocha-North Local Government Area, Delta state, Nigeria. Hence, the need to carry out a research of these nature in the study area.

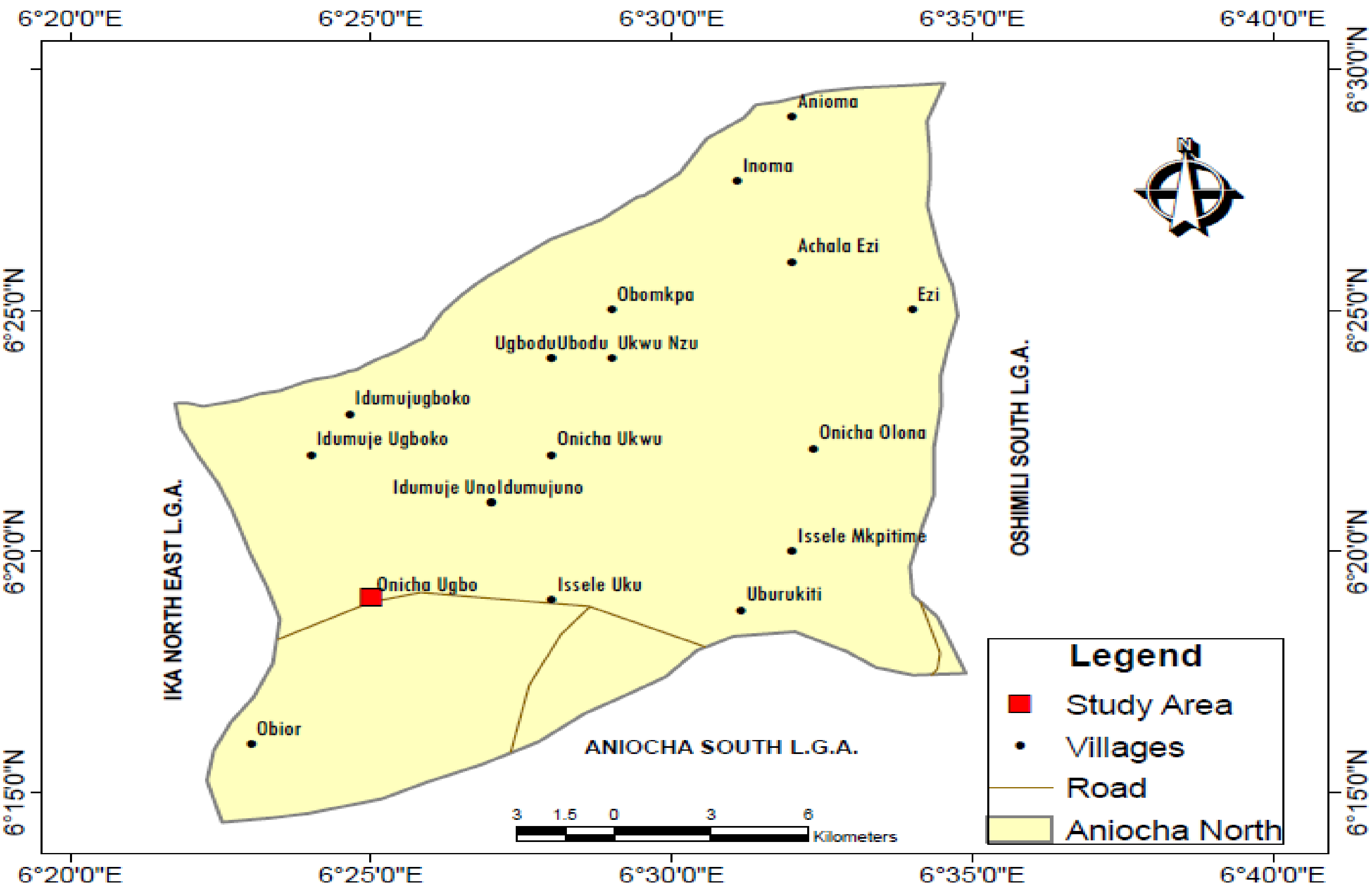
CHAPTER THREE:THE STUDY AREA AND METHODOLOGY

3.1 LOCATION

The study area, OnichaUgbo is a growing town inAniocha North Local Government Area, Delta State, Nigeria.It is situated on a highland at the western boundary of Aniocha North Local Government Area, and is covered with clayey brick-red sand. There is no solid rock near the surface. The town's traditional ruler is the Obi of Onicha-Ugbo; Obi Victor ChukwumaliezeAgbogidi of Onicha-Ugbo(http://en.wikipedia.org/wiki/onicha-ugbo).Onicha-Ugbo is located between latitudes $6^{o}15'$ - $6^{o}15'$N and longitudes $6^{o}23'$ - $6^{o}25'$E and covering an area of 85.19 Square Kilometres (Figure 3.1).

The area is situated about 40 kilometres from Asaba the state capital on the Asaba-Beninhighway connecting the West to the East of Nigeria. Itpopulation of about 10,000 inhabitants. It is bordered to the East by Issele-uku and Idumuje-Unor; to the West by Igbodo (in Ika Local Government Area) and Obior; to the North by Idumuje-Ugboko and Ewohinmi (in Edo state) and to the South by Ubulu-Uku(http://en.wikipedia.org/wiki/onicha-ugbo). As a junction town, Onicha-Ugbo is easily accessible from all the bordering communities through a network of roads.

Onicha-Ugbo is a road junction and offers the main approach to Idumuje-Ugboko and Idumuje-Unor. It is a market centre and boasts of the first telecommunication relay station in Aniocha North Local Government Area, built in 1955. The old Lagos-Asaba trunk 'A' road, which was completed in 1916 particularly, opened it up to the world. The road ran through the town proper.



SOURCE: Adapted and Modified from map of Delta State

Figure 3.1:Map of Aniocha-North Local Government Area showing the study area

3.2 CLIMATE

Climate and climatic variables do considerably influence water resources in the area. The climate of the area is defined by high values of evapotranspiration, humidity, temperature and rainfall that characterized humid tropical equatorial climate of the deltaic environment. The rainfall is mostly convectional and usually falls at any time of the day resulting from the effects of convectional rainfall and blown land and sea breezes. Onichaugbo experiences a humid tropical equatorial climate with fluctuations from humid in the south due to local influence of the river Niger to the sub-humid in the northeast (Ejemeyovwi, 2015).

The two seasonal winds of NE tropical continental airmass that blows from October to February and the SW tropical maritime airmass that blows from march to September maintains an average tropical temperature during the dry season and an average rainfall during the rainy season. The mean annual rainfall is 1254mm – 3032mm and temperature of 26.7oC with relative humidity of 69-80% and sunshine of 4.8 bars (Ejemeyovwi, 2015).

3.3GEOLOGY

The subsurface geology of the Niger Delta Basin to which Onicha-Ugbo belongs is well established. The Basin fill is made up of three formations, namely from the oldest to the youngest, Akata, AgbadaAnd Benin Formations (Nwajide, 2006). The Akata Formation is composed of continuous shale and about 10% sandstone. The shale is believed to be over pressured and under-compacted. It ranges from Eocene to Recent and was deposited under marine conditions(Akpoborie, Nfor, Etoboro and Odagwe, 2011).

The Agbada Formation conformably overlies the Akata Formation in the subsurface. It is a parallic sequence of alternating shale and sandstone with a variable age ranging from Eocene in the north to Pliocene/Pleistocene in the south, and Recent in the delta surface. Its lateral equivalents at the surface are the Ogwashi-Asaba Formation and Ameki Formation of Eocene-Oligocene age (Asseez, 1989). The continental Miocene-Recent Benin Formation conformably overlies the Agbada Formation. It is composed of more than 90% sands and about 10% shale/clays. The shale range in size from gravelly, coarse to fine grained. They are also poorly sorted, sub angular to well-rounded, and bear lignite streaks and wood fragments. The Benin Formation occurs just west and northwest of Asabatown (Akpoborie, Nfor, Etoboro and Odagwe, 2011).

3.4SOILS AND VEGETATION

The soils in the area have low silt and clay content, low cation exchange capacity and consequently low pH (Okpor, 2008). Three soil types are identified in Delta State. These consist of alluvial soil on the marine deposits along the coast; alluvial and hydromorphic soils on marine and lacustrine deposits found in the area closest to the Niger and Benin rivers; and the ferral soils on loose sandy sediments in the dryland areas of the north and northeast which are usually yellowish in colour.The soils are deeply leachedand lack distinct and well defined horizons.

The vegetation is tropical evergreen rainforest with tall trees and undergrowth. This has been interfered by anthropogenic activities such as farming, bush burning, grazing and rapid development in the area. The plant community is basically of evergreen species that yield hardwood such as *Entaudrophragma ssp*., iroko (*Meliciaspp*), mahogany (K*hayainvorensis*), lovoatrichiliodes, oil bean tree (*Pentaclethramacrophylla*), Falseiroko (*Anitiarisafricana*) and bamboo which dots everywhere. Fruit trees in the study area include pawpaw (*Carica papaya*), orange (*Citrus sinensis*), mango (*Mangiferaindica*), avocado pear, fruited pumpkin (*Telfaleriaoccidentalis*) amongst others. However, the emergence of grassland vegetation has been evident in many areas in Delta North region mainly in patches due to anthropogenic activities occasioned by deforestation (Ugboma, 2014).

3.5RELIEF AND DRAINAGE

The entire Delta State is a region built up by the sedimentation of the Niger Delta and consists of the delta in various stages of development. Four major physiographic units are identifiable within it. First, the freshwater swamp which is the most active area, located close to the River Niger, where annual flooding and deposition occurs up to 45km from the river's course. Second, the mangrove swamp area described as an intermediate delta stage. It is much lower and a great proportion of it is brackish, having been invaded by the sea since large amounts of freshwater have ceased flowing into it. Third, the upland and swamp, which is also called the coastal plain. It lies between the flood plain and Benin lowlands. The swamps are more restricted to broad drainage channels created when this area was an active delta. Finally, the upland Niger valley, which is a narrow strip above the delta and relatively flood-free.(onlinenigeria.com).

The River Niger drains the eastern flank of the state and discharges into the sea through its several distributaries such as the Forcados, Escravos and Warri rivers and creeks such as the Bomadi creeks, amongst others. Rivers Jamieson and Ethiope rise from the north and northeast respectively and subsequently join and form the Benin River, which eventually discharges into the sea in the west(onlinenigeria.com).

3.6 PEOPLE AND DEMOGRAPHY

Onicha-Ugbo is today a conglomerate of immigrants from various parts of Southern Nigeria. Christianity is the primary religion of the Onicha-Ugbo community. However, there are pockets of other religious worshippers such as Islamic and traditionalist in the area. The areais naturally made up mainly of the Igbo (delta) ethnic group referred to as 'anioma'. However, large population of Hausa'sand Yoruba's are residents. Although Igbo language is widely used as a medium of communication in the area, English language is the conventional means of communication (Okwechime, 2012).

Noble indigenes from Onicha-Ugbo includes Dr.Ibe Emmanuel Kachikwu, the current Minister of State Petroleum and Group Managing Director (GMD) of the Nigerian National Petroleum Corporation (NNPC) and immediate past vice-chairman ExxonMobil in Africa; Prof Richard Osemeka Patrick, a pastor in Christ Embassy, theCEO of CROP Global Organization and HOD, Department of Business Management at the Federal University Dutsinma; Jude Monye, a silver medallist at the Sidney 2000 Olympics; Prince Austin OnyeamaOgannah, Founder of THEWILL newspaper and IkenwaNnabuogor, a renowned sports journalist, working for National Mirror newspaper, Lagos.

The nearest river in Onicha-Ugbowas the IyiUgo river in Aniofu and until recently, people walked the six kilometres to the river, or to the nearby "tom-tom" spring and the Oha-Bioseh spring in Idumuje-Ugboko (4km's away) and Mkpitime to fetch clean water in the dry season owing to the absence of a flowing river in the area. In the rainy season, the people depended on family ponds (the deep Omi and shallow Ogodo) and water collected during the rains as it cascades down the roofs of houses (mmili-ochichi). In recent times, concrete underground wells were dug and rainwater is directed into them through gutters made round the base of corrugated iron sheet roofs. These wells serve the homes as water reservoirs particularly against the dry season.

3.7 ECONOMIC ACTIVITIES

Agriculture is the main economic activities in the area, due to the favourable climatic characteristics suitable for the cultivation of a wide range of crops, such as cassava, maize, plantain, okra, cocoyam, oil palm and vegetable (ugwu). However, cassava and maize is the most predominant crop cultivated in the area. Hence, a larger percentage of the women folks engage in post-harvest activities such as the conversion of cassava into various products such as garri granules, popogarri, fufu, starch, bobozin, tapioca, local gin, etc which are transported to the markets for sale. Economic infrastructures in the study area includes; Chelsea microfinance bank, a weekly market (usually held on Sundays), and other small scale industries such as provision stores, super-markets, bars, suya-joints, chemist store, hair salons, maternity health care, amongst others.

3.8 METHODOLOGY

3.8.1 Reconnaissance Survey

As a prelude to thisresearch, a reconnaissance survey of the study area was undertaken to enable the researcher acquaint himself with the environment, procure vital information about the study area such as the localities (quarters), the forms of rainwater harvesting cisterns in the area, to pin point the rainwater harvesting cisterns where harvested rainwater samples will be collected and analyzed for physicochemical and microbiological water quality parameters, as well as procure other relevant information that will be vital to the study.

3.8.2Types of Data

In order to achieve the aim and objectives of the study, the following data will be used:

i. Physico-chemical and microbiological properties of rainwater harvested in cisterns was obtained from laboratory analysis of samples from the field.

ii. Types of rainwater harvesting systems employed by households in the study area, which will be obtained from personal field observation.

3.8.3 Sources of Data

Two major sources of data were used in carrying out this research. They are the primary and secondary sources of data. The primary data were obtained from personal observation and fieldwork which includes collection of samples of rainwater harvested in cisterns and taken to the laboratory and analyzed for turbidity, colour, temperature, pH, coliform count, dissolved oxygen, chemical oxygen demand, biological oxygen demand, total suspended solids and total dissolved solid following standard methods for the examination of water quality (Soladoye and Yinusa, 2012). The secondary data source was obtained from relevant documents, published books, journals, seminar papers and past dissertation.

3.8.4 Sampling Techniques

Onicha-Ugbo as earlier mentioned is made up of four (4) quarter (ogbe) namely; Umuolo, Ogbekenu, Ogbe-obi and Ishiekpe. Each of this quarter developed along a main road in a linear settlement pattern. More still, this main roads intersects at a point known as Abu-ano (the town's square). Hence, a systematic sampling method was adopted in determining the sampling size in this study.

Harvested rainwater samples was collected by carefully selecting the 50th rainwater harvesting cistern (left and right side) in each of thesefour main roads across the study area.As a result twenty (20) samples of harvested rainwater was collected; six (6) samples was collected at Umuolo, five (5) samples was collected at Ogbe-obi, five (5) samples was collected at Ogbekenu whilefour (4) rainwater samples was collected atIshiekpe quarters. Note that, the disparity in the number of samples collected in the various quarters is predicated by the fact that the number of rainwater harvesting cisterns present in each of the road differs (in each sides of the road).

Nevertheless, a total of forty (40) harvested rainwater samples were used for this study. Twenty (20) samples as explained above were collected during the dry season (February). Subsequently, during the rainy season (April) period, twenty water samples was collected from the same rainwater harvesting cisterns (as shown in Table 3.1). This was done to account for any seasonal variation in the quality of the harvested rainwater in the rainwater harvesting cisterns.

Table 3.1: Number of selected rainwater harvesting cisterns

	Number of Rainwater samples collected	
Location	**During dry season**	**During rainy season**
Umuolo quarter	6	6
Ogbe-obi quarter	5	5
Ogbe-kenu quarter	5	5
Ishiekpe quarter	4	4
Total	**20**	**20**

3.8.5 Data Collection

In order to obtain accurate results, proper sampling procedures were adopted to eliminate or minimise potential contamination of the samples. The water samples were collected using plastic bailers and stored in one (1) litre capacity plastic bottles. The plastic bottles were first washed with deionised water, and then rinsed several times with the sample water before collection in order to avoid contamination (Anon, 1992). Nevertheless, temperature, colour and pH of the harvested rainwater samples were determined in-situ.

The bottles were labelled according to the code numbers allotted to each sampling cistern and were then stored in an ice packed cooler and transported immediately to the laboratory at Anambra state university, Uli, and analyzed for turbidity, total coliform counts, total dissolved solids (TDS), total suspended solids (TSS), dissolved oxygen (DO), chemical oxygen demand (COD) and biological oxygen demand (BOD) by a competent laboratory scientist using modern state-of-the-art equipment and following standard methods for the examination of water quality (Soladoye and Yinusa, 2012).

3.8.6 Method of Data Analysis

Objective 1: Identification of the forms of rainwater harvesting system in the study area. This objective was achieved by carrying out a personal field observation of the area, hence procured data and pictures on the forms of rainwater harvesting systems employed by inhabitants in the study area.

Objective 2: Examination of the levels of turbidity, colour, pH, total dissolved solids, total suspended solids, chemical oxygen demand, biological oxygen demand, dissolved oxygen and total coliform count of the harvested rainwater samples in rainwater harvesting cisterns of the study area.

To achieve this objective, the physicochemical and microbiological parameters were determined according to procedures and protocols outlined in the Standard Methods for the Examination of Water and Wastewater (APHA, 1992). The harvested rainwater samples were collected early in the morning, in one litre white plastic bottles with fitted covers. However, before any sample was collected, the plastic bottles were washed and rinsed with distilled water. The bottles containing the samples was secured and labelled as to the source, date, location and time of collection. The samples was then transported to the laboratory and analyzed for physicochemical and bacteriological water quality parameters by a laboratory scientist using standard procedures. However, temperature, pH, and colour were analysed in-situ using pH meter, turbidity meter and multi-meter respectively.

*Objective 3: what are the levels of physico-chemical and bacteriological elements of the harvested rainwater samples compared to national and international permissible limits for drinking water in the study area.*To achieve this objective, the data (laboratory results) collected from the physicochemical and microbiological analysis of harvested rainwater in cisterns was entered into the computer and computed using Microsoft Excel software. The results were presented using charts, while descriptive statistics such as Mean, Minimum, Maximum, and Standard Deviation were used in the comparison with World Health Organization (WHO, 2010) and Nigerian Standard for Drinking Water Quality (NSDWQ, 2007) drinking water standards.

Objective 4: Determination of the pollution index of individual water quality parameters from the harvested rainwater in cisterns in the study area. This objective was determinedas follows:

$$\text{Pollution index (Pi)} = \frac{\text{Concentration}}{\text{Standard}}$$

Pollution index (Pi) is expressed as a function of the concentration of individual parameter as against the baseline standard. It shows the relative contribution by each item. The critical value is 1. Values greater than 1.0 indicate significant degree of pollution while a value less than 1.0 shows no significant pollution (Akpoveta, OkohandOsakwe, 2011).

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1FORMS OF RAINWATER HARVESTING CISTERNS

Cisterns (storage tank) are receptacles built to catch and store rainwater (Pacey and Cullis, 1986).They harvest the rainwater that falls on a property's roof, diverting the flow from the guttering into a tank rather than allowing it to enter the drain (See Plate 4.1). Cisterns can be built either above or below ground; however, factors such as soil, outside temperature ranges and cost is used to determine whether a tank is placed above or below ground. Cisterns alsocome in range of forms (i.e. concrete tanks, fiberglass, bladder, polyethylene, galvanized steel or plastic), sizesand shapes with varying features.

Plate 4.1: A cistern with its features at Ogbekenu, Onicha-Ugbo

The forms of rainwater harvesting cisterns in the study area are predominantly below-ground concrete tanks. This concrete tanks are poured-in-place, thus are very attractive and easily integrated into new construction. However, once poured, are considered permanent. One unique advantage of poured concrete tank is that the concrete will over time decrease the corrosiveness of rainwater by leaching into the water. These results in a desirable taste imparted to the water by calcium in the concrete being dissolved in locations where there’s slightly acidic rainwater.

Plate 4.2(a): Below-ground concrete cistern atUmuolo, OnichaUgbo.

Plate 4.3: Below-ground concrete cistern at Umuolo, OnichaUgbo.

Plate 4.4: Below-ground concrete cistern at Ogbe-obi, OnichaUgbo.

4.2 PHYSICO-CHEMICAL ANALYSIS

From the physico-chemical and bacteriological analysis of the harvested rainwater samples collected, variations in the levels of turbidity, pH, TDS, TSS, DO, COD, BOD, temperatureand total coliform count was observed between water samples collected during the rainy and dry seasons respectively. Also, the results of the laboratory analysis of the harvested rainwater samples revealed that all the water quality parameters examined were detected in each of the samples analyzed though with varying degrees of concentration.

Furthermore, the summary of the physico-chemical and bacteriological analysis of all harvested rainwater samples are presented in Tables 4.1a and 4.1b for rainy and dry season respectively. This shows the variation in-terms of minimum, maximum, mean and standard deviation of the concentration in each physico-chemical and bacteriological water quality parameter. However, the results of each of the parameters examined in this study are vividly represented using histograms which reveal the levels of each water quality parameter during the rainy and dry seasons respectively.

4.2.1 pH

The pHvalue or hydrogen ion concentration is a measurement of the acidity or alkalinity of water. The pH of water is measured on a scale that runs from 0 to 14. Seven (7) is neutral, while measurements below 6.5 indicates the presence of acid and measurements above 7.0 indicates alkalinity. Nevertheless, the World Health Organization (2010) specifies a pH concentration between 6.5 and 8.5 as the standard for potable water.

In this study, the pH of water samples fell below the permissible limit of 6.5 – 8.5 as prescribed by the World health organization (2010) and NSDWQ (2007) standards for potable water.The pH levels ranged between 5.55 to 6.75 with a mean pH value of 6.21 and Standard deviation of 0.39086 during the wet season. While during the dry season, pH levels of the water samples ranged from 5.20 to 6.20 with an average pH concentration and Standard deviation of 5.63 and 0.46760 respectively. Also, during this period, cistern 6 had the highest pH value while cistern 20 had the lowest pH value of 5.20 in the study area.

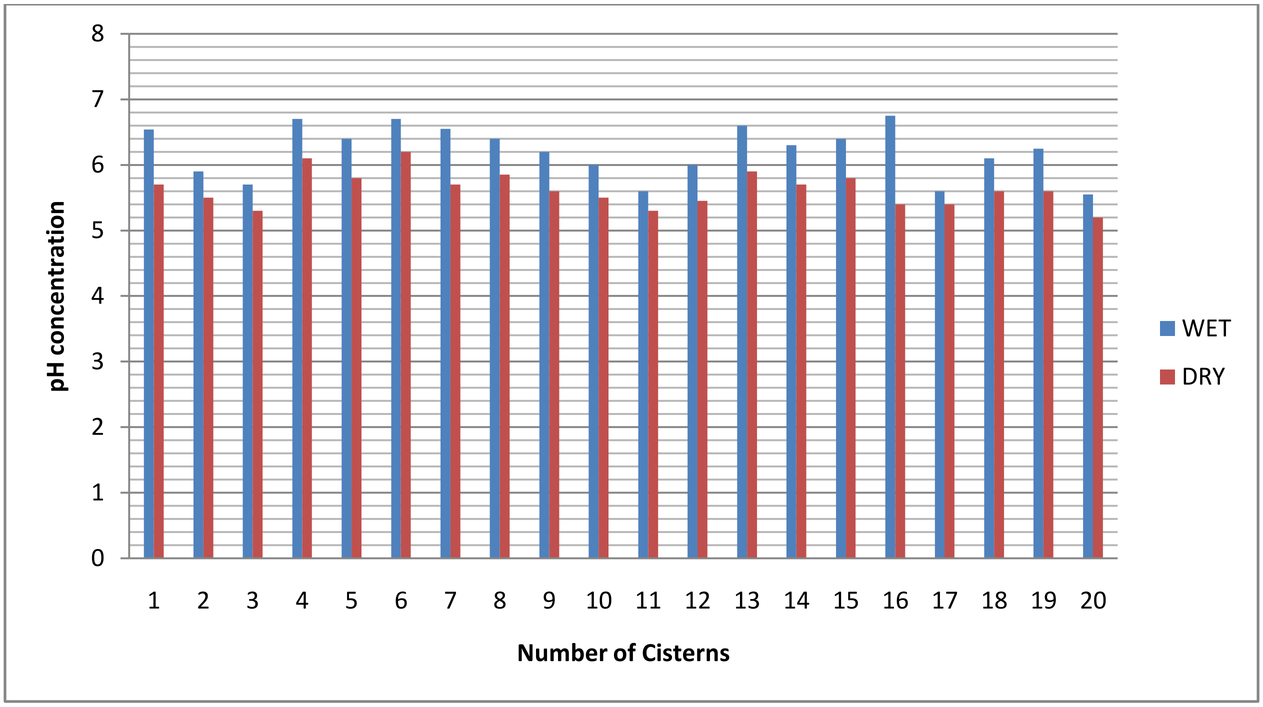


Figure 4.1: pH concentration of harvested rainwater during Wet and Dry season

The analyses revealed that all the harvested rainwater samples were acidic (i.e. having pH concentrations below 6.5). This may be attributed to the nature of rainwater, which is acidic in nature. Furthermore, harvested rainwater samples were more acidic during the dry season as compared to the rainy season period. Richard *et al*., (1996) noted that low pH levels obtained in well water may be traced to the acidity produced by organic wastes decomposing under partially reducing conditions into organic acids. In addition, Ogunkoya and Efi (2003) opined that higher rainwater acidity in the area has been attributed to the dissolution in rainwater of acidic gases including CO_2, NO_2 AND SO_2 that originates from gas flares and vehicular exhaust in the environment.

Although, the pH of water is generally considered to have no direct impact on humans (Olalekan, Abubakar and Abdul-mumini, 2005), long-term intake of acidic water can invariably lead to mineral deficiencies (Fairweather-Tait and Hurrell, 1996). Also, a pH level below 6.5 causes corrosion in pipes resulting in release of toxic metals. Abnormal values of pH also causes bitter taste of water, affects mucous membranes, causes corrosion and affects aquatic life. Acidic water has also been known to be aggressive in promoting the dissolution of iron and manganese which causes unpleasant taste in water (Hammer and Hammer, 2004). More importantly, prolong exposure to such acidic water will only negate the various efforts of government to enhance nutrition of the people.

4.2.2 Temperature

Temperature is the degree of coldness or hotness of a body (Adejuwon and Mbuk, 2011). Temperature is an important water quality indicator because it can influence the solubility of dissolved oxygen and other materials in the water column (eg. ammonia); affects other phenomena such as the rate of biochemical and chemical reactions in the water body and amplification of tastes and colours of water (Olajire and Imeokperia, 2001).

In this study, Temperature of all the samples was fairly uniform in almost all the sampled wells during both the wet and dry season periods. None of the samples had temperatures that exceeded the permissible limit of 30^oC for potable water. All the samples had temperatures within the specified range of 20^oC - 30^oC as prescribed by the World Health Organization (2010).

Temperatures of the Water Samples ranged from 23°C – 24°C with a mean of 23.47°C and standard deviation of 0.30483 during the wet season.

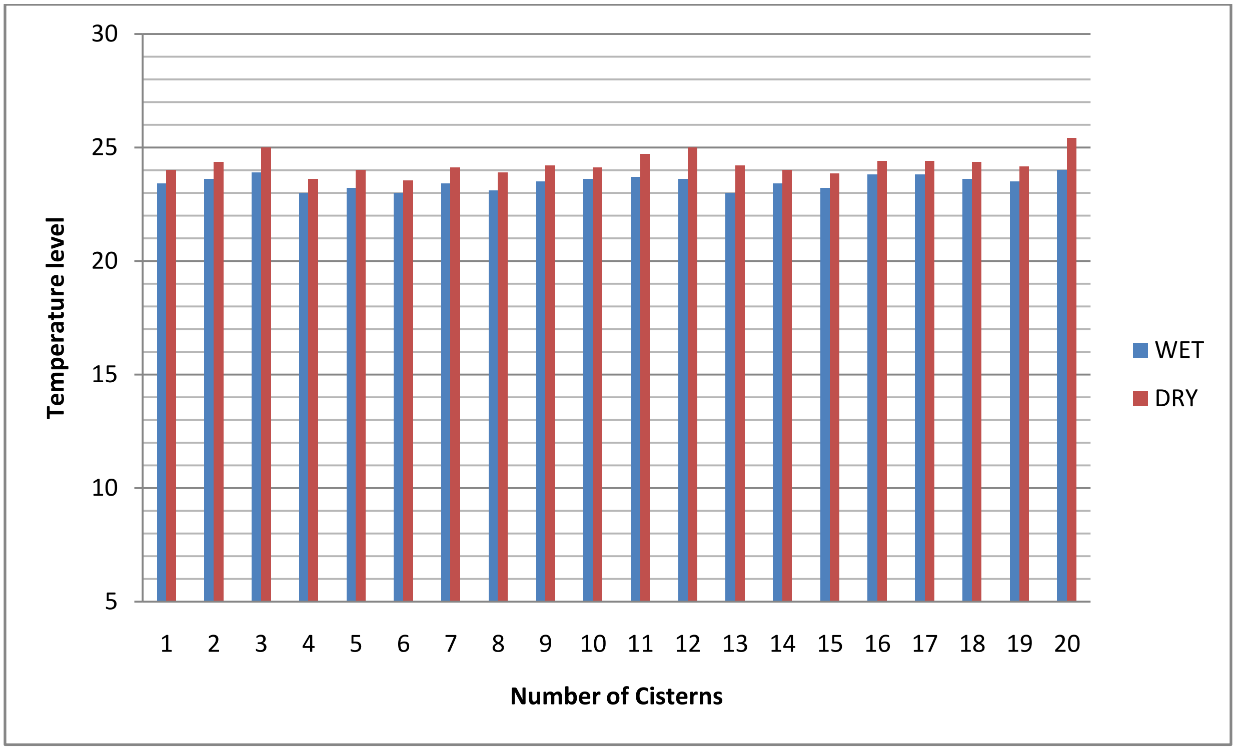


Figure 4.2: Temperature levels of harvested rainwater during Wet and Dry season

Temperature was highest at cistern 20 (24°C). Meanwhile, during the dry season, the water samples had temperatures ranging from 23.55°C to 25.40°C. The mean during this period was 24.26°C while the standard deviation was 0.46760. A temperature of the samples was highest at cistern 20 (25.40°C). These variations observed in the water temperatures of the water samples is as a result of the fact that water temperature varies with season, elevation, geographic location and climatic conditions (Barnes, Meyer and Freeman, 1998).

4.2.3 Colour and Turbidity

Bhutia (2009) stated that pure water is colourless; hence any water with characteristic colour insinuates contamination. The result of the physico-chemical analysis of the harvested rainwater samples indicates clear water in all the cisterns during both the dry and rainy season. Hence the water samples met the recommended standards put forward by the World Health Organization and Nigeria Standard for Drinking Water Quality for drinking water.

Turbidity refers to water clarity. It is a measure of the cloudiness in water caused by the presence of suspended matter in water such as sand, silt, clays, mud, algae, silica and bacteria. The World Health Organization (WHO, 2008) and the Nigerian Standard for Drinking Water Quality (NSDWQ, 2007) prescribes a turbidity level of 5.0 NTU (Nephelometric Turbidity Unit) as a permissible limit for drinking water (See Table 4.1a and 4.1b).

In this study, low values of turbidity within the range of 0-2 NTU were observed in all harvested rainwater sampled. This conforms to the acceptable standards and guidelines for potable water quality of 5.0 NTU. In this study, mean turbidity levels was 0.9500, with standard deviation of 0.7592 during the wet season. However, during the dry season, mean turbidity levels was 0.4000 while the standard deviation was 0.5026. During the wet season, the maximum turbidity levels was recorded at cisterns 3, 7, 8, 11 and 18 respectively with turbidity value of 2NTU.

The decline in the average turbidity levels during the dry season indicates higher turbidity levels during the wet season in the area. This may be related to the presence of particles of clay, organic components and other microscopic substances in the water (Ovrawah and Hymone, 2001).Moreso, it may also be an indication of deposits of pollutant loads whichmay be attributed to the introduction of wind-blown dirt’s, leaves, faecal droppings from birds and other animals, insects and contaminated litter on the catchment areas into the rainwater cistern when the rain begins to fall.

4.2.4Total Dissolved Solids (TDS)

The total dissolved solids (TDS) content of water can be a good indication of contamination or low quality of water. TDS is a measurement of the amount of dissolved ions in water. TDS is predominantly comprised of inorganic salts and small amounts of organic matter present in solution in water, which includescalcium, magnesium, potassium,sodium,bicarbonate,chloride, sulphate, nitrate and organic ions, many of which are necessary life sustaining nutrients. Consequently, the World Health Organization (2010) specifies500mg/l as the permissible limit for potable water.

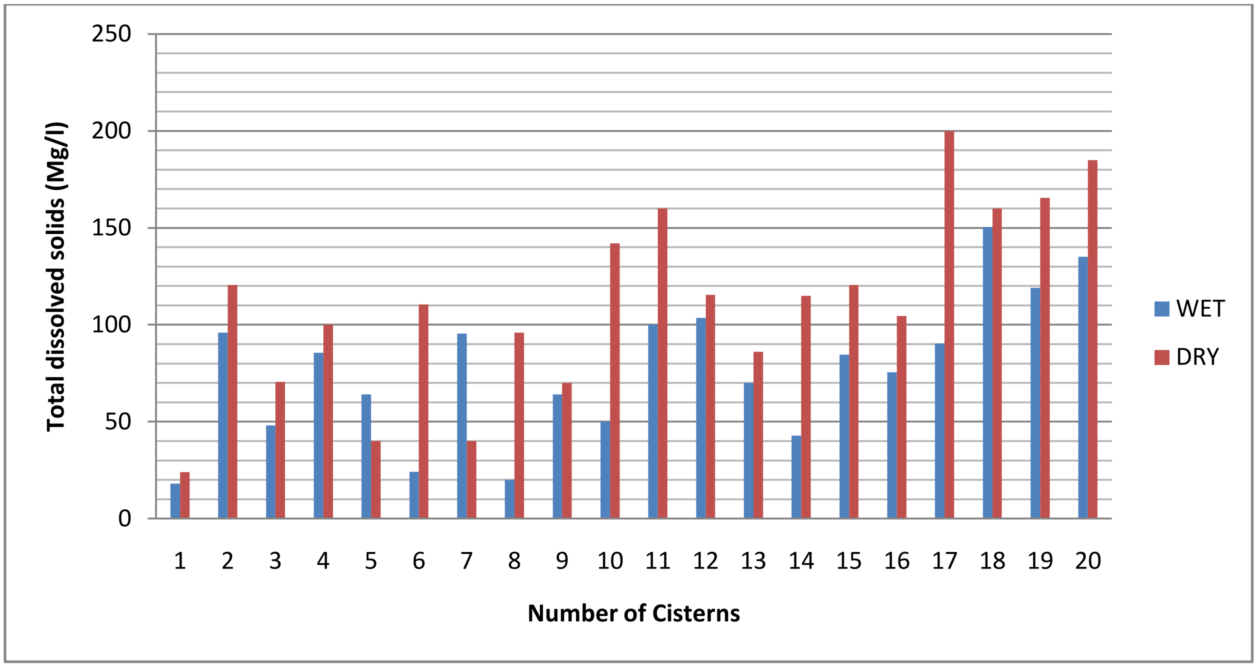


Figure 4.3: TDS levels in harvested rainwater during Wet and Dry season

In this study, TDS levels ranged between 18.00 to 150.50mg/l, with a mean of 76.81mg/l and standard deviation of 36.58527 during the wet season. During this period, TDS levels were highest at cistern 18 while the lowest concentration of TDS was recorded at cistern 1. On the other hand, during the dry season period, TDS levels ranged from 24.00 to 200mg/l with a Standard deviation of 48.29805. However, TDS was highest at cistern 17 while it was lowest at cistern 1 (Figure 4.3).In summary, all the water samples had TDS levels below the 500mg/l permissible limit set by the World Health Organization and the Nigerian Standard for Drinking water Quality.

As earlier stated certain materials determined the amount of TDS in water. These materials include; carbonate bicarbonate, chloride, sulphate, nitrate, calcium, magnesium, sodium, organic ions and other ions. Consequently, the possible cause of low amount of TDS was the minimal presence of these chemicals in the water samples, while, samples with higher TDS concentration was due to the high presence of the chemicals in the water (Salisu, 2004). Also, high TDS in water results in water hardness; scale formation; bitter taste in drinking water caused by calcium and magnesium carbonates and salty taste of the water resulting from Sodium Chloride (NaCl).

4.2.5 Total Suspended Solids (TSS)

Total Suspended Solids (TSS) is a significant factor in observing water clarity. They are particles larger than 2 microns found in the water column; while anything smaller than 2 microns (average filter size) is considered a dissolved solid. Most suspended solids are made up of inorganic materials; bacteria and algae can contribute to the total solids concentration. However, organic particles from decomposing materials can also contribute to the TSS concentration.

Most people consider water with a TSS concentration less than 20mg/l to be clear. Water with TSS levels between 40 and 80 mg/l tends to appear cloudy, while water with concentrations over 150 mg/l usually appears dirty. However, the nature of the particles that comprise the suspended solids may cause these numbers to vary.

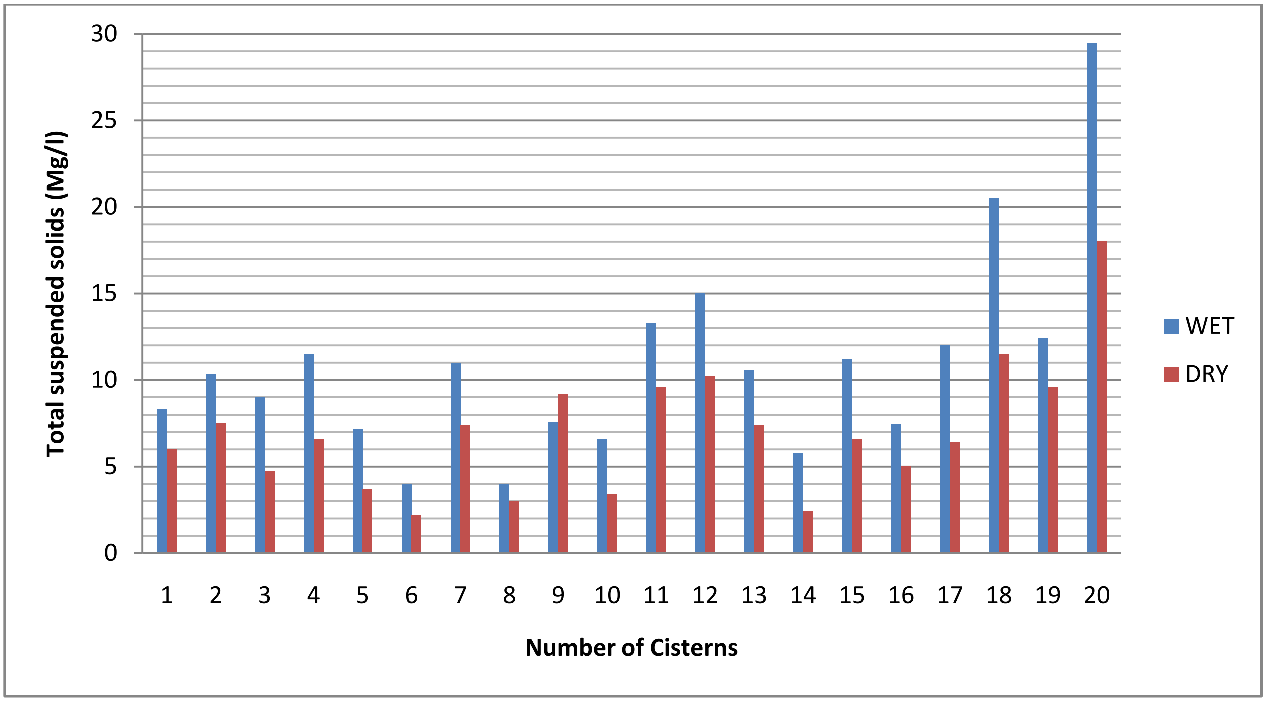


Figure 4.4: TSS concentration in harvested rainwater during Wet and Dry season

In this study,Total Suspended Solids (TSS) of the harvested rainwater samples varied between 4.00mg/l and 29.50mg/l, with a mean TSS level of 10.86mg/l and Standard deviation of 5.8576 during the rainy season. But during the dry season, TSS ranged from 2.20mg/l to 18.00 mg/l. the mean TSS concentration was 7.02mg/l while the standard deviation was 3.7360. Moreover, 18 of the harvested rainwater samples exceeded the WHO maximum acceptable limit of 5mg/l for drinking water during the wet season, while only 14 exceeded the limit during the dry season. However, none of the water samples has TSS concentration above the WHO maximum allowable limit of 30mg/l for drinking water (Figure 4.4).

4.2.6 Dissolved Oxygen (DO)

The dissolved oxygen (DO) refers to the actual amount of oxygen available in dissolved form in the water. The amount of oxygen water can hold depends on some factors such as temperature (more oxygen can be dissolved in water in colder water), pressure (more oxygen can be dissolved in water at greater pressure), and salinity (more oxygen can be dissolved in water at lower salinity). A high DO level in a community water supply is good because it makes drinking water taste better. However, high dissolved oxygenconcentrations speed up corrosion in water pipes.

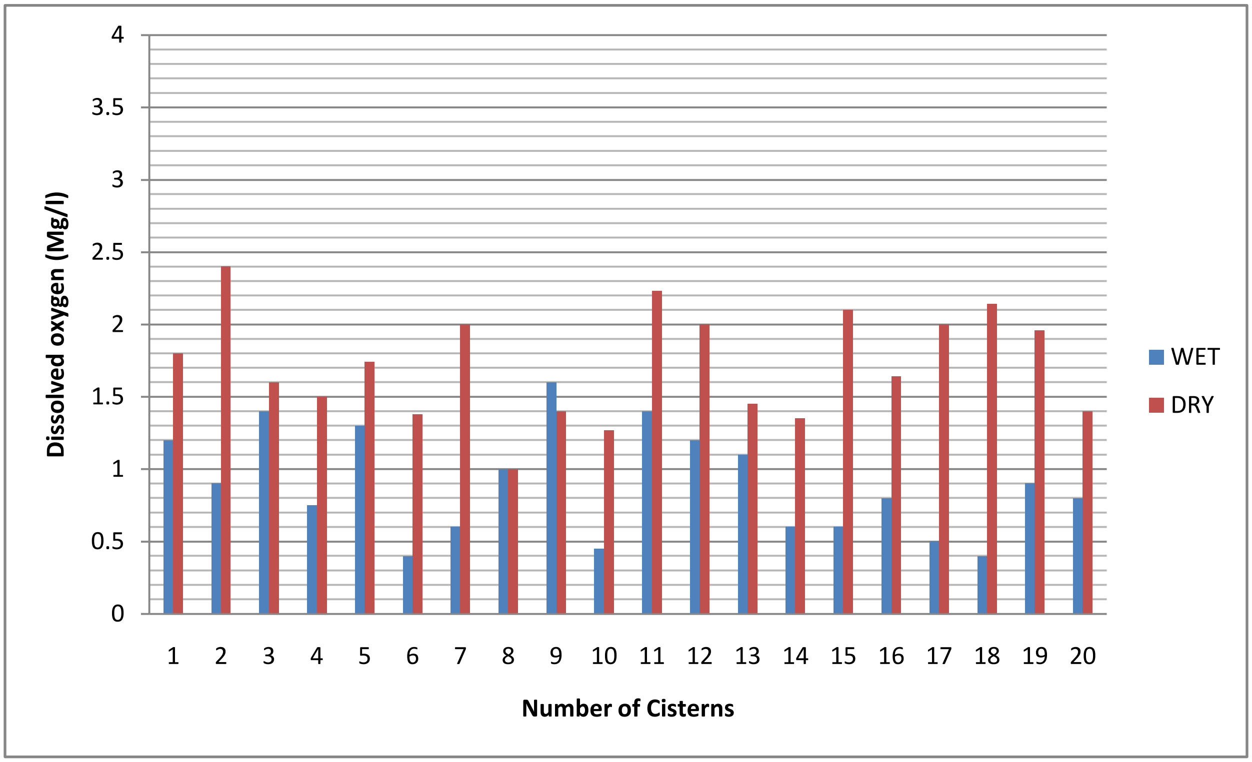


Figure 4.5: Dissolved oxygen levels in harvested rainwater during Wet and Dry season

The results from the laboratory analysis conducted in this study reveals that Dissolved Oxygen (DO) ranged from 0.4mg/l to 1.6mg/l during the rainy season with a mean of 0.90mg/l and standard deviation of 0.3667. During this period, cistern 18 and cistern 6 had the lowest DO concentration (0.40mg/l) while the maximum DO level was recorded at cistern 9. However during the dry season, DO range between 1.0mg/l and 2.4mg/l, with a mean DO level of 1.72mg/l and standard deviation of 0.3744. Nonetheless, the Dissolved Oxygen concentration of all the harvested rainwater samples conformed to the maximum permissible limit of 5.0mg/l for drinking water as specified by the WHO (Figure 4.5).

4.2.7 Biological Oxygen Demand (BOD)

Biological Oxygen Demand (BOD) is a measure of the quantity of oxygen used by micro-organisms (e.g. aerobic bacteria) in the oxidation of organic matter. A low BOD is an indicator of good quality water while a high BOD level is an indicator of polluted water, as systems with high BOD tend to have low dissolved oxygen. Succinctly, a water sample with BOD between 1.0mg/l and 2.0mg/l indicates very clean water; 3.0mg/l to 5.0mg/l indicates moderately clean water, while water with BOD greater than 5.0mg/l indicates a nearby pollution source (Brian, 2015).

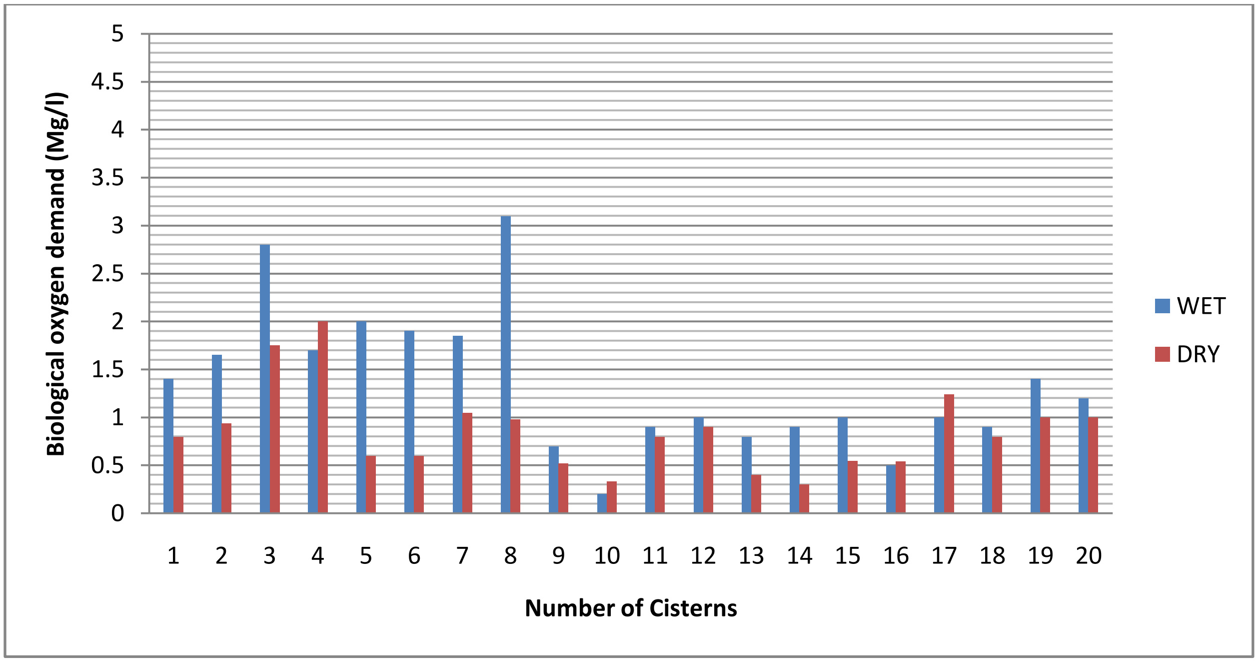


Figure 4.6: BOD levels in harvested rainwater during Wet and Dry season

In this study, all the harvested rainwater sampled (both during the wet and dry season) had BOD concentration within the maximum acceptable limits (5.0mg/l) for drinking water as prescribed by the World Health Organization (see Figure 4.6). The concentration of the harvested rainwater samples range from 0.2mg/l to 3.10mg/l with the mean and standard deviation at 1.35mg/l and 0.7299 respectively during the wet season. However, during the dry season period, BOD levels were between 0.30mg/l and 2.00mg/l while the mean and standard deviation was 0.86mg/l and 0.4353 respectively.

4.2.8 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) is a measure of the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals. It determines the oxygen required for the chemical oxidation of organic matter. Water with COD is greater than BOD for any given sample and is typically less than 20mg/l in unpolluted waters (nerrs.noaa.gov).

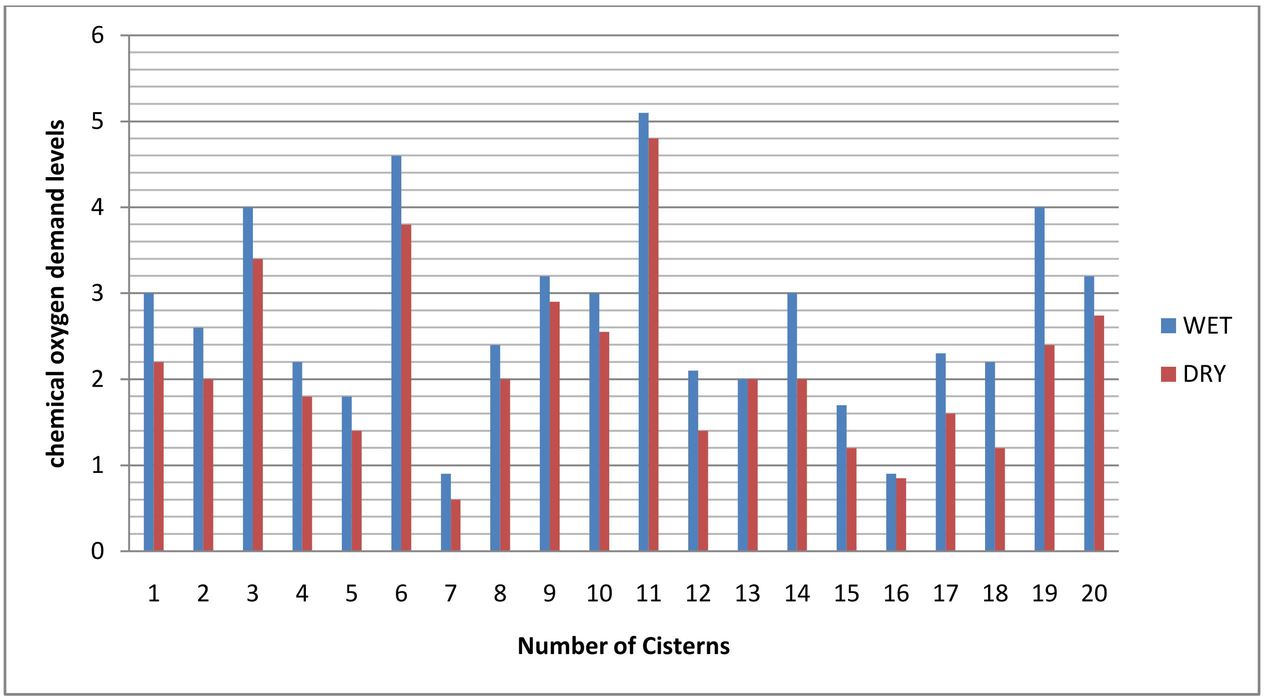


Figure 4.7: COD levels in harvested rainwater during Wet and Dry season

The result of the physicochemical analysis carried out in this study revealed that COD concentration range from 0.90mg/l to 5.10mg/l with a mean of 2.71mg/l and standard deviation of 1.1102. But, during the dry season period, COD concentration range between 0.60mg/l to 4.80mg/l with mean of 2.14mg/l and standard deviation of 0.4064. Consequently, all the water samples had COD concentration below the maximum permissible limit of 10.0mg/l as specified by the World Health Organization (2010).

4.3 BACTERIOLOGICAL ANALYSIS

The sanitary quality of rainwater in an area is assessed by its bacteriological composition. Total coliform is a widely used indicator to determine the possible presence of pathogenic organisms. Total coliform counts tests are used to assess bacteriological water quality. These tests are used to index hygiene quality because total and faecal coliform are usually associated with faecal contamination and thus, their numbers reflect the degree of pathogenic risks (Olobaniyi, 2007).

The World Health Organization (WHO, 2010) specifies that any disease causing organisms must not be detectable in any 100ml of water sample and must not be present in 95% of sample taken throughout any twelve (12) months period (Olaoye and Olaniyan, 2012).

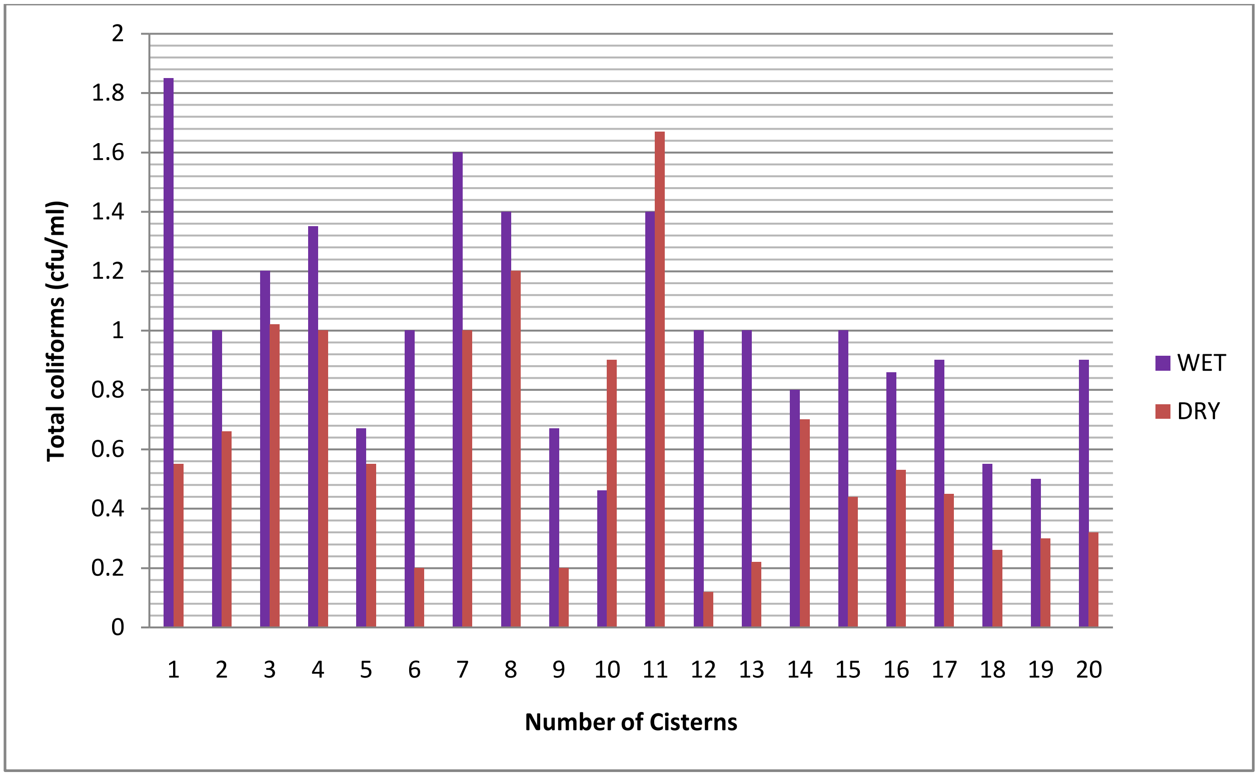


Figure 4.8: Coliform levels in harvested rainwater during Wet and Dry season

Consequently, the World Health Organization recommends that drinking water should contain zero coliform bacteria per every 100ml of drinking water (0cfu/100ml) while, the Nigeria Standard for Drinking Water Quality (NSDWQ, 2007) recommends that drinking water may contain up to 10cfu/100ml total coliform.

The bacteriological analysis of harvested rainwater in studied area revealed that the Total coliform count of sampled harvested rainwater were more than the World Health Organization specified limit of 0cfu/100ml. total coliform count ranged between 0.40-1.85cfu/100ml with mean values of 1.01cfu/10ml during the wetseason. However during the dry season, total coliform count ranged from 0.12cfu/100ml to 1.67cfu/100ml with mean level of 0.6145cfu/100ml and standard deviation of 0.4064.

In addition, the maximum total coliform count was observed in cistern 1 and cistern 11 during the wet and dry season respectively. Nevertheless, total coliform count was shown to be slightly higher during the wet season. This is attributed to the washing down of bird droppings, leave fall after precipitation, sewage leakage into the cisterns. The presence of coliform bacteria in the water indicates that faecal pollution has occurred, which poses great danger to human health. These pathogenic organisms are responsible for the infection of the intestinal tracts and diseases caused include: diarrhoea, cholera, bacillary dysentery, typhoid, hepatitis to mention but a few. Hence, one may conclude that harvested rainwater samples from the study area were polluted and unsuitable for drinking.

Table 4.1a:Descriptive statistics of harvested rainwater during the Rainy season

Parameters	Unit	Sample Size	Minimum Concentration	Maximum Concentration	Mean	Standard Deviation	WHO (2010)	NSDWQ (2007)
pH	Unit	20	5.55	6.75	6.2120	0.3909	**6.5 – 8.5**	**6.5 – 8.5**
Temperature	^{o}C	20	23.00	24.00	23.4650	0.3048	**20 – 30**	**Ambient**
Turbidity	NTU	20	0.00	2.00	0.9500	0.7592	**5.0**	**5.0**
TSS	Mg/L	20	4.00	29.50	10.8600	5.8576	**5 – 30**	**-**
DO	Mg/L	20	0.40	1.60	0.8950	0.3667	**5.0**	**10.0**
TDS	Mg/L	20	18.00	150.50	76.8100	36.5853	**500**	**500**
BOD	Mg/L	20	0.20	3.10	1.3450	0.7299	**5.0**	**6.0**
COD	Mg/L	20	0.90	5.10	2.7100	1.1102	**10.0**	**-**
Total Coliform	cfu/100ml	20	0.40	1.85	1.0055	0.3703	**0.0**	**10.0**

Table 4.1b:Descriptive statistics of harvested rainwater during the Dry season

Parameters	Unit	Sample Size	Minimum Concentration	Maximum Concentration	Mean	Standard Deviation	WHO (2010)	NSDWQ (2007)
pH	Unit	20	5.20	6.20	5.6300	0.2633	**6.5 – 8.5**	**6.5 – 8.5**
Temperature	^{o}C	20	23.55	25.40	24.2625	0.4676	**20 – 30**	**Ambient**
Turbidity	NTU	20	0.00	1.00	0.4000	0.5026	**5.0**	**5.0**
TSS	Mg/L	20	2.20	18.00	7.0225	3.7360	**5 – 30**	**-**
DO	Mg/L	20	1.00	2.40	1.7180	0.3744	**5.0**	**10.0**
TDS	Mg/L	20	24.00	200.00	111.27	48.2981	**500**	**500**
BOD	Mg/L	20	0.30	2.00	0.8550	0.4353	**5.0**	**6.0**
COD	Mg/L	20	0.60	4.80	2.1420	1.0255	**10.0**	**-**
Total Coliform	cfu/100ml	20	0.12	1.67	0.6145	0.4064	**0.0**	**10.0**

4.4 POLLUTION INDEX

Pollution index (Pi) is expressed as a function of the concentration of individual parameter as against the baseline standard. It shows the relative contribution by each item. The critical value is one (1.0). Values greater than 1.0 indicate significant degree of pollution while a value less than 1.0 shows no pollution (Akpoveta, OkohandOsakwe, 2011). The pollution index (pi) physic-chemical and bacteriological analysis is shown in Table 4.2a and 4.2b for rainy and dry seasons respectively.

The pollution index (pi) for all the physicochemical water quality parameters was below the critical value of 1.0. Thus, it indicates that there is ‘no significant pollution’ for pH, turbidity, colour, temperature, chemical oxygen demand (COD), dissolved oxygen (DO), biological oxygen demand (BOD), total suspended solids (TSS) and total dissolved solids (TDS) in samples of harvested rainwater in cisterns in the study area.

However, Pollution index (pi) results obtained for Total coliform count indicates significant degree of pollution in all the harvested rainwater samples in the study area during both sampling periods (the dry and rainy season). All the harvested rainwater samples had Pollution index value above the critical value of 1. Also, the degree of pollution of coliform bacteria presence in individual water quality parameters was higher during the rainy season period.

Table 4.2a:Pollution Index (Pi) of physico-chemical and bacteriological water quality parameters during the Rainy season.

Pollution Index (Rainy season)										
LOCATION	**CISTERNS**	**pH**	**TEMP (^{o}C)**	**TURBIDITY (NTU)**	**TSS (Mg/L)**	**DO (Mg/L)**	**TDS (Mg/L)**	**BOD (Mg/L)**	**COD (Mg/L)**	**TOTAL COLIFORM COUNTS (cfu/100ml)**
Umuolo	1	0.77	0.78	0.20	0.28	0.24	0.04	0.28	0.20	1.85
Umuolo	2	0.69	0.79	0.20	0.35	0.18	0.19	0.33	0.26	1.00
Umuolo	3	0.67	0.79	0.40	0.30	0.28	0.09	0.56	0.40	1.2
Umuolo	4	0.79	0.77	0.20	0.38	0.15	0.17	0.34	0.22	1.35
Umuolo	5	0.75	0.77	0.20	0.24	0.26	0.13	0.40	0.18	0.67
Umuolo	6	0.79	0.77	0.20	0.13	0.08	0.05	0.38	0.46	1.00
Ogbe-obi	7	0.77	0.78	0.40	0.37	0.12	0.19	0.37	0.09	1.60
Ogbe-obi	8	0.75	0.77	0.40	0.13	0.20	0.04	0.62	0.24	1.40
Ogbe-obi	9	0.73	0.78	-	0.25	0.32	0.13	0.14	0.32	0.67
Ogbe-obi	10	0.71	0.79	-	0.22	0.09	0.10	0.04	0.30	0.46
Ogbe-obi	11	0.66	0.79	0.40	0.44	0.28	0.20	0.18	0.51	1.40
Ogbe-kenu	12	0.71	0.79	-	0.50	0.24	0.21	0.20	0.21	1.00
Ogbe-kenu	13	0.78	0.77	-	0.35	0.22	0.14	0.16	0.20	1.00
Ogbe-kenu	14	0.74	0.78	-	0.19	0.12	0.09	0.18	0.30	0.80
Ogbe-kenu	15	0.75	0.77	0.20	0.37	0.12	0.17	0.20	0.17	1.00
Ogbe-kenu	16	0.79	0.79	-	0.25	0.16	0.15	0.10	0.09	0.86
Ishiekpe	17	0.66	0.79	0.20	0.40	0.10	0.18	0.20	0.23	0.90
Ishiekpe	18	0.71	0.79	0.40	0.68	0.08	0.30	0.18	0.22	0.55
Ishiekpe	19	0.74	0.78	0.20	0.41	0.18	0.24	0.28	0.40	0.50
Ishiekpe	20	0.65	0.80	0.20	0.98	0.16	0.27	0.24	0.32	0.90

Note: Baseline standards: pH = 8.5, Temp = 30^{o}C, Turbidity = 5NTU, TSS = 30mg/l, DO = 5mg/l, TDS = 500mg/l, BOD = 5mg/l, COD=10mg/l, Total coliform counts= 0cfu/100ml (Adopted from WHO, 2010).

Table 4.2b: Pollution Index (Pi) of physico-chemical and bacteriological water quality parameters during the Dry season.

			Pollution Index (Dry season)							
LOCATION	**CISTERNS**	**pH**	**TEMP. (^oC)**	**TURBIDITY (NTU)**	**TSS (Mg/L)**	**DO (Mg/L)**	**TDS (Mg/L)**	**BOD (Mg/L)**	**COD (Mg/L)**	**TOTAL COLIFORM COUNTS (cfu/100ml)**
Umuolo	1	0.67	0.80	-	0.20	0.36	0.05	0.16	0.22	0.55
Umuolo	2	0.65	0.81	-	0.25	0.48	0.24	0.19	0.20	0.66
Umuolo	3	0.63	0.83	0.20	0.16	0.32	0.14	0.35	0.34	1.02
Umuolo	4	0.71	0.79	-	0.22	0.30	0.20	0.40	0.18	1.00
Umuolo	5	0.68	0.80	-	0.12	0.35	0.08	0.12	0.14	0.55
Umuolo	6	0.73	0.79	-	0.07	0.28	0.22	0.12	0.38	0.20
Ogbe-obi	7	0.67	0.80	0.20	0.25	0.40	0.08	0.21	0.06	1.00
Ogbe-obi	8	0.69	0.79	0.20	0.10	0.20	0.19	0.19	0.20	1.20
Ogbe-obi	9	0.66	0.80	-	0.31	0.28	0.14	0.10	0.29	0.20
Ogbe-obi	10	0.65	0.80	-	0.11	0.25	0.28	0.07	0.26	0.90
Ogbe-obi	11	0.63	0.82	0.20	0.32	0.47	0.32	0.16	0.48	1.67
Ogbe-kenu	12	0.64	0.83	0.20	0.34	0.40	0.23	0.18	0.14	0.12
Ogbe-kenu	13	0.69	0.81	-	0.25	0.29	0.17	0.08	0.20	0.22
Ogbe-kenu	14	0.67	0.80	-	0.08	0.27	0.23	0.06	0.20	0.70
Ogbe-kenu	15	0.68	0.79	-	0.22	0.42	0.24	0.11	0.12	0.44
Ogbe-kenu	16	0.64	0.81	-	0.17	0.33	0.21	0.11	0.09	0.53
Ishiekpe	17	0.64	0.81	-	0.21	0.40	0.40	0.25	0.16	0.45
Ishiekpe	18	0.66	0.81	0.20	0.38	0.43	0.32	0.16	0.12	0.26
Ishiekpe	19	0.66	0.81	0.20	0.32	0.39	0.33	0.20	0.24	0.30
Ishiekpe	20	0.61	0.85	0.20	0.60	0.28	0.37	0.20	0.27	0.32

Note: Baseline standards: pH = 8.5, Temp = 30^oC, Turbidity = 5NTU, TSS = 30mg/l, DO = 5mg/l, TDS = 500mg/l, BOD = 5mg/l, COD=10mg/l, Total coliform counts= 0cfu/100ml (Adopted from WHO, 2010).

CHAPTER FIVE: SUMMARY, CONCLUSION AND RCOMMENDATIONS

5.1 SUMMARY OF FINDINGS

Based on the aim and objectives of the study, the following findings emerged:

- Most of the physico-chemical water quality parameters examined such as temperature, colour, turbidity, TDS, TSS, DO, COD and BOD showed satisfactory concentration in line with the specifications of the World Health Organization (2010) as well as the Nigerian Standards for Drinking Water Quality (NSDWQ, 2007).
- The concentrations of pH however, were higher and hence showed unsatisfactory concentration when compared to the prescription of theWorld Health Organization (2010) and the Nigerian Standards for Drinking Water Quality (NSDWQ, 2007). Most of the harvested rainwater samples had pH levels below the 6.5 acceptable limits for drinking water quality.
- Total coliform counts, which are used to assess the bacteriological water quality of the harvested rainwater, indicated that the sanitary quality of the rainwater samples was compromised. The total coliform counts revealed the presence of coliform bacteria in harvested rainwater in the area. Hence, total coliform counts did not fall within the specifications of the World Health Organization (2010) of 0cfu/100ml.
- The study also confirmed that the quality of harvested rainwater in cisterns in the area varies during the dry and rainy season period. For example, the levels of total suspended solids (TSS) were higher during the rainy season as compared to the dry season.

5.2 CONCLUSION

The study revealed the following:

- The harvested rainwater in rainwater harvesting cisterns (as described on Page 62) in the study area showed satisfactory concentration in terms of the physicochemical water quality parameters examined. However, most of the harvested rainwater had pH below the acceptable limits for drinking water as prescribed by the World Health Organization (2010) and the Nigerian Standards for Drinking Water Quality (NSDWQ, 2007). Hence, the harvested rainwater from the cisterns should undergo further purification/treatment before consumption to safeguard the health of the people.
- The unacceptable coliform counts in the harvested rainwater samples in the study area may be linked to incidence of respiratory tract diseases in the area. This is because many inhabitants rely on this harvested rainwater for drinking and other domestic purposes.

5.3 RECOMMENDATION

Arising from the research findings, the following are the recommendations for improving the present state of the rainwater from rainwater harvesting cisterns in the area.

- Harvested rainwater in cisterns should be purified before drinking. Local methods of purification includes: boiling and filtering, addition of *Moringaoleifera* seeds into the water.
- Rainwater harvesting should be done atleast 10 – 15 minutes of rainfall to minimise impurities from the catchment roofs into the cisterns.
- Additional liming of the water and other methods of cleansing acidic water may be employed in the interim. Also, knowing that water treatment chemicals are very

dangerous when not properly used, it is recommended that they are administered by exerts and professionals in water quality control.

- Human activities within the vicinities of the sources of rainwater should be monitored to check factors responsible for impairment of the rainwater in the cisterns.
- There is need for proper education of the populace on the dangers of consumption of water from the rainwater harvesting cisterns without subjecting such to treatment.
- Septic tanks, pit latrines and drainage network should be sited far away from the rainwater harvesting cisterns.
- The metallic content of harvested rainwater in the area not analysed for this study should be investigated in future research works to ascertain their concentrations in the study area.

Appendix 1: **Results of laboratory analysis of harvested rainwater samples during the rainy season**

Detected levels of water parameterduring the rainy season											
Location	**Cisterns**	**pH**	**Temp. (^{o}C)**	**Turbidity (NTU)**	**Colour**	**TSS (Mg/l)**	**DO (Mg/l)**	**TDS (Mg/l)**	**BOD (Mg/l)**	**COD (Mg/l)**	**Coliforms (cfu/100ml)**
Umuolo	1	6.54	23.40	1	-nd-	8.30	1.20	18.00	1.40	3.00	1.85
Umuolo	2	5.90	23.60	1	-nd-	10.35	0.90	96.00	1.65	2.60	1.00
Umuolo	3	5.70	23.90	2	-nd-	9.00	1.40	48.20	2.80	4.00	1.20
Umuolo	4	6.70	23.00	1	-nd-	11.50	0.75	85.50	1.70	2.20	1.35
Umuolo	5	6.40	23.20	1	-nd-	7.20	1.30	64.00	2.00	1.80	0.67
Umuolo	6	6.70	23.00	1	-nd-	4.00	0.40	24.10	1.90	4.60	1.00
Ogbe-obi	7	6.55	23.40	2	-nd-	11.00	0.60	95.50	1.85	0.90	1.60
Ogbe-obi	8	6.40	23.10	2	-nd-	4.00	1.00	20.00	3.10	2.40	1.40
Ogbe-obi	9	6.20	23.50.	0	-nd-	7.55	1.60	64.00	0.70	3.20	0.67
Ogbe-obi	10	6.00	23.60	0	-nd-	6.60	0.45	50.10	0.20	3.00	0.46
Ogbe-obi	11	5.60	23.70	2	-nd-	13.30	1.40	100.00	0.90	5.10	1.40
Ogbe-kenu	12	6.00	23.60	0	-nd-	15.00	1.20	103.50	1.00	2.10	1.00
Ogbe-kenu	13	6.60	23.00	0	-nd-	10.55	1.10	70.80	0.80	2.00	1.00
Ogbe-kenu	14	6.30	23.40	0	-nd-	5.80	0.60	42.70	0.90	3.00	0.80
Ogbe-kenu	15	6.40	23.20	1	-nd-	11.20	0.60	84.50	1.00	1.70	1.00
Ogbe-kenu	16	6.75	23.80	0	-nd-	7.45	0.80	75.40	0.50	0.90	0.86
Ishiekpe	17	5.60	23.80	1	-nd-	12.00	0.50	90.40	1.00	2.30	0.90
Ishiekpe	18	6.10	23.60	2	-nd-	20.50	0.40	150.50	0.90	2.20	0.55
Ishiekpe	19	6.25	23.50	1	-nd-	12.40	0.90	119.00	1.40	4.00	0.50
Ishiekpe	20	5.55	24.00	1	-nd-	29.50	0.80	135.00	1.20	3.20	0.90

nd = not detectable

Appendix 2: Results of laboratory analysis of harvested rainwater samples during the dry season

Detected levels of water parameterduring the dry season											
Location	**Cisterns**	**pH**	**Temp. (^oC)**	**Turbidity (NTU)**	**Colour**	**TSS (Mg/l)**	**DO (Mg/l)**	**TDS (Mg/l)**	**BOD (Mg/l)**	**COD (Mg/l)**	**Coliforms (cfu/100ml)**
Umuolo	1	5.70	24.00	0	-nd-	6.00	1.80	24.00	0.80	2.20	0.55
Umuolo	2	5.50	24.35	0	-nd-	7.50	2.40	120.50	0.94	2.00	0.66
Umuolo	3	5.30	25.00	1	-nd-	4.75	1.60	70.50	1.75	3.40	1.02
Umuolo	4	6.10	23.60	0	-nd-	6.60	1.50	100.00	2.00	1.80	1.00
Umuolo	5	5.80	24.00	0	-nd-	3.70	1.74	40.00	0.60	1.40	0.55
Umuolo	6	6.20	23.55	0	-nd-	2.20	1.38	110.50	0.60	3.80	0.20
Ogbe-obi	7	5.70	24.10	1	-nd-	7.40	2.00	40.00	1.05	0.60	1.00
Ogbe-obi	8	5.85	23.90	1	-nd-	3.00	1.00	96.00	0.98	2.00	1.20
Ogbe-obi	9	5.60	24.20	0	-nd-	9.20	1,40	70.00	0.52	2.90	0.20
Ogbe-obi	10	5.50	24.10	0	-nd-	3.40	1.27	142.00	0.33	2.55	0.90
Ogbe-obi	11	5.30	24.70	1	-nd-	9.60	2.23	160.00	0.80	4.80	1.67
Ogbe-kenu	12	5.45	25.00	1	-nd-	10.20	2.00	115.50	0.90	1.40	0.12
Ogbe-kenu	13	5.90	24.20	0	-nd-	7.40	1.45	86.00	0.40	2.00	0.22
Ogbe-kenu	14	5.70	24.00	0	-nd-	2.40	1.35	115.00	0.30	2.00	0.70
Ogbe-kenu	15	5.80	23.85	0	-nd-	6.60	2.10	120.55	0.55	1.20	0.44
Ogbe-kenu	16	5.40	24.40	0	-nd-	5.00	1.64	104.50	0.54	0.85	0.53
Ishiekpe	17	5.40	24.40	0	-nd-	6.40	2.00	200.00	1.24	1.60	0.45
Ishiekpe	18	5.60	24.35	1	-nd-	11.50	2.14	160.00	0.80	1.20	0.26
Ishiekpe	19	5.60	24.15	1	-nd-	9.60	1.96	165.40	1.00	2.40	0.30
Ishiekpe	20	5.20	25.40	1	-nd-	18.00	1.40	185.00	1.00	2.74	0.32

nd = not detectable

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