

**KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI**  
**COLLEGE OF SCIENCE**

**DEPARTMENT OF ENVIRONMENTAL SCIENCE**

**IMPACT OF ROOFING MATERIALS AND STORAGE SYSTEMS ON RAINWATER  
POTABILITY**

A THESIS SUBMITTED TO THE DEPARTMENT ENVIRONMENTAL SCIENCE IN  
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE  
MASTER OF SCIENCE DEGREE IN ENVIRONMENTAL SCIENCE

By

LINDA KYEI B.Sc. (Hons.)

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## DECLARATION

I hereby declare that this submission is my own work towards the Master of Science (MSc.) Degree in Environmental Science, and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University or elsewhere, except where due acknowledgement has been made in the text.

Linda Kyei

Student (PG 6090511)

.....  
Signature

.....  
Date

Certified by:

Dr. John A. Larbi  
(Supervisor)

.....  
Signature

.....  
Date

Certified by:

Dr. Isaac K. Tetteh  
(Head of Department)

.....  
Signature

.....  
Date

## DEDICATION

This thesis is dedicated to God who has been the backbone to my achievements and also to my parents for their enormous support as stewards of my life.



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## ABSTRACT

Rainwater is the main freshwater resource that recharges both surface and ground water. It is usually contaminated by atmospheric pollution which varies the composition of the rainwater from place to place. Due to lack of public pipe borne water supply there is a high level of dependence on rainwater for drinking and other purposes in some communities. This study conducted at Pokuase, a peri-urban community determined the physico-chemical quality of rainwater from aluminum and slate roofs as well as the physico-chemical and bacteriological properties of rainwater from storage systems (plastic barrels, concrete tanks and polytanks). Purposive sampling method was used to select the various houses where the samples were taken. Standard method was used to determine the physico-chemical properties while membrane filtration method was used to determine the bacteriological properties of samples.

The physico-chemical parameters of rain rainwater samples from the aluminum and slate roofing systems were below the WHO standard for drinking water except for turbidity (9.62 NTU and 9.51 NTU respectively). Turbidity of rainwater that flowed from aluminum roofs into plastic barrels and concrete tanks were above the WHO standards recorded as 6.488 NTU and 9.06 NTU respectively. Furthermore, turbidity of rainwater that flowed from slate roofs into plastic barrels and polytanks were above the WHO standards which were recorded 7.21 NTU and 7.3NTU respectively. The pH of samples (runoff from slate and aluminum roofs) collected from plastic barrels was below the WHO standards (6.22 pH Units and 6.44 pH Units). Iron content of rainwater that flowed from the slate roofs into the polytanks was above the WHO standards (0.46mg/l). Rainwater samples collected from concrete tanks had high counts of total coliform, faecal coliform and *E.coli* ( $7.3975 \times 10^2$  CFU/100 ml,  $1.5425 \times 10^2$  CFU/100 ml and  $1.030 \times 10^2$  CFU/100 ml) respectively when compared to the other storage systems while samples collected from plastic barrels had high count of total heterotrophic bacteria ( $2.95950 \times 10^3$  CFU/100 ml) when compared to the other storage systems. All the bacteriological counts were however, above the WHO standards. Total suspended solids, ammonium, fluoride, lead, cadmium, arsenic and mercury were not detected in the rainwater samples.

It was generally observed that both roofs and storage systems have an impact on the potability of rainwater harvested in the area. However, the harvested rainwater in storage systems could be used possibly for all purposes which include washing, flashing, cleaning, and cooking among others except for drinking, due to the high values of the bacteriological parameters. It is thus advisable to boil or treat it before drinking.

# CHAPTER ONE

## 1.0 INTRODUCTION

Water is a vital component in our daily lives. It is basic for both life and health. Man's right to water is indispensable for leading a healthy life. It is a pre-requisite to the realization of all other human rights (UNCESCR, 2002). However, it is not evenly distributed therefore most people do not gain access to potable water. It is estimated that 1.1 billion people do not have access to "improved drinking water sources" (WHO/UNICEF, 2000).

Water borne diseases are a result of consuming water contaminated by human, animal or chemical waste. These diseases cause an estimated 12 million deaths worldwide each year (Buor, 2004). Globally, one person dies from water-related disease every minute (UNICEF, 2005). Contaminated water is the source of viral hepatitis, cholera, leptospirosis, typhoid fever, amoebiasis and echinococcosis. In Ghana, prominent diseases directly linked to water pollution include diarrheal, intestinal worms and typhoid infections (Buor, 2004).

Many communities in Ghana do not get adequate amount of water which in turn affect the citizens and their activities there by, reducing productivity. The main renewable source of all freshwater resources is rainfall.

Rainfall harvesting is an ancient system used in collecting and storing water for various uses. The first rainwater harvesting techniques are thought to have originated in Iraq more than 5000 years ago (Mbilinyi *et. al*, 2005). Studies have indicated that one of the most growing domestic water resource is harvesting of rainwater and the major harvesting source is the roof top (Englmann, 1993).

Generally, rooftop rainwater harvesting is the collection and storing of rainwater from rooftops, using simple techniques such as pots, tanks or cisterns as well as more complex systems such as underground check dams. Rooftop rainwater harvesting, can ensure an independent water supply when municipal water is inaccessible or can assist in a conjunctive use of water resources especially when water is inadequate.

Most villages and few towns in Ghana use rainwater harvesting to obtain water for their daily use. Storage systems such plastic barrels, concrete tanks, metal tanks, clay pots and polytanks are usually used in by citizens in these villages and towns in Ghana. Rainwater is usually used for municipal, agricultural, industrial and domestic purposes.

### **1.1 PROBLEM STATEMENT**

Rainwater quality is an important component of rainwater usage. Rainwater is usually considered as pure but while it is pure it may become contaminated during collection or by collection of particulate matter in the air as it falls (Brown *et al.*, 2005). Moreover, rainwater does not contain chlorine, contamination from airborne pollutants, which settles onto rooftops, may be a risk in urban areas. Acidic rain in heavy industrial areas could also contribute to the deposition of heavy metals through scavenging of atmospheric particulate matter and enhanced weathering of roofing materials and their final incorporation into roof runoffs (Polkowska *et al.*, 2001). Various sources of contamination within the collection system can negatively affect water quality (Lye, 2002, Mendez *et al.*, 2010).

Contamination in harvested rainwater is affected by roof type, including roofing materials, slope, and length (Kingett, 2003; Yaziz *et al.*, 1989). Uba and Aghogho (2000) in Nigeria observed that zinc roofs provided the best quality roof runoff. Additionally, previous studies have shown that

contamination in roof runoff is affected by the length of time between rain events (Förster, 1998), land use (Bucheli *et al.*, 1998), roof orientation to sunlight and wind direction (Evans *et al.*, 2007; Evans *et al.*, 2006), rainfall pH, rainfall intensity, and rainfall quantity (Yaziz *et al.*, 1989).

Assessing rainwater quality in this present study will assist citizens to know the best roofing material and storage systems that can be installed for harvesting rain for optimum quality. Additionally, assessing rainwater quality will assist citizens to decide on what to use harvested rainwater for, in order to improve productivity in a community. It will also help in identifying the health risk involved in the usage of harvested rain from any roofing or storage system.

## **1.2 JUSTIFICATION**

Only 2.5% of the water on earth is fresh water but of which 68.9% is inaccessible. Accessible freshwater is being polluted thereby increasing cost of water treatment to obtain potable water.

Only about 7% of urban dwellers in Accra have in-house piped water, and water supply across the city is inconsistent (Awuah and Assan 2007). People living in areas where water is inaccessible or inadequate walk over a long distance in order to gain access to water for their daily use. This would then reduce time spent on activities that could improve the economic/financial status of individuals and also improve the development status of the country at large. The water supply services provided by Ghana Water Company are unable to reach certain areas in the country due to rapid population increase, low investment, and illegal tapping of water from water transmission pipes. Due to increase in population, many people are now settling at the outskirts of Accra therefore, the main water supply is unable to get to such places. The people of Pokuase therefore depend on a Sunkwa, Nsaki and other rivers in the area as well as rainwater. They use water from these sources for all purposes, including washing, drinking, bathing and cooking, although the quality of such

harvested water is largely unknown. Coastal areas like Accra and surrounding communities, where groundwater is saline due to saltwater intrusion, have rainwater harvesting as the best alternative.

Contamination in harvested rainwater is affected by roof type, including roofing materials, slope, and length (Kingett, 2003; Yaziz *et al.*, 1989). There are different roof catchments which include aluminum, asbestos, shingle, clay tiles, concrete, and thatched. According to Jawas *et al.* (1988) storage tank materials can impact on the quality of water stored and this has become a major concern for research. There are many types of rainwater storage containers in different geographical regions. These include underground tank, ferro-cement tank, plastic-lined tank, etc. In Africa, earthenware cisterns, large pots, metal and plastic drums are also used (Issaka, 2011).

Rainwater harvesting serves to provide water to supplement other sources of water or be the main source for daily use. Assessing the rainwater quality of harvested rainwater shall provide information about the rain harvesting system that can provide the optimum quality. Furthermore, it will also inform manufacturers and suppliers to produce the best alternatives. Additionally, determining the quality of harvested rainwater would help contribute to water security for communities in Ghana.

Therefore this study seeks to focus on the physico-chemical parameters of rainwater from the roofing and storage systems. Also, the bacteriological parameters of rainwater from the storage systems will be determined.

### **1.3 MAIN OBJECTIVE**

To assess the physico-chemical and bacteriological properties of rainwater from different roof and storage systems in Pokuase.

### 1.3.1 Specific Objectives

The specific objectives for this study were to determine:

- i. The physico-chemical quality of rainwater from different aluminum and slate roofs in Pokuase.
- ii. The physico-chemical quality of rainwater from plastic barrels, concrete tanks and polytanks in Pokuase. Physico-chemical parameters that would be determined include pH, Total Dissolved Solids, Total Suspended Solids, colour, Dissolved metals (Pb, Fe, Mn, As, Cu, Zn, Cd, and Hg), chloride, calcium, magnesium, ammonium, nitrite, nitrate, carbonate, sodium, phosphate, nitrite, potassium and sulphate.
- iii. To determine the faecal coliforms, total coliforms, total heterotrophic and *E. coli* of rainwater stored in plastic barrels, concrete tanks and polytanks in Pokuase.

## CHAPTER TWO

### 2.0 LITERATURE REVIEW

#### 2.1 RAINWATER

Rainwater is a liquid in the form of droplets that have condensed from atmospheric water vapor and then precipitated that is, it becomes heavy enough to fall under gravity. It is a major component

of water on the water cycle which is responsible for depositing most of the fresh water on the earth. It provides suitable conditions for many types of ecosystems to function in their optimum capabilities (<http://en.m.wikipedia.org>). Rainwater is use for many purposes for growth of individual, environment and the economy.

## **2.2 USES OF RAINWATER**

### **2.2.1 Municipal applications**

Rainwater harvesting can be used in a variety of municipal applications. Direct roof capture off city buildings or capture of excess runoff from paved surfaces can be used to fill cisterns and other storage facilities that can be used for irrigation of green spaces and recreational facilities, washing and cleaning of streets and facilities, or for fire fighting. Such bulk water storage can be used to augment emergency water supplies following natural disasters when the potable supply may be out of operation. In this case filtration and treatment will need to be applied before distribution.

### **2.2.2 Agricultural applications**

Crop irrigation and livestock watering have heavy water demands. In the Caribbean agricultural production is predominantly rain-fed with the exception of larger commercial farm holdings where water is abstracted from irrigation drains, natural watercourses and wells (UNEP, 2009). Under rainfed production, crop yields will drop significantly during the dry season unless supplemental irrigation is applied. Livestock production is similarly impacted where water is in short supply. RWH from farm building catchments and constructed surfaces can greatly contribute to meeting water demands during the drier months for sustained production.

### **2.2.3 Commercial and industrial applications**

Rainwater harvested off roofs and surface catchments such as roads and parking lots can be stored and used as required to offset the need for use of the potable supply for nondrinking purposes. Typical applications will include washing and cleaning, cooling, firefighting, bathing pool recharge and irrigation. Where water may be required for food preparation and other manufacturing processes, treatment will need to be applied.

### **2.2.4 Residential use**

Harvested rainwater can be safely used for indoor residential purposes such as drinking, food preparation, toilet flushing, and cleaning, and washing car, clothes washing and bathing as long as it has been treated and stored.

## **2.3 HISTORY OF RAINWATER HARVESTING**

Rainwater harvesting has been used since ancient times throughout the world. Some of the oldest evidence of roof catchment systems dates back to Roman times. Roman villas and even whole cities were designed to take advantage of rainwater as the principal water source for drinking and domestic purposes since at least 2000 B.C (Kovacs, 1979). Roman Empire then collected rainwater in a giant underground cistern in today's Istanbul called Yerebatan Sarayı (Sunken Palace) which is the world's largest rainwater tank. This was constructed during the rule of Caesar Justinian (A.D. 527-565). It measures 140m by 70m and has a capacity of 80,000 cubic metres (<http://www.crd.bc.ca>). In Israel, tanks for storing runoff from hillsides for both domestic and agricultural purposes have allowed housing and farming in areas with as little as 100mm of rain per year (Evenari, 1961).

## **2.4 RAINWATER HARVESTING AND ITS UTILISATION IN SOME PARTS OF THE WORLD**

Rainwater is harvested and used for several purposes in many parts of the world.

### **2.4.1 Caribbean**

The Caribbean region has a sub-tropical climate with approximately 80% of the annual rainfall concentrated between May to December. Rainfall ranges from 1,500mm to in excess of 3,000mm per year, depending on island size and relief. Before the advent of centralized conventional potable water supply systems, RWH was the only means of water security in all the Caribbean islands. The practice continues to remain the mainstay of water supply in many of the drier islands such as the Grenadines, the Virgin Islands and the Bahamas. Rainwater harvesting is not only useful for domestic purposes, but can also be used for agricultural and industrial/ commercial applications that have heavy water requirements (UNEP, 2009).

### **2.4.2 Asia**

Rainwater harvesting and its utilisation in Tokyo Japan, is been promoted to mitigate water shortages, control floods and secure water for emergency. The Ryogoku Kokugikan Sumowrestling Arena, built in 1985 in Sumid City, is a well-known facility that utilizes rainwater on a large scale. The 8400m<sup>2</sup> rooftop of this arena is the catchment surface of the rainwater utilization system. Following this example, many new public facilities have begun to introduce rainwater utilization systems in Toyo. At the community level, a simple and unique rainwater utilization facility, “Rojison”, has been set up by local residents in the Mukojima district of Tokyo to utilize rainwater collected from the roofs of private houses for garden watering, fire-fighting

and drinking water in emergencies. To date, about 750 private and public buildings in Tokyo have introduced rainwater collection and utilization systems (UNEP, 2006).

In Thailand, rainwater storage from rooftop run-off into jars is an appropriate and inexpensive means of accessing high quality drinking water. Population and Community Development Association (PDA) in Thailand demonstrated success of the rainwater jar project has encouraged the Thai government to embark on an extensive national program for rainwater harvesting (UNEP, 2006).

In Indonesia, groundwater is becoming scarcer in large urban areas due to reduced water infiltration. The decrease of groundwater recharge in the cities is directly proportional to the increase in the pavement and roof area. Also, there is high population density which has brought about high groundwater consumption. The Indonesia government therefore introduced a regulation requiring all that buildings have an infiltration well (UNEP, 2006).

In Philippines, a rainwater harvesting programme was initiated in 1989 in Capiz Province with the assistance of the Canadian International Development Research centre (IDRC) and was later implemented as part of an income generation initiative. Under this arrangement loans were channeled into the cost of tanks and related agricultural operation. This innovative mechanism for financing rural water supplies can help avoid the requirement for water resources development subsidies (UNEP, 2006).

#### **2.4.3 Brazil**

Many NGOs and grassroots organisation over the past decade have focused their work on the supply of drinking water using rainwater harvesting, and the irrigation of small-scale agriculture using subsurface impoundments. Citizens have traditionally utilized rainwater collected in hand

dug rock catchment and river bedrock catchments. A group of NGOs together with the government initiated a project involving the construction of one million rainwater tanks over five years period, benefiting 5 million people. This was done to address the issue concerning the unreliability of rural drinking water supply in north eastern Brazil. Rainwater harvesting, and its utilization is now an integrated part of educational programs for sustainable living in the semiarid regions of Brazil. There is an establishment of the Brazilian Rainwater Catchment Systems Association, which was founded in 1999 and held its 3<sup>rd</sup> Brazilian Rainwater Utilization Symposium in the fall of 2001 (UNEP, 2006).

#### **2.4.4 Africa**

Rainwater harvesting is becoming more widespread in Africa with projects currently in Botswana, Togo, Mali, Malawi, South Africa, Namibia, Zimbabwe, Mozambique, Sierra Leone and Tanzania and others. Out of these and the other countries that practice rainwater harvest, Kenya is the country that leads. Since the late 1970s, a lot of rainwater harvesting projects has emerged in most parts of the country with their designs and implementation strategies. These projects together with various indigenous builders' efforts have brought about the abundance of the system in place to assist productivity in the country (UNEP, 2006).

A rainwater harvesting project was organized in rural Tanzania Karagwe which receives less than 800mm of rainfall per year, rendering the area arid or semi-arid. Due to their long period of dryness, which is from June to October, storage of water was highly required. (<http://arc.peacecorpsconnect.org>). In Botswana, thousands of roof catchment and tank systems have been constructed in schools, health clinics and government houses all over the country by the government (UNEP, 2006)

## 2.5 TYPES OF RAINWATER HARVESTING SYSTEMS

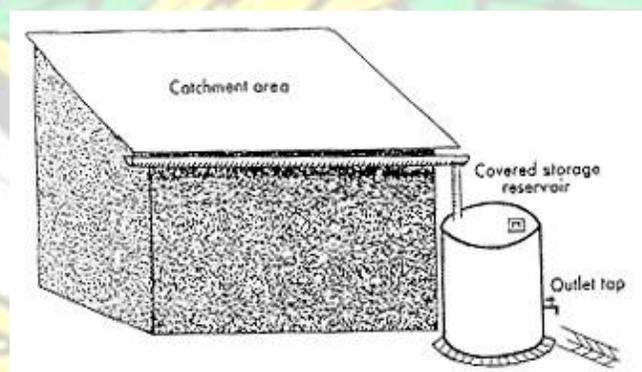
Normally, a rainwater harvesting system consists of three basic elements: the collection system or catchment area, the conveyance system or channel or roof gutters, and the storage system.

### 2.5.1 Collection Area or Catchment Area

The catchment area of a water harvesting system is the surface, which receives rainfall directly and contributes the water to the system. Four types of catchment areas have been considered namely; roof, rainwater platforms, watershed management and hill slopes (UNEP, 2006).

#### 2.5.1.1 Simple roof water collection systems

The main components in a simple roof water collection system are the cistern itself, the channel that leads to the cistern and the appurtenances within the cistern. The materials and the degree of sophistication of the whole system largely depend on the initial capital investment. Some cost effective systems involve cisterns made with ferro cement, etc. In some cases, the harvested rainwater may be filtered. In other cases, the rainwater may be disinfected (UNEP, 2006).



**Plate 1: Example of a roof catchment system**

### 2.5.1.2 Land Surface Catchments

Rainwater harvesting using ground or land surface catchment areas can be a simple way of collecting rainwater. Compared to rooftop catchment techniques, ground catchment techniques provide more opportunity for collecting water from a larger surface area. By retaining the flows (including flood flows) of small creeks and streams in small storage reservoirs (on surface or underground) created by low cost (e.g., earthen) dams, this technology can meet water demands during dry periods. There is a possibility of high rates of water loss due to infiltration into the ground, and because of the often marginal quality of the water collected, this technique is mainly suitable for storing water for agricultural purposes (UNEP, 2006). An example of a ground catchment is shown in plate 2 below.



**Plate 2: Example of a ground catchment system**

### **2.5.1.3 Collection of Storm water in Urbanized Catchments**

The surface runoff collected in storm water ponds/reservoirs from urban areas is subject to a wide variety of contaminants. Keeping these catchments clean is of primary importance, and hence the cost of water pollution control can be considerable (UNEP, 2006).

### **2.5.2 Conveyance Area or Channel or Roof Gutters**

Conveyance systems are designed to drain out the rainwater that falls in the catchment area into the nearest storage system.

It may be of any material such as Poly Vinyl Chloride (PVC), asbestos or Galvanized Iron (GI), or any available material. Channels have to be all around the edge of a sloping roof to collect and transport rainwater to the storage tank (UNEP, 2006).

### **2.5.3 Storage Systems**

Storage tanks for collecting rainwater may be located either above or below the ground. They may be constructed as part of the building, or may be built as a separate unit located some distance away from the building. The design considerations vary according to the type of tank and other factors (UNEP, 2006). Storage tanks are normally constructed with inert materials. Reinforced concrete, fiberglass, polyethylene, and stainless steel are also suitable materials. Ferro-cement tanks and jars made of mortar or earthen materials are commonly used. As an alternative, interconnected tanks made of pottery or polyethylene are also found suitable. They are easy to clean and have many openings which can be fitted with connecting pipes (UNEP, 2006). Bamboo reinforced tanks are less successful because the bamboo may become infested with termites,

bacteria and fungus. Precautions are required to prevent the entry of contaminants into storage tanks (UNEP, 2006).

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## 2.6 ROOFING SYSTEMS

Different types of materials are used as roof examples are corrugated aluminum and galvanized iron, concrete, clay, fiberglass shingles, tiles, slates, mud, etc. Mud is used primarily in rural areas (UNEP, 2006).

### 2.6.1 Roofing systems and their Impact on Quality of water

Water quality from different roof catchments is a function of the type of roof material, climatic conditions, and installation the surrounding environment (Vasudevan, 2002).

Bamboo roofs are least suitable because of possible health hazards while asbestos roofs are also dangerous due to its toxic potential that causes runoff from it to be toxic. Clay and concrete tiles are both porous which can lead to water loss, its texture, inefficient flow, or evaporation makes it not appropriate and bacterial growth (Brown *et al.*, 2005).

In composite or asphalt shingle roofs, toxins leach and cause the water to be contaminated. Composite roofs have an approximated 10-percent loss due to inefficient flow or evaporation (Radlet and Radlet, 2004).

Wood shingle, tar, and gravel roofing materials are rare, and the water harvested is usually suitable only for irrigation due to leaching of compounds (Brown *et al.*, 2005).

Some other roofing systems that are usually painted or coated are equally dangerous. Examples like lead, chromium, and zinc-based paints/coatings should not be used on roofing systems. Similarly, roofs with metallic paint or other coatings are not recommended as they may impart tastes or colour to the collected water. Dust, leaves and bird droppings are usually captured by the roofs which increase bacterial contamination and therefore change the quality of collected water. Roofs which are closer to over-hanging trees have birds and other animals on the trees defecating on thereby, reducing the quality of the water collected (UNEP, 2006).

## **2.7 SOURCES OF CONTAMINATION**

### **2.7.1 Contamination from the atmosphere**

Rainwater is generally a very pure form of water. However, pollutants in the air can be absorbed by raindrops (Chang *et al.*, 2004), a problem in highly industrialized and/or urbanized areas that are characterized by high pollution emissions. The deposition rates of these particles depend on particle size, meteorological conditions, and concentrations of the pollutants in the atmosphere (Pryor *et al.*, 2000).

### **2.7.2 Contamination during the capturing of rain**

Catchment contamination can be chemical or biological. Chemical contamination may occur if the catchment is manufactured from, and/or coated with materials that may leach or dissolve into water flowing across the catchment surface. A common concern relates to the use of roofing sheets coated with toxic paints (containing lead and other compounds) [Chang *et al.*, 2004]. Although the manufacture of paints using lead-based pigments was banned several years ago, many older buildings may still have roofs coated with these paints. Chemical compounds in the roofing

materials usually may leach when it gets into contact with acidic rain as well as organic substances deposited on the roof top (plant matter, insect matter, waste from living organisms such as birds) may be also absorbed by rainwater (Chang *et al.*, 2004). High roof top temperature, which is caused by its exposure to direct sunlight may accelerate the chemical reactions and organic decompositions of material deposited on the roof (Chang *et al.*, 2004).

Noxious chemical compounds originating from nearby industrial areas as air-borne emissions may become deposited on catchment surface, posing a contamination hazard. In humid areas, dry depositions on the roof surface reacts with the moisture and increase the corrosion rate of the roofing material (Pringle, 1998). During rainfall events, the weathered roof particles are washed from the roof surface into the roof runoff.

### **2.7.3 Contamination during storage**

The type of storage material use can pose a threat to the quality of rainwater stored. Hart and White (2006) indicated in their study that, leaching of metals from metal tanks was found significant in but concrete or plastic tanks did not have any notable impact on the concentration of zinc, lead or copper. Spinks *et al.* (2005) also reported that, chemical contaminants may dissolve during precipitation and leach due to characteristics of the rainwater system components and storage design. In addition, microorganisms found to be carried by birds and animal vectors include *Cryptosporidium*, *Giardia*, *Campylobacter* and *Samonella spp.* into stored rainwater (Gerba and Smith, 2005). Additional risks exist in the case of below-ground storage facilities located in areas that may be prone to flooding. Should polluted flood waters, particularly when contaminated with human seepage, inundate underground storage, this will render the water polluted. Adeniyi and

Olabanji (2005) reported that storage tanks also play a role in harvested rainwater quality, especially for rainwater intended for later use and there by stored for long period of time.

## 2.8 PHYSICAL AND CHEMICAL PARAMETERS

### 2.8.1 pH

The pH of rain water represents the concentration of the free hydrogen ions in it. Low pH rainwater can occur as a result of sulphur dioxide, nitrous oxide and other industrial emissions (UNEP, 2006). All these atmospheric pollutants are as results of the various human activities that occur within particular vicinity. These pollutants contribute to Acid rain which is a word used for describing rainfall that has a pH level of less than 5.6 (Radojevic and Harrison, 1992). The chemical reactions that lead to acid rain begin as energy from sunlight in the form of photons which hit ozone molecules to form free oxygen and single reactive oxygen atoms. These oxygen atoms react with water molecules to produce electrically charged, negative, hydroxyl radicals which are responsible for oxidizing SO<sub>2</sub> and NO<sub>2</sub> to sulfuric and nitric acids (Radojevic and Harrison, 1992). Most metals will become more soluble in water as the pH decreases. For example, sulfur in the atmosphere from the burning of coal that create acid rain will dissolve metals such as copper, lead, zinc and cadmium as the rain runs off of man-made structures and into bodies of water. The excesses of dissolved metals in solution will negatively affect the health of organisms (Bellingham, 2009).

The alkalinity of natural waters is controlled by the concentration of hydroxide and represented by a pH greater than 7. This is usually an indication of the amount of carbonates, and bicarbonates

that shift the equilibrium producing  $[\text{OH}^-]$ . Other contributors to an alkaline pH include boron, phosphorous, nitrogen containing compounds and potassium

### **2.8.2 Electrical Conductivity**

Electrical conductivity is a measure of the ability of water to pass an electrical current (CWQRB, 2005). Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge). Organic compounds like oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore have a low conductivity when in water. A conductivity of  $300\mu\text{S}/\text{cm}$  is the ideal for consumption (WHO, 2006).

### **2.8.3 Turbidity**

Turbidity is the measure of relative clarity of a liquid. It is an optical characteristic of water and is an expression of the amount of light that is scattered by material in the water when a light is shined through the water sample. The higher the intensity of scattered light, the higher the turbidity. Material that causes water to be turbid includes clay, silt, finely divided inorganic and organic matter, algae, soluble colored organic compounds, and plankton and other microscopic organisms (<http://ga.water.usgs.gov>). Excessive turbidity, or cloudiness, in drinking water is aesthetically unappealing, and may also represent a health concern. Turbidity can provide food and shelter for pathogens. If not removed, turbidity can promote re growth of pathogens in the distribution system, leading to waterborne disease outbreaks, which have caused significant cases of gastroenteritis throughout the United States and the world. Although turbidity is not a direct indicator of health

risk, numerous studies show a strong relationship between removal of turbidity and removal of protozoa (<http://ga.water.usgs.gov>).

It is measured in Nephelometric Turbidity Unit (NTU) (Shelton, 2000). The level of total coliform bacteria and the grade of turbidity in rainwater collected from the rooftop are affected by dry spell, and especially the intensity of rainfall. The longer the dry period in between rainfall events, greater is the amount of turbidity in the rainwater (Shelton, 2000). The more the intensity of rainfall, the more efficient is the cleaning process and greater is the presence of pollutants in the runoff (Shelton, 2000).

#### **2.8.4 Alkalinity**

Alkalinity is the measure of an aggregate property of water and can be interpreted in terms of specific substances only when the chemical composition of the sample is known. The main sources of natural alkalinity are rocks, which contain carbonate, bicarbonate, and hydroxide compounds. Borates, silicates, and phosphates may also contribute to alkalinity (CWQRB, 2005).

#### **2.8.5 Colour**

The term “colour” is used here to mean true colour that is the colour of water from which turbidity has been removed. Colour in water may result from the presence of natural metallic ions (iron and manganese), humus and peat materials, plankton, weeds and industrial waste.

#### **2.8.6 Total Dissolved Solids (TDS)**

Total Dissolved Solids (TDS) are the compounds in the water that cannot be removed by a traditional filter. TDS are made up of salts or compounds which dissociate in water to form ions (Bauder and Sigler 2006). The TDS can be estimated by measuring the specific conductance of the

water. Dissolved solids in natural waters range from less than 10mg/L for rainwater to more than 100,000 mg/L for brines (Shelton, 2000).

### **2.8.7 Total Suspended Solids (TSS)**

TSS provides an actual weight of the particulate material present in the sample (CWQRB, 2005). In water quality monitoring situations, a series of more labor intensive TSS measurements can be paired with relatively quick and easy turbidity measurements to develop a site-specific correlation. Once satisfactorily established, the correlation can be used to estimate TSS from more frequently made turbidity measurements, saving time and effort. Because turbidity readings are somewhat dependent on particle size, shape, and color, this approach requires calculating a correlation equation for each location (Shelton, 2000).

### **2.8.8 Total Hardness**

Hardness of water is caused by the presence of high levels of calcium and magnesium ions. These ions combine with carbonate, dissolved in water to produce scale which is composed of insoluble carbonates ( $\text{CaCO}_3$  and  $\text{MgCO}_3$ ). The scale can build up on plumbing parts, eventually causing blockages to water flow. There is no health related guideline value for total hardness (Olszowy, 2012).

## **2.9 ANIONS**

### **2.9.1 Nitrite and Nitrate**

Nitrate is the more stable oxidized form of combined nitrogen in most environmental media. Most nitrogenous materials in natural waters tend to be converted to nitrate, and, therefore, all sources of combined nitrogen (particularly organic nitrogen and ammonia) should be considered as

potential nitrate sources. Nitrates occur naturally in mineral deposits (generally sodium or potassium nitrate), in soils, seawater, freshwater systems, the atmosphere, and in biota. Lakes and other static water bodies usually have less than 1.0  $\mu\text{g/L}$  of nitrate-nitrogen (USEPA, 2006). Groundwater levels of nitrate-nitrogen may range up to 20  $\mu\text{g/L}$  or more, with higher levels characteristically occurring in shallow aquifers beneath areas of extensive development. Major sources of nitrates or nitrite in drinking water include fertilizer, sewage, and feedlots (USEPA, 2006).

The toxicity of nitrate in humans is due to the body's reduction of nitrate to nitrite (Pushard, 2005). This reaction takes place in saliva of humans at all ages and in the gastrointestinal tract of infants during the first three months of life (Pushard, 2005).

### **2.9.2 Phosphates**

According to the US Environmental Studies Board (USES B) [2003], phosphates come from fertilizers, pesticides, industry, and cleaning compounds. Natural sources include phosphate-containing rocks and solid or liquid wastes. Phosphates enter waterways from human and animal wastes (the human body releases about a pound of phosphorus per year), phosphate-rich rocks, wastes from laundries, cleaning, industrial processes, and farm fertilizers.

Phosphates exist in three forms: orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphate. Ortho forms are produced by natural processes and are found in wastewater. Poly forms are used for treating boiler waters and in detergents; they can change to the ortho form in water. Organic phosphates are important in nature and also may result from the breakdown of organic pesticides which contain phosphates (USES B, 2003)

### **2.9.3 Chloride**

The Secondary Maximum Contaminant Level (SMCL) of 250 mg/l for chloride is the level above which the taste of the water may become objectionable to the consumer. In addition to the adverse taste effects, high chloride concentration levels in the water contribute to the deterioration of domestic plumbing, water heaters, and municipal waterworks equipment. High chloride concentrations in the water may also be associated with the presence of sodium in drinking water. For the preceding reasons, the SMCL for chloride represents a desirable and reasonable level for protection of the public welfare (Shelton, 2000).

### **2.9.4 Sulphates**

The aesthetic objective for Sulphates in drinking water is 500 mg/L. Sulphates, which occur naturally in numerous minerals, are used in the mining and pulping industries and in wood preservation (Shelton, 2000). Large quantities of Sulphates can result in catharsis and gastrointestinal irritation. The presence of Sulphates above the aesthetic limit can result in noticeable taste. Some sensitive individuals may find the taste objectionable at lower Sulphates concentrations (USESB, 2003).

### **2.9.5 Carbonate**

Carbonate is one component of alkalinity and its concentration is in a balance with bicarbonate between the pH range of 8.2 and 9.6. At a pH of 9.6 and higher, there is no carbon dioxide or bicarbonate, with all alkalinity being in the carbonate form (Olszowy, 2012).

## **2.9.6 Fluoride**

Fluoride is essential for good oral health and serves to guard against tooth decay. Fluoride occurs naturally from fluoride-containing rocks and it is therefore often found in elevated concentrations in bore waters. High concentrations can cause dental fluorosis (Olszowy, 2012).

## **2.10 CATIONS 2.10.1**

### **Sodium**

Due to aesthetic reasons (taste), sodium should not exceed 180mg/l to make the taste noticeable. As a precautionary note, sodium should be monitored for babies and those in a community who need to monitor their intake of salt. Waters with high sodium can cause blood pressure problems (Olszowy, 2012).

### **2.10.2 Potassium**

Potassium plays a major role in the cell therefore, water containing high content of it can help sodium's effect on blood pressure (Olszowy, 2012).

### **2.10.3 Calcium**

Calcium is an important element for good health but very high levels however, will produce scale and clog up water pipes (Olszowy, 2012).

### **2.10.4 Magnesium**

High levels of magnesium will also produce scale and clog up water pipes (Olszowy, 2012).

## 2.11 METALS

### 2.11.1 Manganese

Manganese occurs naturally in surface and underground waters because it is derived from rocks. Therefore, bore waters may have high levels of manganese. The aesthetic quality (taste and staining) of drinking water will deteriorate above 0.1mg/l of manganese. Elevated levels will also cause discolouration of washing porcelain ware etc. Manganese can be removed from water by aeration (Olszowy, 2012).

### 2.11.2 Iron

According to Antonovics *et al.* (1971), Metallic iron occurs in the free state and is widely distributed and ranked in abundance among all the element in the earth's crust, next to aluminum. Chemically, iron is an active metal, and combines with the halogens (fluorine, chlorine, bromine, iodine and astatine) sulfur, phosphorus, carbon, and silicon. When exposed to moist air, iron forms a reddish-brown, flaky, hydrated ferric oxide commonly known as rust. There are two kinds of iron with respect to the mechanism of absorption in diet. These are heme-iron and nonheme iron (Halberg, 1982). Before iron can be absorbed, two conditions must exist, first, the iron is separated from its organic complex, and second, and the ferric iron is reduced to ferrous iron. Although the body can absorb both the ferrous (Fe+2) and ferric (Fe+3) iron, absorption is greater when iron is available in the ferrous form (Fifield and Haines, 1996). The absorption of iron occurs primarily in the upper part of the small intestine, usually the duodenum (Gutlirie, 1989). An average adult human has 4.2 g of iron, mostly combined in proteins of various kinds. These play roles in the

transport of oxygen in proteins of various kinds and also in the blood it enhances redox reactions used to generate metabolic energy by the body (Charalambous, 1984)

Generally, about 2-15 % of ingested iron is absorbed from the gastrointestinal tract whereas elimination is only about 0.01 % per day (percent body burden or amount absorbed). Normally, excess ingested iron is excreted, and some is contained within shed intestinal cells and in bile and urine and even smaller amounts in sweats, nails and hair. Total iron excretion is usually in order of 0.5 mg/day (Charalambous, 1984). Acute iron toxicity is nearly always due to accidental ingestion of iron containing medicines and most often occurs in children. Severe toxicity occurs after ingestion of more than 0.5 g of iron or 2.5 g of iron sulphate ( $\text{FeSO}_4$ ). Toxicity becomes manifest with vomits being bloody owing to ulceration of the gastrointestinal tract; stools become black. These are followed by signs of shocks and metabolic acidosis, liver damage and hepatic cirrhosis.

Iron has the chemical symbol Fe; it is a silvery, malleable and ductile metallic transition element with atomic number 26 and relative atomic weight of 55.847. It belongs to group VIII of the periodic table and in the same group with element like: Ruthenium (Ru), Osmium (Os), etc. It is in period IV just as arsenic (As), copper (Cu), and Zinc (Zn). Pure iron melts at about 1535 °C (about 2795 °F), boils at 27500 °C (4982 °F) and has a specific gravity of 7.86. The metal exists in three different forms; ordinary or  $\alpha$ -iron (alpha iron),  $\gamma$ -iron (gamma iron), and  $\delta$ -iron (delta iron). The internal arrangement of the atoms in the crystal lattice changes in the transition from one form to another. The transition from  $\alpha$ -iron to  $\delta$ -iron occurs at 910 °C (Charalambous, 1984).

### 2.11.3 Lead

Lead is available in several forms including foil, granules, ingots, powder, rod, shot, sheet, and wire (Watkins *et al.*, 1983). Small and large samples of lead foil, sheet, and wire (and lead alloy in ingot form) can be purchased from metal shops. Its principal ores are galena (PbS), cerusite (PbCO<sub>3</sub>), Anglesite (PbSO<sub>4</sub>) and Jamesonite [Pb<sub>4</sub>FeSb<sub>6</sub>S<sub>14</sub>]. Galena, the principal primary ore of lead is by far the most important and widely distributed. It occurs in many geological formations e.g. veins in the Cambrian clay, slates in bed or nests within the sandstones and limestone (Watkins *et al.*, 1983)

Lead is a bluish-white lustrous metal. It is very soft, highly malleable, ductile, and a relatively poor conductor of electricity. It is very resistant to corrosion but tarnishes upon exposure to air. Lead pipes bearing the insignia of Roman emperors, used as drains from the baths, are still in service. Alloys include pewter and solder. Tetraethyl lead (PbEt<sub>4</sub>) is still used in some grades of petrol (gasoline) but is being phased out on environmental grounds (Gutliric, 1989).

High lead values can sometimes be attributed to the composition of certain roofing materials (UNEP, 2006)

### 2.11.4 Zinc

Zinc is an essential and beneficial element in human growth. Concentrations above 5mg/l can cause a bitter astringent taste. Zinc ranks 24th in abundance among the elements in the earth crust. It never occurs free in nature, but is found as zinc oxides (ZnO) in the mineral zincite; as zinc silicate (ZnO.SiO<sub>2</sub>.2H<sub>2</sub>O), in the mineral franklinite; and as zinc sulphides (ZnS) in the mineral sphalerite, or zinc blend. The ores most commonly used as a source of zinc are smithsonite and sphalerite (Sabadell and Axtmann, 1975). Zinc has a chemical symbol Zn, with atomic number 30 and

relative atomic weight 65.38. It is a member of group (XII) of the periodic table of elements just as cadmium and mercury. It is in period (IV) of the periodic table and in the same period with copper, nickel, manganese and iron. Pure zinc is a crystalline metal, insoluble in hot and cold water but soluble in alcohol, acids and alkalis. It is extremely brittle at ordinary temperatures, but becomes malleable between 120 °C and 150 °C (248 F and 302 F) and can be rolled into sheets between heated rollers (Shelton, 2000). Zinc is unaffected by dry air, in moist air, it is oxidized and becomes coated with a carbonate film that protects it from further corrosion. Zinc melts at about 420 °C (about 693 F), boils at about 907 °C (about 1180 F) and has a specific gravity of 7.14. There are five stable isotopes (mass number 64, 66, 67, 68 and 70) and six radioactive isotopes are known. Chemically, it is a reactive metal, combining with oxygen and other non-metals and reacting with dilute acids to release hydrogen gas. It also dissolves in alkaline medium to give zincates. Most of its compound contain  $Zn^{2+}$  ion. It is amphoteric, forming zincates with bases (Shelton, 2000).

The human body contains between 2 g - 25 g of zinc with three quarters of this amount concentrated in the skeleton. A high concentration of zinc also appears in the skin, hair and testes. In the blood most of the zinc occurs in the red blood cells, platelets and the blood serum. Zinc is found in biological systems only in the +2 valence state. This is due to the extra stability associated with filled d-orbital electronic configuration (Ar) 3d<sup>10</sup>.

This also accounts for the differences between zinc and its congeners with unfilled d-orbital such as iron, copper and Arsenic ( $As^{2+}$ ,  $Fe^{2+}$  and  $Cu^{2+}$ ) [USES, 2003]. Biological redox functions of zinc are largely based on its presence in zinc metalloenzymes. Zinc absorption occurs mostly in the duodenum and proximal jejunum (upper part of the small intestine) [Shelton, 2000].

The absorption process is active, energy dependent and apparently mediated by specific zinc transport (binding) ligands. The absorption plays an important role in homeostatic regulation. Zinc is transported in blood plasma mostly by albumin (60-70) and by macroglobulin and free amino acids (Shelton, 2000). Only a small portion of dietary zinc is absorbed from the intestine, the major fraction passing out through the faeces. The Pancreas account for 25% of total excretion whilst sweat losses are generally minor but can be appreciable in tropical climate or under physical stress (USES, 2003).

### **2.11.5 Cadmium**

Cadmium is found in very low concentrations in most rocks, as well as in coal and petroleum. Mostly cadmium is found in combination with zinc (WHO, 1992). Cadmium uses include electroplating, nickel-cadmium batteries, paint and pigments, and plastic stabilizers (WHO, 1992). It is introduced into the environment from mining smelting and industrial operations, including electroplating, reprocessing cadmium scrap, and incineration of cadmium containing plastics. The remaining cadmium emissions are from fossil fuel use, fertilizer application, and sewage sludge disposal. Cadmium may enter drinking water as a result of corrosion of galvanized pipe. Landfill leachates are also an important source of cadmium in the environment (Wester *et al.*, 1992). Acute and chronic exposure to cadmium in animals and humans results in kidney dysfunction, hypertension, anemia, and liver damage (Wester *et al.*, 1992). The kidney is considered to be the critical target organ in humans who are chronically exposed to cadmium by ingestion. Cadmium has been classified in United States EPA's Group B1 (probable human carcinogen), based upon evidence of carcinogenicity in humans through inhalation exposure.

### **2.11.6 Copper**

Copper can occur naturally in underground water supplies after passing over a zone of mineralization rich in copper minerals. In most waters, the copper concentration is <1 mg/l. Elevated levels in household water supplies can occur from the corrosion of copper plumbing parts, especially if the water is slightly acidic (eg. rainwater) or otherwise corrosive. High concentrations (5 mg/l) will start to colour the water bluish green (Olszowy, 2012).

### **2.11.7 Mercury**

Mercury in water is carcinogenic or toxic, affecting, among others, the central nervous system, the kidneys or liver, the skin, bones, or teeth (Zevenhoven and Kilpinen, 2001).

## **2.12 MICROBIAL PARAMETERS**

The most commonly tested fecal bacteria indicators are total coliforms, fecal coliforms, *Escherichia coli*, fecal streptococci, and enterococci. Members of two bacteria groups, coliforms and fecal streptococci, are used as indicators of possible sewage contamination because they are commonly found in human and animal feces. Although they are generally not harmful themselves, they indicate the possible presence of pathogenic (disease-causing) bacteria, viruses, and protozoans that also live in human and animal digestive systems. Therefore, their presence in water sources suggests that pathogenic microorganisms might also be present and that swimming, drinking and eating shellfish might be a health risk. Sources of fecal contamination to surface waters include wastewater treatment plants, on-site septic systems, domestic and wild animal manure, and storm runoff (<http://water.epa.gov>, 2012).

In addition to the possible health risk associated with the presence of elevated levels of fecal bacteria, they can also cause cloudy water, unpleasant odors, and an increased oxygen demand (<http://water.epa.gov>, 2012).

Total coliforms are a group of bacteria that are widespread in nature. All members of the total coliform group can occur in human feces, but some can also be present in animal manure, soil, and submerged wood and in other places outside the human body. Thus, the usefulness of total coliforms as an indicator of faecal contamination depends on the extent to which the bacteria species found are faecal and human in origin. For drinking water, total coliforms are the standard test because their presence indicates contamination of a water supply by an outside source (<http://water.epa.gov>, 2012).

Faecal coliforms, a subset of total coliform bacteria, are more faecal-specific in origin. However, even this group contains a genus, *Klebsiella*, with species that are not necessarily faecal in origin. *Klebsiella* are commonly associated with textile and pulp and paper mill wastes. Therefore, if these sources get into contact with a water source, there will be a need to consider monitoring more faecal and human-specific bacteria (<http://water.epa.gov>, 2012)

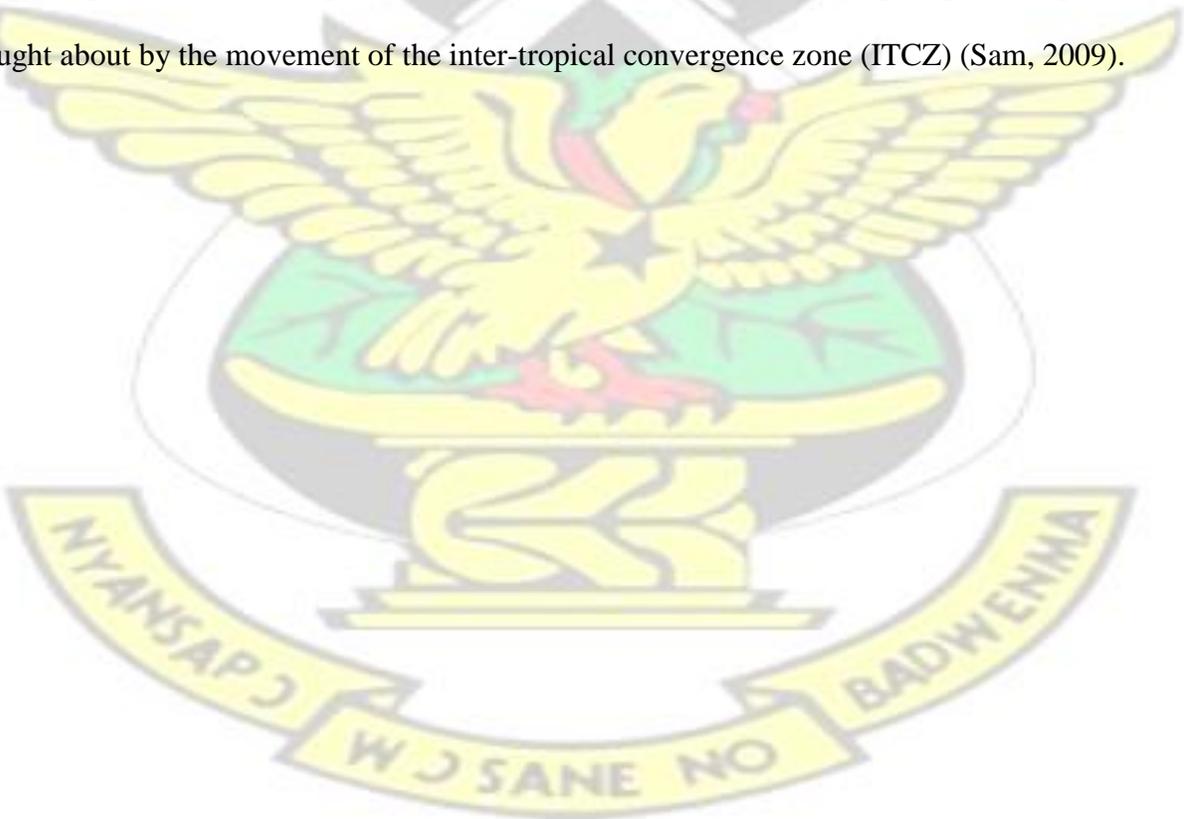
*E. coli* is a species of faecal coliform bacteria that is specific to faecal material from humans and other warm-blooded animals. *E. coli* are composed of a number of species of bacteria that share common characteristics such as shape, habitat, or behavior; *E. coli* is a single species in the fecal coliform group (<http://water.epa.gov>, 2012).

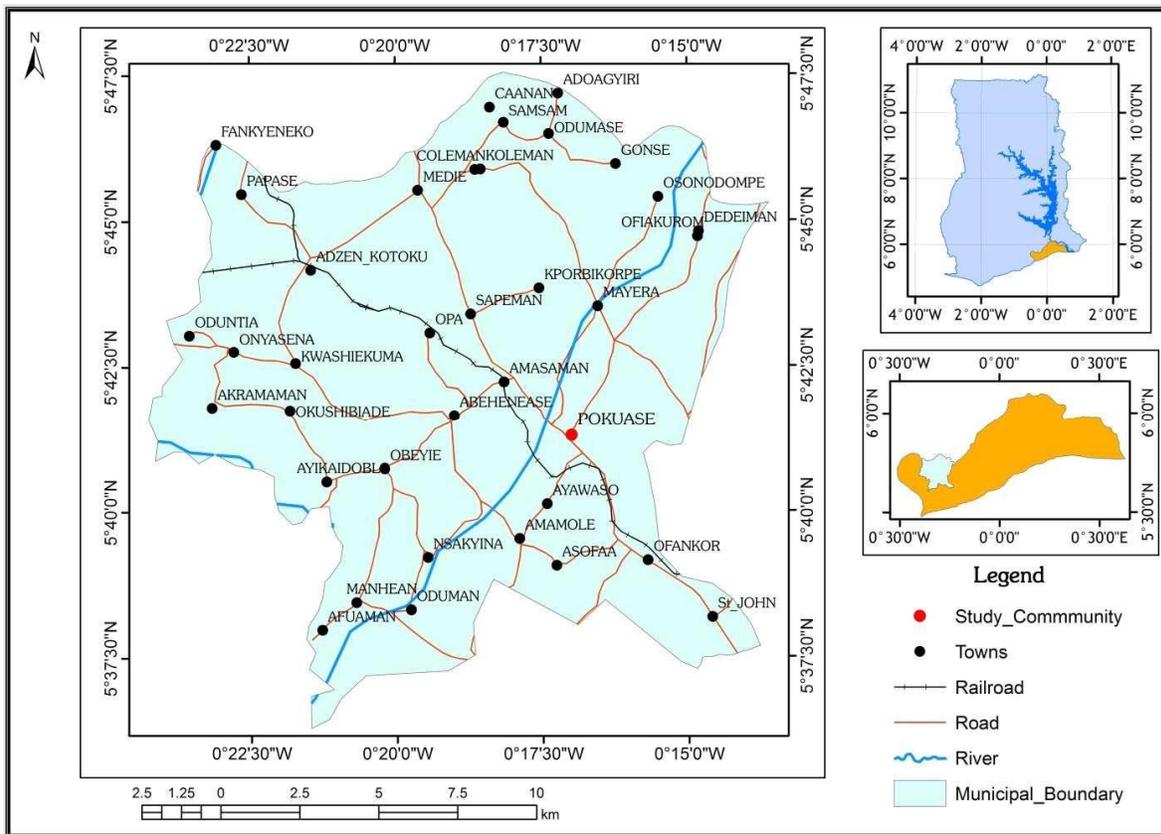
## CHAPTER THREE

### 3.0 MATERIALS AND METHODS

#### 3.1 Study Area

Pokuase is in the Ga West Municipality of the Trobu-Amasaman Constituency of the Greater Accra Region (Twumasi, 2011). Pokuase lies within longitude  $0^{\circ} 7' 00''$  West and latitude  $5^{\circ} 41' 15''$  North. Pokuase township shares boundaries with Amasaman, Mahea, Amanfrom, Kwabenya, Ofanko, Amomole, Afiaman and Katapo. The weather is predominantly sunny with a bimodal rainfall pattern. The first rainfall season falls between May and mid-July and the second occurs between mid-August and October. The mean annual rainfall is about 1204.2 mm (Ghana Meteorological Services Department, 2013). The seasonality in the precipitation patterns is brought about by the movement of the inter-tropical convergence zone (ITCZ) (Sam, 2009).





(Stemn E, 2014)

**Figure 1: A map showing Pokuase and its neighboring towns**

### 3.1.1 Soil and vegetation

The soil type in Pokuase is Fete-Bediesi. Fete is a type of soil that mostly occurs over the Voltaian rocks from the extreme north of the Densu Basin to just west and north-east of Koforidua while Bediesi also occurs over a discontinuous line of the Togo hills and outliers stretching from Aburi to the sea west and north of Senya Beraku (Soil Research Institute, 2013).

The major crops grown in the community are cassava (*manihot esculenta*), maize (*zea mays*) and okro (*Abelmoschus esculenta*).

### **3.1.2 Demography and household characteristics**

According to the 2010 population census, the total number of households in Pokuase was about 3,610. There were about 14, 223 people living in these households, 7,142 being male and 7,081 female (Ghana Statistical Services Department, 2010). Most buildings are roofed with roofing sheets of either slate (asbestos) or aluminum.

### **3.1.3 Economic Activities**

Pokuase has a mixture of lively retail shopping areas, with local stores, bars or 'drinking spots', bus/taxi stations, and a market (GhanaWeb.com, 2012). The predominant occupation of the people in the area is trading. The roads in the study area are un-tarred and very dusty. Pokuase also has 'high-end' developing residential areas, as well as the long-established gated community of Estates (GhanaWeb.com, 2012).

## **3.2 SAMPLING PROCEDURES**

### **3.2.1 Sampling Areas**

Pokuase was the sampling area. Majority of the buildings in Pokuase with the rain harvesting systems have their roofing systems being either slate or aluminum and their storage systems are underground concrete tanks, poly tanks and plastic barrels. Purposive sampling method was used to choose the various houses where the samples were taken. The selection was based on the availability of roofing materials and storage systems under study.

### **3.2.2 Preparation of sampling containers**

Sample containers (plastic bottles) were soaked in nitric acid overnight. They were later washed with distilled water, rinsed with de-ionized water and dried in a drying cabinet. Thirteen dry containers were selected and filled with distilled water and the pH was tested. The containers were

ready for use when the pH was neutral. This served as a quality control. Sample containers were labeled to enhance record keeping. Samples that were collected from the roofing systems were labeled; A and S for aluminum and slate roofs respectively while that of the storage system were  $C_A$ ,  $P_A$ ,  $B_A$ ,  $C_S$ ,  $P_S$ , and  $B_S$  for rainwater from aluminum roof to concrete tanks, rainwater from aluminum to polytanks, rainwater from aluminum to plastic barrels, rainwater from slate to concrete tanks, rainwater from slate to polytanks, rainwater from slate to plastic barrel respectively.

### **3.2.3 Sample collection**

Samples were collected from the roofing and storage systems in Pokuase. Collections of samples occurred during rain events. The selected roofing systems were aluminum and slate while the storage systems were concrete tanks, plastic barrels and polytanks. Also, Rainwater was collected directly from the sky and used as control. The samples from roofing systems were collected ten minutes after start of the rain to allow the first flush. Samples from storage systems were taken three days after the rainfall. These samples were collected into the plastic containers and placed in coolers that contains ice blocks under the temperature of 4°C and then transported to the (WRI) laboratory the for physicochemical and bacteriological analyses to be done.

## **3.3 LABORATORY ANALYSIS**

### **3.3.1 pH**

The pH was immediately taken at the site after samples were collected. pH was measured with a pH meter and a combination electrode (a set of glass electrode and reference electrode).

The electrode was connected to the meter and calibrated using imported standard pH 4, 7 and 10 buffers. A beaker was rinsed and filled with pH 7 buffer into which the electrode is immersed and stirred gently once or twice. The stirring was ceased with the electrode suspended in the solution for about 1-2 minutes for a stable reading to be obtained. The electrode was withdrawn, rinsed with deionized water and shook gently to remove water. The process was repeated using a pH buffer 4.

Once the calibration of the electrode was done it was then rinsed with deionized water. The samples are then measured and recorded to gain the pH value. pH results were reported to the nearest 0.01 pH units.

### **3.3.2 Conductivity**

Conductivity was measured in the laboratory using the conductivity meter. The instrument was first calibrated with standard KCl (0.01 M), which has a conductivity of 1413  $\mu\text{S}/\text{cm}$  at 25°C. The conductivity cell (probe) and the beaker were rinsed thoroughly with a portion of the sample to be examined. The beaker was filled completely. Thereafter, the probe was inserted into the beaker. The conductivity meter used had temperature compensation therefore, after the water sample and the equipment have reached the same temperature, the indicated value was read on the meter.

### **3.3.3 Total Dissolved Solids (TDS)**

TDS was determined using the factor 0.55 to multiply the conductivity of the sample.

### **3.3.4 Total Suspended Solids (TSS)**

TSS was determined using the hach kit which was based on the principle of photometry. 10ml of the sample was poured into a glass container and read using the kit.

### **3.3.5 Turbidity - Nephelometric Method**

The turbidity meter was used. The turbidity meter was calibrated using a standard of 0.1 NTU. The calibration knob was then adjusted to read 0.1.

Samples were then shaken vigorously and poured into sample cell to two-thirds full. The appropriate range was selected using the range knob. The value was then recorded at a stable turbidity reading.

### **3.3.6 Colour by Visual Comparison Method**

Colour was determined by visual comparison of rainwater samples with special glass colour disks which have been properly calibrated. Nessler tube was filled to the 50 ml mark with the rainwater samples. The samples were placed in the right hand compartment of the Nesslerizer lighted cabinet while distilled water was placed in the left hand compartment for reference. The colour disk was then placed in the disk compartment. The light of the Nesslerizer was switched on and the disk was rotated until a colour match was obtained. The colour in Hazen was then read.

### **3.3.7 Alkalinity by Strong Acid Titration Method**

**Hundred millilitres** of sample was mixed with two or three drops of phenolphthalein indicator in a conical flask. There was no colour change produced. Few drops of methyl orange indicator were added. The sample then turned yellow. The sample was titrated with hydrogen chloride until the first perceptible colour changed to orange.

### **3.3.8 Total Hardness / Magnesium (EDTA Titrimetric Method)**

**Fifty millilitres** of the sample was pipetted into a conical flask. One millilitre of the buffer solution was added to produce a pH of 10. Few crystals (0.1 – 0.2 f) of Erichrome Black T indicator was

added, mixed evenly by shaking and titrated with standard 0.01 M EDTA until the last traces of purple disappeared and turned to bright blue.

### 3.3.9 Calcium (EDTA Titrimetric Method)

Fifty millilitres of sample was pipetted into a beaker. Two millilitres of NaOH solution was added and stirred. Murexide indicator (0.1 – 0.2 g) was added and titration was done immediately after that. EDTA titrant was slowly added with continuous stirring until the colour changed from Salmon to orchid purple. Not more than 15 ml EDTA was used in the titration.

Total hardness and Calcium determination.

- CALCULATIONS
- From the calcium titration, calculate calcium hardness.
- Calcium hardness as mg CaCO<sub>3</sub>/L =  $\frac{\text{ml EDTA} \times \text{mg CaCO}_3}{\text{ml sample}}$

Where:

= ml titrant for sample

= mg CaCO<sub>3</sub> equivalent to 1.00 ml EDTA titrant at the calcium indicator endpoint.

OR

- From the calcium titration, calculate calcium.

Calcium as mg Ca/L =  $\frac{\text{ml EDTA} \times \text{mg Ca}}{\text{ml sample}}$

Where:

= ml titrant for sample.

= mg CaCO<sub>3</sub> equivalent to 1.00 ml EDTA titrant at the calcium indicator endpoint.

Then calcium hardness as mg CaCO<sub>3</sub>/L = \_\_\_\_\_

Where 0.4 = \$ \_\_\_\_\_ !"# %

- Record the total hardness concentration as mg/L CaCO<sub>3</sub>.
- Magnesium hardness as mg / L CaCO<sub>3</sub> = Total hardness – Calcium hardness.
- Mg / L Mg = (Total hardness – Calcium hardness) × 0.243

Where 0.234 = \_\_\_\_\_ molecular weight of CaCO<sub>3</sub> atomic weight of Mg

### 3.3.10 Nitrate

Ten millilitres of the water sample was pipetted into a test tube. 1.0 ml of 1.3 M NaOH was added and mixed gently. Then after, 1.0 ml of the reducing mixture was added and mixed gently. It was then heated at 6°C for 10 minutes in a water bath. It was then cooled to room temperature after which 1.0 ml colour developing reagent was added. It was shook to mix and the absorbance read.

### 3.3.11 Nitrite

Two millilitres of buffer-color reagent was added to each standard sample, mixed and allowed colour to develop for at least 15 minutes. The absorbance was measured in the spectrophotometer at 540 nm.

### 3.3.12 Phosphate

One drop phenolphthalein indicator (0.05 ml) was added to 100 ml of sample. 4.0 ml molybdate reagent I and 0.5 ml (10 drops) stannous chloride reagent were added. There was a thorough mixing after each reagent added. 10 minutes later, absorbance at wavelength 690 nm on the spectrophotometer was measured. The spectrophotometer was zeroed with blank solution (with 100 ml deionized water).

### 3.3.13 Sulphate

**Hundred millilitres** of sample was measured into a 250 ml Erlenmeyer flask. Exactly 5 ml conditioning reagent was added and mixed by stirring. A spoonful of barium chloride crystals was added while still stirring and begin timing immediately for 60 seconds at a constant speed. After stirring, the absorbance at 420 nm was measured on the spectrophotometer within five minutes.

### 3.3.14 Fluoride

Five millilitres of samples were pipetted into thirteen tubes. SPADNS reagent (1 ml) was added to each sample and mixed well. Spectrophotometer was set to zero absorbance with the blank solution. The absorbance was obtained.

### **3.3.15 Ammonia**

Samples were allowed to settle. After settling, 50 ml was pipetted into a conical flask. Five drops of Rochelle salt was added to samples and mixed well. Nessler's reagent (2 ml) was added. A blank solution (50 ml of ammonia-free water plus five drops Rochelle salt and 2 ml nessler's reagent) was prepared. Samples were allowed to stand for 10 minutes for colour development.

The absorbance was determined using a UV/VIS spectrophotometer with the blank solution.

### **3.3.16 Sodium**

The flame photometer was used. The Coarse Sensitivity Knob was adjusted to the 3rd position for sodium. The liquefied petroleum Gas attached to the flame photometer was then opened. The Gas knob on the photometer was turned, eleven (11) full times anti-clockwise to allow the gas to flow into the machine. The Power switch on the flame photometer was then turned on to ignite the gas and also displayed the digital readings. After that, the Decimal Push bottom was pressed to set the decimal point. The flame was then adjusted into fine distinct cones by using the Gas knob on the machine. The Zero knob was set to zero whilst aspirating the diluent or the deionized distilled water. The highest concentration was set with the fine sensitivity knob whilst aspirating the highest standard solution. Then after, the machine was allowed to warm up for 15 minutes whilst aspirating the diluent. The zero setting was checked and the highest standard was set again. This was then proceeded by running standards from lowest to highest to obtain a calibration curve. Samples were then run.

### **3.3.17 Potassium**

The power from the mains into the Flame Photometer and the compressor was switched on. The

Filter Selector on the Flame Photometer was pushed to K. The Coarse Sensitivity Knob was then adjusted to the 2nd position for potassium. The liquefied petroleum Gas attached to the machine was then opened. The Gas knob on the photometer was turned, eleven (11) full times anticlockwise to allow the gas to flow into the machine. Then after, the Power switch on the flame photometer was turned on to ignite the gas and also displayed the digital readings. The Decimal Push bottom was pressed to set the decimal point. After that, the flame was adjusted into fine distinct cones by using the Gas knob on the machine. The Zero knob was then set to zero whilst aspirating the diluent or the deionized distilled water. Then after, the highest concentration was set with the fine sensitivity knob whilst aspirating the highest standard solution. Fifteen minutes was then allowed for the machine to warm up whilst aspirating the diluent. The zero setting was checked and the highest standard was set again. It was then proceeded by running standards from lowest to highest to obtain a calibration curve. Samples were then run.

### **3.3.18 Heavy metals**

Twenty millilitres of sample was poured into a beaker. 5 ml of concentrated nitric acid was added to the sample for all particles to dissolve. The atomic absorption spectrometer was then calibrated using standard solution prepared in the laboratory using concentrations of 1, 2, 2.5 ppm. Then after, the samples were read.

### **3.3.19 Microbial analysis**

Indicators of faecal contamination (i.e. total coliform, faecal coliform bacteria, total heterotrophic and *E. coli*) was determined using the membrane filtration method. Several different-sized portions of the samples were filtered using filters with a standard diameter and pore size. Each filter was then placed on a selective nutrient medium in a petri plate, incubating the plates at a

specified temperature for a specified time period depending on the bacteriological parameter. After that, the colonies that have grown on the filter are counted.

Only rainwater from the different storage tanks were subjected to these bacteriological parameters. Results obtained from this study were compared with the work of others and the World Health Organisation (WHO) recommended standards for drinking water.

### **3.4 Statistical analysis**

The resulting data was analysed using Genstat discovery edition 4, SAS and Microsoft excel. ANOVA was used to determine the significance between rainwater collected from aluminum roofs and slate roofs, and also among the plastic barrels, concrete tanks and polytanks. A confidence interval of 95% was used for the main effect while 98% was used for the interaction.

## **CHAPTER FOUR**

### **4.0 RESULTS 4.1 PHYSICO-CHEMICAL PARAMETERS OF RAINWATER FROM ALUMINUM**

#### **AND SLATE ROOFING SYSTEMS.**

##### **4.1.1 Physical parameters of rainwater from aluminum and slate roofs.**

From table 1, rainwater that flowed on slate roofs recorded a mean conductivity of  $31.47 \pm 4.993 \mu\text{S/cm}$  which was higher compared to that from aluminum roofs which recorded  $16.68 \pm 8.207$ . The difference in conductivity was significant as recorded  $P = 0.0001$ . Similarly, the mean value for total dissolve solids (TDS) in rainwater that flowed through the slate roofs was  $16.18 \pm 3.734 \text{ mg/l}$ . This was found higher when compared to the rainwater from aluminum roofs which recorded

9.177±4.52 mg/l. The difference in TDS was also significant (P = 0.0004). Colour of rainwater from both roofs however, did not differ.

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**Table 1: Mean measurement of physical parameters in rainwater that flowed on both aluminum and slate roofs.**

PHYSICAL PARAMETERS	MEAN CONCENTRATION AND STANDARD DEVIATION		
	Aluminum	Slate roof	WHO standard
pH (pH Units)	7.238 ±0.77	7.275±0.94	6.5 – 8.5
Conductivity ( μS/cm )	16.68±8.207	31.47±4.993	0.5 - 3
Colour (Hz)	7.25±3.646	7.25±3.646	15
Turbidity (NTU)	9.62±6.863	9.51±5.95	5
Total Dissolve Solids (mg/l)	9.177±4.52	16.18±3.734	1000
Total Suspended Solids (mg/l)	<1.0	<1.0	

#### 4.1.2 Chemical parameters of rainwater from aluminum and slate roofs.

Total hardness and carbonate in rainwater from the slate roofs recorded higher as  $11.17 \pm 3.344$  mg/l and  $9.475 \pm 2.976$  mg/l respectively when compared to that of the rainwater from the aluminum roofs which recorded  $6.167 \pm 3.508$  mg/l and  $5.38 \pm 1.612$  mg/l respectively as shown in table 2. The difference in total hardness was significant, recorded as  $P=0.0017$ . Also, the difference in calcium and alkalinity were significant, recorded as  $P=0.0010$  and  $P=0.0001$  respectively.

Furthermore, the difference in carbonate and sulphate were significant, recorded as  $P= 0.0004$  and  $P =0.0013$  respectively. Meanwhile, calcium and sodium of rainwater that flowed on the slate roofs recorded  $65 \pm 7.47$  mg/l and  $6.025 \pm 4.633$  mg/l respectively. These were also found higher when compared to that from the aluminum roofs which recorded  $1.367 \pm 1.235$  mg/l and  $4.63 \pm 2.924$  mg/l respectively. However,  $\text{NO}_2$ ,  $\text{NO}_3$ , phosphate and potassium of rainwater did not differ significantly.

**Table 2: The mean concentration of chemical parameters in rainwater from aluminum and slate roofs.**

CHEMICAL PARAMETERS	<u>MEAN CONCENTRATION AND STANDARD DEVIATION</u>		
	Aluminum roof	Slate roof	WHO standard
Calcium (mg/l)	$1.367 \pm 1.235$	$9.65 \pm 7.47$	200
Magnesium (mg/l)	$0.67 \pm 0.2498$	$0.725 \pm 0.456$	150
Chloride (mg/l)	$1.67 \pm 0.492$	$2 \pm 0.853$	250
Total Hardness (mg/l)	$6.167 \pm 3.508$	$11.17 \pm 3.344$	500
Alkalinity (mg/l)	$4.417 \pm 1.322$	$7.475 \pm 1.56$	25 - 75
$\text{HCO}_3$ (mg/l)	$5.38 \pm 1.612$	$9.475 \pm 2.976$	

NH <sub>3</sub> (mg/l)	<0.001	<0.001	0 – 1.5
NO <sub>2</sub> (mg/l)	0.0338±0.01	0.0448±0.02	1
NO <sub>3</sub> (mg/l)	0.286±0.1317	0.378±0.167	10
PO <sub>4</sub> (mg/l)	0.2198±0.0335	0.256±0.0785	10
SO <sub>4</sub> (mg/l)	4.638±1.631	7.05±1.572	250
Potassuim (mg/l)	0.583±0.204	1.008±1.007	30
Na (mg/l)	4.63±2.924	6.025±4.633	200
Fluoride (mg/l)	<0.005	<0.005	

#### 4.1.3 Concentration of metals in rainwater from aluminum and slate roofs.

According to table 3, Lead, Asernic, cadium, copper, zinc, and mercury concentration were below detection as recorded <0.005 mg/l, <0.001 mg/l, <0.002 mg/l, <0.02 mg/l, <0.005 mg/l, <0.001 mg/l respectively. However, the Fe of rainwater that flowed on slate roofs was less than that from the aluminum roofs recorded as 0.052±0.0573 mg/l and 0.108±0.198 mg/l respectively. Manganese did not differ significantly.

**Table 3: Mean concentration of metals in rainwater from aluminum and slate roofing systems.**

METAL PARAMETERS	MEAN CONCENTRATION AND STANDARD DEVIATION		WHO standard
	Aluminum roof	Slate roof	
Fe (mg/l)	0.108±0.198	0.052±0.0573	0.3
Mn (mg/l)	0.01±0.019	0.012±0.022	0.4

As (mg/l)	<0.001	<0.001	0.01
Pb (mg/l)	<0.005	<0.005	0.01
Cd (µg/l)	<0.002	<0.002	0.003
Cu (mg/l)	<0.02	<0.02	2
Zn (mg/l)	<0.005	<0.005	3
Hg (µg/l)	<0.001	<0.001	0.001

## **4.2 PHYSICO-CHEMICAL PARAMETERS OF THE INTERACTION OF RAINWATER FROM ROOFING SYSTEMS INTO STORAGE SYSTEMS.**

### **4.2.1 Physical parameters of rainwater's interaction from aluminum and slate roofs into the three storage systems.**

From table 4 the pH of rainwater that flowed through aluminum roofs into plastic barrels was acidic when compared to the pH of rainwater from aluminum roofs to concrete tanks or polytanks as recorded  $6.22 \pm 0.43$  pH units,  $7.68 \pm 0.795$  pH Units and  $6.73 \pm 0.176$  pH Units respectively. However, conductivity and TDS of rainwater that flowed from slate roofs into concrete tanks was  $58.48 \pm 28.583$  µS/cm and  $51.95 \pm 24.13$  mg/l respectively. This was high when compared to the conductivity and TDS of rain that flowed from slate roofs into either plastic barrels or polytanks recorded as  $33.35 \pm 1.457$  µS/cm and  $18.35 \pm 0.79$  mg/l,  $32.6 \pm 5.17$  µS/cm and  $17.93 \pm 2.879$  mg/l respectively.

Furthermore, the value of colour in rainwater that flowed from slate roofs to polytanks was high when compared to the colour of rainwater from slate roofs to plastic tanks or concrete tanks as recorded  $13.25 \pm 8.45$  Hz,  $10.0 \pm 8.898$  Hz and  $3.38 \pm 1.974$  Hz respectively. Moreover, turbidity of rainwater from aluminum roofs to concrete tanks was high when compared to the turbidity of rainwater from aluminum roofs to plastic barrels or polytanks as recorded  $9.06 \pm 4.53$  NTU,  $6.488 \pm 2.99$  NTU and  $4.63 \pm 1.17$  NTU respectively.

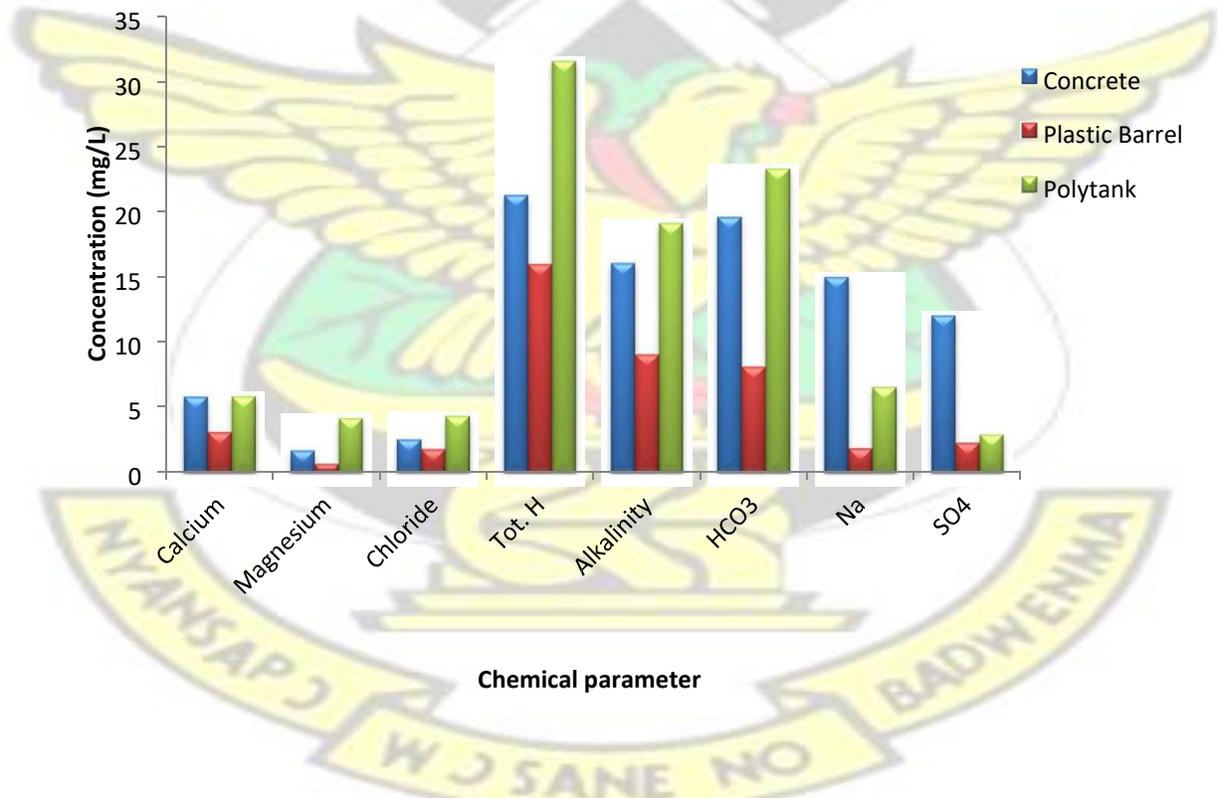
**Table 4: Mean measurement of physical parameters in rainwater that flowed from the aluminum and slate roofs to the three storage tanks.**

PHYSICAL PARAMETERS	MEAN CONCENTRATION AND STANDARD DEVIATION					
	<u>Plastic Barrel</u>		<u>Concrete tank</u>		<u>Polytank</u>	
	<u>Aluminum</u>	<u>Slate</u>	<u>Aluminum</u>	<u>Slate</u>	<u>Aluminum</u>	<u>Slate</u>
pH (pH Units)	$6.22 \pm 0.43$	$6.44 \pm 0.21$	$7.68 \pm 0.795$	$6.93 \pm 0.391$	$6.73 \pm 0.176$	$6.76 \pm 0.30$
Conductivity ( $\mu$ S/cm)	$26.63 \pm 10.433$	$33.35 \pm 1.457$	$57.6 \pm 6.13$	$58.48 \pm 28.583$	$28.53 \pm 7.22$	$32.6 \pm 5.17$
Colour (Hz)	$4.25 \pm 2.53$	$10.0 \pm 8.898$	$6.5 \pm 4.36$	$3.38 \pm 1.974$	$4.63 \pm 3.95$	$13.25 \pm 8.45$
Turbidity (NTU)	$6.488 \pm 2.99$	$7.21 \pm 4.14$	$9.06 \pm 4.53$	$4.36 \pm 1.76$	$4.63 \pm 1.17$	$7.3 \pm 3.31$
TDS (mg/l)	$11.42 \pm 2.187$	$18.35 \pm 0.79$	$31.65 \pm 3.34$	$51.95 \pm 24.13$	$15.7 \pm 4.0$	$17.93 \pm 2.879$

TSS (mg/l) <1 <1 <1 <1 <1 <1

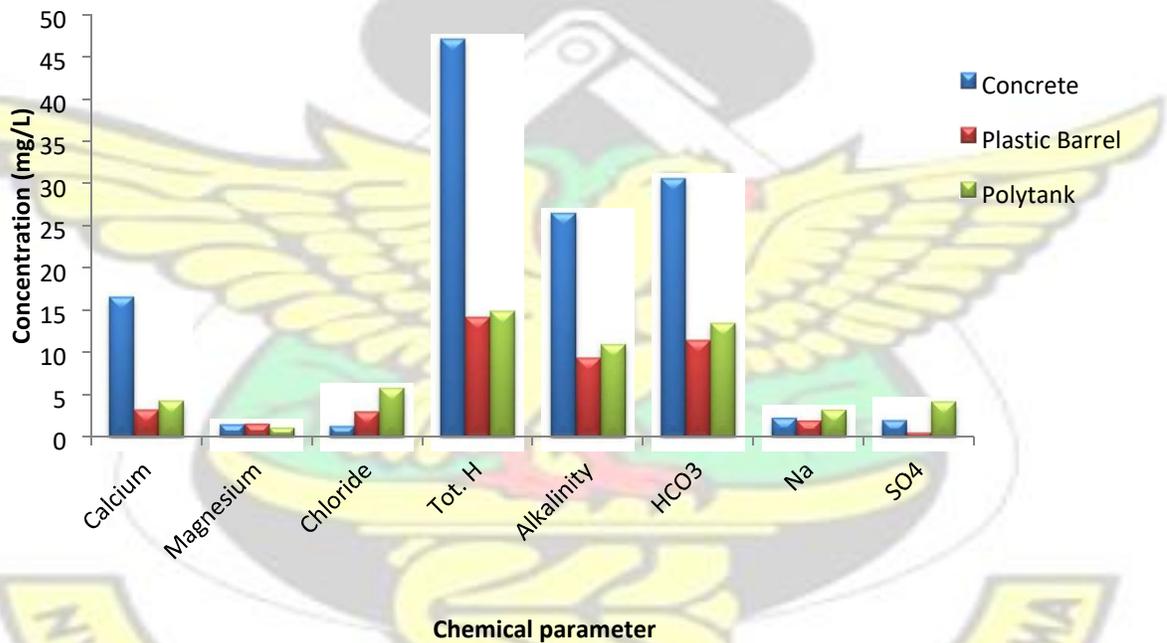
**4.2.2 Chemical parameters of rainwater’s interaction of rainwater from aluminum and slate roofs into the three storage systems.**

Sulphate and sodium of the rainwater that flowed from aluminum to concrete tanks was 11.98±1.078 mg/l and 14.95±0.87 mg/l. This is high when compared to the rainwater from aluminum roofs to plastic barrels and polytanks recorded 2.27±0.99 mg/l and 1.85±1.44 mg/l, and 2.9±2.52 mg/l and 6.53±0.202 mg/l respectively. The differences were significant in nitrate (P=0.01), sulphate (P =0.0010), potassium (P=0.0015) and sodium (P= <.0001).

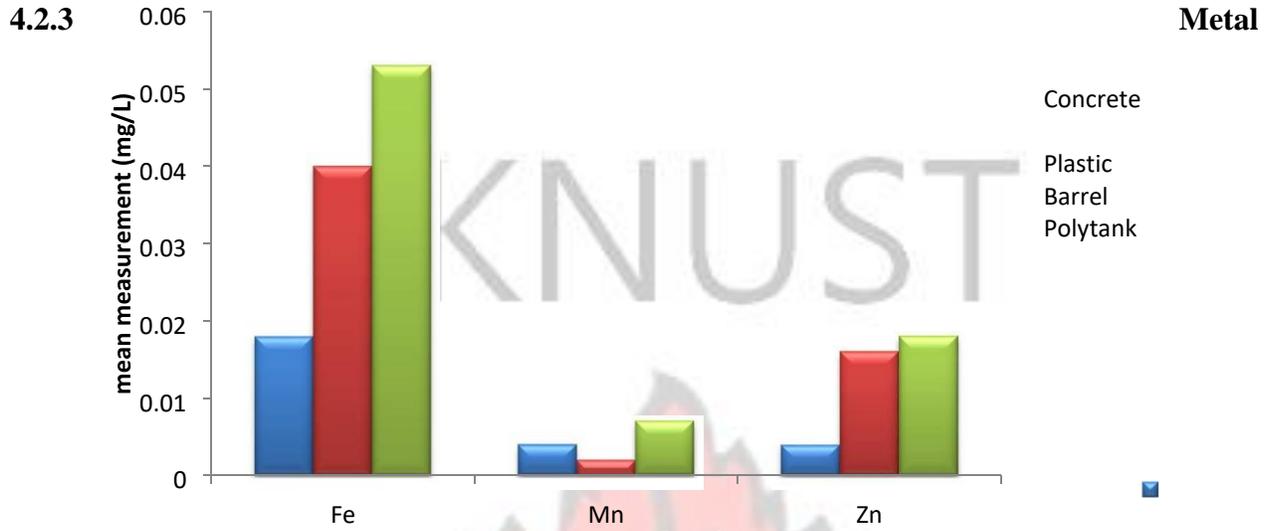


**Figure 2: Mean concentration of chemical parameters in rainwater that flowed from aluminum roofs to the three storage systems**

Total hardness and alkalinity concentrations in rainwater that flowed through slate roofs into concrete tanks were  $47.1 \pm 25.48$  mg/l and  $26.5 \pm 13.59$  mg/l, respectively. This was high when compared to the rainwater that flowed from slate roofs into plastic barrel or polytanks as  $9.4 \pm 1.78$  mg/l and  $14.9 \pm 2.299$  mg/l,  $14.2 \pm 1.47$  mg/l and  $11 \pm 1.25$  mg/l respectively. Similarly, carbonate and calcium concentrations in rainwater that flowed through slate roofs into concrete tanks  $30.63 \pm 17.8$  mg/l and  $16.53 \pm 9.29$  mg/l were found high when compared to the rainwater that flowed from slate roofs into plastic barrels or polytanks which was recorded as  $11.48 \pm 2.14$  mg/l and  $3.23 \pm 0.709$  mg/l, and  $13.48 \pm 1.49$  mg/l and  $4.28 \pm 0.97$  mg/l respectively.



**Figure 3: Mean concentration of chemical parameters in rainwater that flowed from slate roofs to the three storage systems**



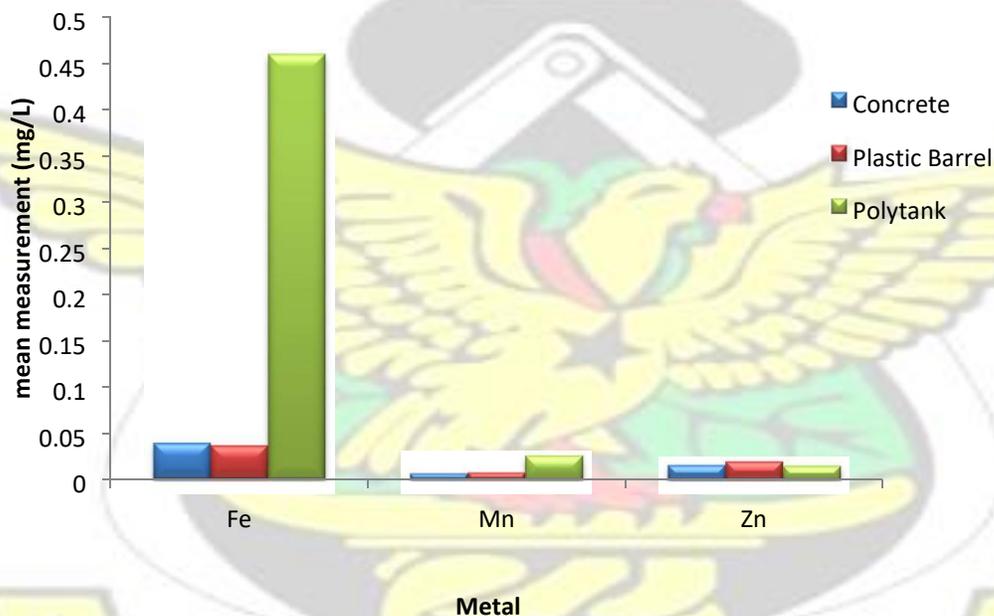
parameter of rainwater's interaction between aluminum and slate roofs and the three storage systems.

Generally, rainwater that flowed from aluminum roofs into polytanks had high concentrations of iron ( $0.053 \pm 0.067$ ), manganese ( $0.007 \pm 0.006$ ) and zinc ( $0.018 \pm 0.016$ ) as compared to the other storage tanks.

**Figure 4: Mean concentration of metals in rainwater that flowed from the aluminum roofs to the three storage systems**

Rainwater that flowed through slate roofs to polytanks had a high iron concentration of  $0.46 \pm 0.29$  mg/l when compared to the values of iron in rainwater that flowed through the slate roofs into plastic barrel and concrete tanks which are  $0.037 \pm 0.06$  mg/l and  $0.04 \pm 0.03$  mg/l respectively. Iron concentration differ significantly ( $P=0.0071$ ).

The zinc and manganese concentrations in the rainwater did not differ significantly among the interactions. However, the manganese concentrations in rainwater that flowed on slate roofs into polytanks  $0.026 \pm 0.015$  mg/l was high when compared to rainwater that flowed from slate roofs into either plastic tanks or concrete tanks which are  $0.008 \pm 0.007$  mg/l and  $0.007 \pm 0.003$  mg/l respectively. Meanwhile, the value of zinc in rainwater that flowed from slate roofs into plastic barrels was  $0.02 \pm 0.01$  mg/l. It was high compared to that from slate roofs to concrete tanks and polytanks that is  $0.016 \pm 0.008$  mg/l and  $0.015 \pm 0.008$  mg/l respectively as showed in figure 7.



**Figure 5: Mean concentration of metals in rainwater that flowed from the slate roofs to the three storage systems**

### 4.3 MICROBIAL CONCENTRATION IN DIFFERENT STORAGE TANKS.

Total heterotrophic concentration in rainwater stored in plastic barrel was  $2.95950 \times 10^3$  CFU/100 ml. This was found high compared to concrete tanks and polytanks which recorded  $1.89350 \times 10^3$  CFU/100 ml and  $1.59850 \times 10^3$  CFU/100 ml respectively. Total Coliform concentration in rainwater stored in concrete tanks was  $7.3975 \times 10^2$  CFU/100 ml, which was also high compared to the plastic barrels and polytanks that recorded  $6.5825 \times 10^2$  CFU/100 ml and  $3.250 \times 10^2$  CFU/100 ml respectively as observed from table 7 below. Also, the Faecal coliform and *E. coli* concentration in rainwater stored in concrete tanks was  $1.5425 \times 10^2$  CFU/100 ml and  $1.03 \times 10^2$  CFU/100 ml respectively. It was high when compared to the plastic barrels and polytanks which recorded  $7.325 \times 10$  CFU/100 ml and  $3.05 \times 10$  CFU/100 ml,  $2.05 \times 10$  CFU/100 ml and  $1.525 \times 10$  CFU/100 ml respectively.

**Table 5: Mean concentration of bacteriological parameters in rainwater from plastic barrel, concrete tanks and polytanks.**

Bacteria	<u>MEAN COUNTS AND STANDARD DEVIATION</u>		
	Plastic Barrel	Concrete tank	Polytank
<b>Total Heterotrophic (CFU/100ml)</b>	$2.95950 \times 10^3$ $\pm 1.34826 \times 10^3$	$1.89350 \times 10^3$ $\pm 1.237026 \times 10^3$	$1.59850 \times 10^3$ $\pm 9.66055 \times 10^2$
<b>Total Coliform (CFU/100ml)</b>	$6.5825 \times 10^2$ $\pm 3.7568 \times 10^2$	$7.3975 \times 10^2$ $\pm 4.4116 \times 10^2$	$3.250 \times 10^2$ $\pm 1.14481 \times 10^2$
<b>Faecal Coliform (CFU/100ml)</b>	$7.325 \times 10$ $\pm 8.149 \times 10$	$1.5425 \times 10^2$ $\pm 2.69222 \times 10^2$	$2.050 \times 10$ $\pm 3.1649 \times 10$

<i>Escherichia coli</i> (CFU/100ml)	$3.050 \times 10$ $\pm 3.15013 \times 10$	$1.030 \times 10^2$ $\pm 1.79364 \times 10^2$	$1.525 \times 10$ $\pm 2.2677 \times 10$
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## CHAPTER FIVE

### 5.0 DISCUSSION

Ambient rainwater is a source of water most people all over the world depend on since some other freshwater sources are not potable while others are not available within a locality. Ambient rainwater is however susceptible to contamination. Urban aerosols have recently been shown to contain up to 1,800 different types of bacteria, which is comparable to the diversity of bacteria found in soils that are currently present in ambient rainwater (Brodie *et al.*, 2006). Studies have also detected a range of organic compounds in ambient rainwater samples, including polycyclic aromatic hydrocarbons (PAHs) and pesticides, with concentrations exceeding USEPA drinking water standards (Basheer *et al.*, 2003; Polkowska *et al.*, 2001).

Moreover, the contamination could also come from leaching chemicals from rooftops which occur through the absorption of accumulated contaminants such as organic compounds during dry and wet deposition by roofs, which are later released during rain (Chang *et al.*, 2004). This leaching is

usually due to the acidic nature of ambient rainwater (King and Bedient, 1982). These leached chemical compounds contaminate the harvested water. Additionally, previous studies have shown that contamination in roof runoff is affected by the length of time between rain events (Yaziz *et al.*, 1989), season (Jones and Harrison, 2004; Lighthart, 2000; Forster, 1998), land use (Bucheli *et al.*, 1998), and others such as environmental factors and anthropogenic activities which affects rainwater quality in different locations.

### **5.1 Physico-chemical parameters of rainwater from aluminum and slate roofing systems.**

The pH values of the samples from both aluminum and slate roofs were high or more basic than the control samples. The acidity of the control could be due to atmospheric oxidation of NO<sub>x</sub> and SO<sub>2</sub> emitted by vehicles, milling machines and welding of vehicles around the area. The general increase in the pH of roofs might also be due to the replacement of H<sup>+</sup> ions by metal ions in the case of aluminum roofs and leaching of certain compounds such as calcium and carbonate from slate roofs during the interaction of runoffs with the roofs. The pH of rainwater from the slate roof was slightly higher than that from the aluminum roofs. This is similar to the findings of Quek and Forster (1993), where the alkaline nature of roofs containing cement such as Clay tiles and asbestos or slate through weathering causes pH of roof runoff to be alkaline. Generally, the mean pH for both roofing systems was within the WHO standards.

The conductivity of rainwater that flowed on the slate roofs was 31.47 µS/cm. This was higher when compared to the control which was 17.95 µS/cm. This could be attributed to the contributions from soluble inorganic dissolved solids in the atmosphere such as chloride, nitrate, sulfate, and phosphate ions and some cations generated from anthropogenic activities and subsequently,

deposited on the roofing materials (Thomas and Greene, 1993). There was a significant difference ( $P= 0.0001$ ) between rainwater from slate roofs and that from aluminum roofs. This is similar to studies by Thomas and Greene (1993) and Foster (1996), indicating that conductivity has been found to be highest in runoff from roofs with rougher surfaces such as asbestos or slate and clay tiles than smoother ones like the metal sheets. However, the values obtained for electrical conductivity of all the roofing materials were above the standard for drinking water.

The colour of rainwater that flowed from both roofing systems were within the WHO drinking water standards. Nevertheless, the control sample was 7.5 Hz which is high compared to the samples from both roofs. This observation could be attributed to the presence of dust in the area of study. The roads in the area were not tarred during the studied period.

The high turbidity values obtained (Table 1) could be attributed to the breaks between the rainfalls in the year of study. Also, the untarred nature of the road and vehicular movement, which circulates sand and dust that forms aerosol and subsequently, settles on roofing systems. Turbidity of runoff from aluminum were higher (Table 1) and this could be attributed to the smooth nature of the aluminum roofs which helps it flush most settled dust into runoffs. Turbidity of rain from both roofing systems and control exceeded the WHO standard for drinking water limits.

TDS values depend on the suspended and dust particles in the rainwater (Chughtai *et al* 2014). The presence of welding shop in the study area might contribute to the suspended particles since in many welding processes, air pollutants are generated and take the form of gases and particles which are larger than one in diameter. These dust particles fall in close vicinity to the arc and consist largely of welding spatter. These particles generally remain suspended in air and in that way can be carried long distances from the welding arc (Arbeitsschutz, 1985). TDS of rainwater from slate

roofs were high compared to that of aluminum roofs. This could be attributed to the absorbent nature of the slate roofs which causes it to absorb water that contains these particles that are later dissolved in runoff. The values were however, below WHO guideline for drinking water.

Chloride content of rainwater from slate was higher than that from the aluminum roofs. The value of chloride in control was higher than that of aluminum roofs and equal to that of the slate roofs. This may be attributed to some anthropogenic activities such as refuse incineration of PVC, which produces HCl in gas phase (Sigg *et al.*, 1987) which can therefore change the quality of ambient rainwater. Also, due to the absorption nature of slate roofs, the chloride in rain can be absorbed and consequently washed into the runoffs.

Chemically, hardness is often defined as the sum of polyvalent cation concentrations dissolved in water. The most common polyvalent cations in fresh water are calcium ( $\text{Ca}^{++}$ ) and magnesium ( $\text{Mg}^{++}$ ) [Wilson, 2013]. Hardness is also defined as the measure of dissolved mineral salts (mainly chlorides, bicarbonates, and sulphates of calcium, sodium, magnesium and potassium); the harder the water the more mineral salts it contains (Shepard and Gromicko 2009). However, in addition to  $\text{Ca}^{++}$  and  $\text{Mg}^{++}$ , iron ( $\text{Fe}^{++}$ ), strontium ( $\text{Sr}^{++}$ ), and manganese ( $\text{Mn}^{++}$ ) may also contribute to hardness according to the American Public Health Association (APHA *et al.* 1998).

In this study, calcium, carbonate, chloride, sulphate, sodium, magnesium, potassium as well as alkalinity also increased with increase hardness of rain. This conforms to the explanation of Shepard and Gromicko (2009) who said that the harder the water the more mineral salts it contains. Slate roofs had higher values of sulphate, sodium, potassium and magnesium when compared to that of aluminum roofs. Total hardness, calcium, alkalinity and carbonate of rainwater from slate

roofs were also high compared to aluminum roof. Slate roofs are made by quarrying slate rocks. According to Shepard and Gromicko (2009), weathering in slate roofs are based on the gradual delamination (which is caused by the reaction of certain minerals to longterm moisture) or the increasingly porous state of the slate as its minerals dissolve from repeated moisture cycles. UV radiation and moisture also cause lime and other mineral (like feldspars, chloritoid, tourmaline, carbonates, iron sulphides, etc) to break down. This causes slate to be porous. These minerals are eventually deposited as powder on the surface of the roof which can then dissolve in rainwater causing it to be hard. Chloritoid appears in slate with high content of magnesium (<http://www.roofingslate.wordpress.com>) and could be a contributing factor for the high concentration of calcium, total hardness, alkalinity and carbonate of rainwater from slate roofs when compared to aluminum roofs. The difference in calcium was significant ( $P= 0.001$ ) between rainwater from slate roofs and aluminum roofs.

Three major source-types responsible for the presence of phosphate in rainwater can be emissions from sea water, soil-derived dust and anthropogenic activities (Bergametti *et al.*, 1992). The slate roofs had a high phosphate concentration than the aluminum roofs and may be attributed to the settling of soil derived dust containing phosphate on roofs, and since slate roofs absorb more moisture which contains these soil-derived dusts with phosphate, it could then dissolve into runoff.

The difference in sulphate between rainwater from slate roofs and aluminum roofs was significant ( $P=0.0013$ ). The sulphate content in samples from slate roofs was high compared to that took from aluminum roofs and the control samples. Levels of sulphate in rainwater correlate with emissions of sulfur dioxide from anthropogenic sources (Keller *et al* 1986). Specifically, sulphate is known to be a gas emitted from automobiles exhaust which reacts with water droplets and accounts for

the presence of sulphate ions in rainwater (Chughtai *et al*, 2014). However in this study, the control samples were lower than the samples from slate roofs. It could be attributed to sulphate emission from vehicles that settled and dissolved in absorbed moisture by the slate roofs. These may have subsequently dissolved in runoff contributing to the high sulphate content of samples from slate roofs. The values were however, within the WHO standards for drinking water.

The potassium content in control samples was lower when compared to the values of rainwater from both roofs. Presence of potassium in rainwater presumably comes from dust in the atmosphere from land surface (Chughtai *et al*, 2014). This dust probably settles on the roofs and accounts to the high level of potassium in rainwater from the roofs when compared to the control.

The main source of sodium in rainwater is sea salt. When waves split, fine droplets of seawater are injected into the atmosphere. The water evaporates, leaving a solid aerosol particle, which is transported by winds until it is dissolved by rain (Chughtai *et al* 2014). However in this study, the samples from the slate roofs had high sodium content compare to that from aluminum roofs and the control samples. Perhaps, the slate roofs absorb more saltwater in the form of moisture dissolves in runoff causing high sodium content in runoff from the slate roofs.

Forster (1998) explained that nitrites present in roof runoffs may be due to bird faeces deposited on the roofs. Contrary to this explanation, the control samples were high in nitrite when compared to the rainwater from the both roofs. This may therefore be attributed to air combustion, such as those that occur in car engines which produces large amounts of NO gas that oxidizes with atmospheric oxygen to produce nitrite. It was however, high in rainwater samples from slate roofs than that from aluminum roofs. The values were however within the WHO standards.

According to Mendez *et al.*, (2011) nitrate concentrations in harvested rainwater can vary based on geographical location. The nitrate content in slate roofs was high compared to the aluminum roofs and the control.

Metals such as lead, zinc, iron, and aluminum are noted to be associated with metallic roofs. Cadmium and chromium has been identified as major metal components in asbestos or slate and clay tiles roofs (Ayenimo *et al.*, 2006). This study deviated from the findings of Ayenimo *et al.*, (2006) since lead, zinc, cadmium and chromium were not present in their respective roofs in this study except iron. The iron content in samples from aluminum roofs was high compare to from the slate roofs and the control. Manganese was high in the control than in the samples collected from both roofs.

## **5.2 Physico-chemical parameters of rainwater that flowed from aluminum and slate roofs into the three storage systems.**

Thomas and Greene (1993) indicated that, concrete products have high pH value, turbidity and conductivity. This does not deviate from this study since turbidity, conductivity and pH of rainwater stored in concrete tanks were high than the other storage tanks. However, the turbidity and pH of rainwater that flowed from aluminum roofs into concrete tank was the highest when compared to the rainwater that flowed from aluminum roofs into plastic barrels and polytanks. The value of turbidity of rainwater from aluminum roofs was high and there was an addition during the storage period.

The increase in pH and conductivity of rainwater in concrete tanks may be attributed to the concrete that is said to leach lime which contains calcium carbonate. The lime increases the pH.

This study conforms to work by Achadu *et al.*, (2013) and Issaka (2011) where rainwater stored in the concrete tanks also had a high pH to which they attributed to leaching of CaCO<sub>3</sub> from walls of concrete tanks.

Brown (2010) also indicated that rainwater stored in plastic tanks remains naturally acidic unlike concrete tanks as they leach lime into the water thereby reducing acidity. Nevertheless, conductivity of rainwater from slate roofs into concrete tanks was high than the conductivity of rainwater from slate roofs to plastic barrels and polytanks. This contradicts with the study of Issaka (2011) which indicated that except for conductivity, plastic tanks had lower values of pH, total alkalinity, turbidity, nitrite and total hardness which fell within the WHO acceptable limits of drinking water. Conductivity of water is also said to be affected by inorganic dissolved solids which includes sulfate, nitrate, chloride, and phosphate anions or calcium, sodium, iron, magnesium and aluminum cations (U.S. Environmental Protection Agency, 2006). These ions might have initially dissolved in rainwater during its contact with the slate roofs and the concrete tank subsequently added up to increase the conductivity. However, values of pH, and turbidity were within the permissible limits of WHO standard for potable water while conductivity was above the standard.

TDS of rainwater flowed from slate roofs and stored in concrete tanks were high compared to the rainwater that flowed from slate roofs into plastic barrels and polytanks. The TDS value of rain from slate roofs was high and there was a compounding during the storage period. It was however within the permissible standards of WHO.

From the results total hardness, calcium, alkalinity and carbonate levels were within the WHO standards of drinking water. The values of total hardness, calcium, alkalinity and carbonate of

rainwater that flowed from slate roofs and stored in concrete tanks were high when compared to rainwater from slate roofs into plastic tanks and polytanks. Calcium and magnesium ions are the contributing factor to water hardness (U.S. Geological Survey, 2013). Concrete releases calcium there by increasing the hardness of stored rainwater. This study is a confirmation to Van der Sterren *et al.*, (2011) who indicated that concrete increases the hardness and conductivity in the rainwater tank. Concrete tanks are made from lime which is a type of calcium carbonate which leaches into stored rain and raises the pH. This means that rainwater stored in concrete tanks have a high level on calcium carbonate which intends increases alkalinity, carbonate and hardness of the water. Issaka (2011) indicated that due to leaching of  $\text{CaCO}_3$  from the walls, concrete tanks caused high pH, total alkalinity, and total hardness of stored rainwater. Wilson, (2013) also indicated that the ions responsible for alkalinity and hardness originated from the dissolution of geological minerals which contain carbonates and bicarbonate into rain. It was also explained that the carbonate fraction of hardness (expressed as  $\text{CaCO}_3$  equivalents) is chemically equivalent to the bicarbonates of alkalinity present in water (Burton Jr. and Pitt 2002) in areas where the water interacts with limestone (Timmons *et al.*, 2002). The values for these parameters are within the WHO guidelines for drinking water.

However, magnesium was high in rainwater that flowed from aluminum roofs and stored in poly tanks. This study deviates from Achadu, *et al.*, (2013) who found out that the highest values of magnesium were found in the concrete tanks while calcium and magnesium however showed no significant difference in metal and plastic tanks. The value for magnesium was however, below the WHO guideline for drinking water.

Sulphate, nitrate and sodium of rainwater that flowed from aluminum roofs to concrete tanks were the highest compared to the values of rainwater samples that flowed from aluminum roofs to plastic tanks and polytanks. Meanwhile, these parameters were high in rainwater that flowed on slate roofs. Phosphate on the other hand was high in rainwater that flowed from slate roofs into concrete tanks. There are three major source-types responsible for the presence of phosphate. It can be emissions from sea water, soil-derived dust and anthropogenic activities (Bergametti *et al.*, 1992). The emissions from these various sources can settle on concrete tanks which are frequently open to gain access to water. Nitrite was high in rainwater that flowed from slate roofs into polytanks where as potassium was high in rainwater that flowed from aluminum roofs into polytanks.

Zinc was high in rainwater that flowed from slate roofs into plastic barrels. While iron and manganese were high in rainwater that flowed from slate roofs into polytanks. This is partially true to the findings of Achadu *et al.*, (2013) where the presence of metals in stored water were attributed to leaching of metals due to the long storage time of the slightly acidic rainwater in the tanks. From this study, rainwater stored in plastic barrels was more acidic compare to the other tanks however, zinc, manganese and iron were the metals present in water from plastic tanks. Contrary to this study, Despins *et al.*, (2009) also observed that concrete and plastic tanks have no notable impact on the concentrations of heavy metals in stored rainwater. Also, enHealth Council (2004); NRMHC/ EPHC/ HNMRC (2009) deviated from this study since it indicated that the risk of zinc pollution can be significantly reduced using a concrete tanks or plastic barrels. The presence of iron and manganese in storage tanks in this study could be attributed to the contamination of runoff flow on roofing systems. Rainwater that flowed from the roofs did not record any zinc content meanwhile there was some amount of zinc during the interactions. It can therefore be said that the

various storage systems contributed to the zinc content in stored rainwater. All the metal parameters of rainwater in all tanks were within the WHO standards.

### **5.3 Microbial concentration in rainwater stored in all studied storage tanks.**

In this study, rainwater stored in concrete tanks was found to have the highest counts of all the bacteriological parameters except total heterotrophic when compared to the other tanks. This therefore, deviated from the findings of Achadu, *et al.*, (2013) and Zhu *et al.*, (2004) which said that, the concrete tanks had the lowest levels of microbial contamination in the stored rainwater samples while the most contaminated were the plastic tanks which Achadu, *et al.*, (2013) attributed to pH variations while Zhu *et al.*, (2004) attributed it to both pH variation and temperature of the stored rainwater. Furthermore in contrary to this study, Achadu, *et al.*, (2013) indicated that the total coliform was lowest in concrete tanks which have the highest mean pH value. High counts of total coliform, faecal coliform, *E. coli*, and total heterotrophic in concrete tanks may be however attributed to tank crack which is caused by soil shifting under the tank or the freeze and thaw cycle that also lead to expansion of the concrete which will again contract when the weather changes. Additionally, small shocks on the ground which causes the ground to move and possibly affect the foundation of the tank. When concrete tanks cracks, water eventually leaks and drains (Water Collection Tanks, 2012). Also, faecal coliform can seep and build in the cracks that can contaminate and also make the water unsafe for human consumption (Water Collection Tanks, 2012).

Heat and sunlight turn water off which also promotes algae and bacteria growth

(<http://www.abc.net.au>, 2010). Contrary to this study, black and dark coloured tanks like the polytanks which can absorb heat from sunlight had the lowest counts of all studied

bacteriological parameters.

Total heterotrophic counts were high in samples from the plastic barrels compare to the other tanks. This may be attributed to the opening of plastic barrels in expectance of rains. This does not deviate from the findings of Singh *et al.*, (2013) which said that there was more heterotrophic counts in open top containers compare to the closed.

The general turn out of microbial counts from this study may also be attributed to low water levels and long antecedent dry periods, resulting in an increased concentration of faecal contamination levels in the roof run-off and tank water. This is in agreement with that of Van der Sterren *et al.*, (2011) which assumed that the high enumeration of *E. coli* could be attributed to low water levels and long antecedent dry periods, resulting in an increased concentration of faecal contamination levels in the roof run-off and tank water. There was however, no significant difference in all the bacteriological parameters among the studied storage systems.

The microbiological results from tables 7 show that all the stored rainwater samples had high counts which exceeded the WHO limits. Analysis showed that the stored rainwater in the selected tanks was polluted and unsuitable for drinking.

## **CHAPTER SIX**

### **6.0 CONCLUSION AND RECOMMENDATIONS**

#### **6.1 Conclusion**

All parameters of rainwater from aluminum roofs were below the World Health Organisation (WHO) standards for drinking water except turbidity which recorded 9.62 NTU. In comparison, the control was acidic than the samples from the aluminum roofs. The aluminum roof might have

caused an increase in pH of runoff. Moreover calcium, magnesium, total hardness, potassium, and iron in addition to pH of rainwater from aluminum roofs were higher than the control. Also, total suspended solids, fluoride, arsenic, lead, cadmium, copper, zinc and mercury were not detected in both controls and rainwater samples from the aluminum roofs.

Also, all parameters of rainwater samples from the slate roofs were below the WHO standards except turbidity and conductivity which recorded 9.51 NTU and 31.47  $\mu\text{S}/\text{cm}$ . In comparison to the control sample, rainwater samples collected from slate roofs recorded higher values in all the parameters analyzed except colour, turbidity, nitrite, and iron. Chloride of rainwater from slate roofs however, was equal to the control. Nevertheless, total suspended solids, fluoride, arsenic, lead, cadmium, copper, zinc and mercury were not detected in both controls and rainwater samples from the aluminum roofs.

All parameters of rainwater samples from aluminum roofs into plastic barrels, concrete tanks and polytanks were within the WHO guidelines for drinking water in exception of pH of rainwater from aluminum roofs into plastic barrels. Additionally, turbidity of rainwater from aluminum roofs into plastic barrels and concrete tanks were also above the WHO guidelines for drinking water.

The values obtained in samples collected from runoff from slate roofs into all storage tanks were within the WHO guidelines of drinking water except pH of runoff from slate roofs into plastic barrels and turbidity of runoff from slate roofs into plastic barrels and polytanks. Additionally, conductivity of rainwater that flowed from slate roofs into concrete tanks as well as iron of runoff from slate roofs into polytanks was not within the WHO guideline for drinking water.

The values of all bacteriological parameters of stored rainwater from concrete tanks recorded high when compared to that from plastic barrels and polytanks except total heterotrophic. Polytanks on the other hand had low values of all bacteriological parameters when compared to plastic barrels and concrete tanks. All values of the bacteriological parameters were above the WHO standards.

It can be concluded from this study that, roofing and storage systems affects the potability of rainwater and therefore rainwater could be use to complement other source of water or treated before drinking. The metal values in this study may be low but can bioaccumulates in the human body which is a threat to health over a long period. From these findings it can also be said that, aluminum roofs are better for rain harvesting as compare to slate roofs since almost all the parameters were higher in slate roofs than in aluminum. It was found that rainwater that flowed from both roofs into plastic barrels had a low pH which was not within the WHO standard for drinking water and can cause harm to human health. Rainwater from both roofs into concrete tanks on the other hand had a high pH and also had high values of most of the parameters. It can therefore be said that, polytanks could be a good storage system since it had low values in all bacteriological parameters analyzed when compared to the other tanks but could be better if frequently washed.

## **6.2 Recommendations**

From the study it was found that both roofing and storage systems have an impact on the potability of harvested rainwater though most values of parameters were within the WHO guideline for drinking water. Meanwhile, these parameters can pull a threat to the health of the consumers and therefore rainwater can be boiled or disinfected (WHO, 2008) before drinking. Boiling water can kill most harmful bacteria. However, the water is appropriate for other purposes like washing, flushing of toilet and others.

Both tanks and roof gutter must be washed frequently. The frequent cleaning of roof gutters will reduce the contribution of chlorides, phosphate, sulphate and nitrates. Water should be allowed to settle and properly decanted before used. Furthermore, sieves can be placed at the tip of the gutters to sieve the water before it enters the tank. This sieve must be removed and washed frequently.

Additionally, tanks must be covered and open only during rains to avoid settlement of particles especially during the dry periods. Also, other animals would be excluded from access to the water storage such as vermin (rodents, other insects), frogs and toads, birds, as they too can transmit potentially harmful pathogens.

Once storage tanks are fitted with properly fitting lids, all openings are screened, and water extracted using a tap or pump, the likelihood of contamination can be reasonably reduced.

Moreover, dirty containers as well as hands should not be dipped into stored water.

## APPENDIX

**Table 6: Mean measurement of control samples.**

<b>Parameters</b>	<b>Mean values for control</b>
<b>pH</b>	6.85
<b>Conductivity</b>	17.95
<b>Colour</b>	7.50
<b>Turbidity</b>	9.94
<b>Total Dissolved Solids</b>	9.86
<b>Total Suspended Solids</b>	1.00
<b>Calcium</b>	1.35
<b>Magnesium</b>	0.35
<b>Chloride</b>	2.00

<b>Tot. Hardness</b>	4.90
<b>Alkalinity</b>	5.90
<b>Carbonate</b>	7.20
<b>NH<sub>3</sub></b>	<0.001
<b>NO<sub>2</sub></b>	0.052
<b>NO<sub>3</sub></b>	0.291
<b>PO<sub>4</sub></b>	0.2385
<b>SO<sub>4</sub></b>	5.95
<b>Pot</b>	0.41
<b>Na</b>	5.20
<b>Flouride</b>	<0.005
<b>Fe</b>	0.097
<b>Mn</b>	0.0455
<b>As</b>	<0.001
<b>Pb</b>	<0.005
<b>Cd</b>	<0.002
<b>Cu</b>	<0.020
<b>Zn</b>	<0.005
<b>Hg</b>	<0.001

**Table 7 : Mean concentration of chemical parameters in rainwater that flowed from aluminum and slate roofs to the three storage systems.**

	Plastic Barrel		Concrete tank		Polytank	
	Aluminum	Slate	Aluminum	Slate	Aluminum	Slate
<b>Calcium(mg/l)</b>	3.08±1.109	3.23±0.709	5.775±3.355	16.53±9.29	5.8±4.84	4.28±0.97
<b>Magnesium(mg/l)</b>	0.65±0.3	1.475±0.33	1.68±0.74	1.43±0.69	4.13±4.57	1.03±0.171

<b>Chloride(mg/l)</b>	1.75±0.96	3.0±0.82	2.5±1.29	1.3±0.50	4.25±2.10	5.8±4.593
<b>Tot. H(mg/l)</b>	16±17.36	14.2±1.47	21.3±7.01	47.1±25.48	31.6±28.4	14.9±2.299
<b>Alkalinity(mg/l)</b>	9.05±3.93	9.4±1.78	16.05±4.57	26.5±13.59	19.1±17.46	11±1.25
<b>HCO3(mg/l)</b>	8.13±1.57	11.48±2.14	19.6±5.57	30.63±17.8	23.3±21.34	13.48±1.49
<b>NH3(mg/l)</b>	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
<b>NO2(mg/l)</b>	0.04±0.01	0.05±0.01	0.04±0.015	0.07±0.05	0.043±0.012	0.069±0.01
<b>NO3(mg/l)</b>	0.57±0.22	0.51±0.02	0.99±0.27	0.29±0.16	0.52±0.26	0.371±0.16
<b>PO4(mg/l)</b>	0.38±0.05	0.28±0.013	0.27±0.012	0.46±0.03	0.38±0.162	0.45±0.17
<b>SO4(mg/l)</b>	2.27±0.99	0.5±0.6	11.98±1.078	1.98±2.7	2.9±2.52	4.15±4.74
<b>Potassium(mg/l)</b>	0.43±0.096	0.8±0.12	2.25±0.058	1.35±0.76	2.65±0.404	1.05±0.71
<b>Na(mg/l)</b>	1.85±1.44	1.9±0.23	14.95±0.87	2.2±0.58	6.53±0.202	3.15±3.13
<b>Flouride(mg/l)</b>	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

**CHEMICAL MEAN CONCENTRATION AND STANDARD DEVIATION PARAMETERS**

**Table 8: Mean concentrations of metal in rainwater that flowed from the aluminum and slate roofs to the three storage systems.**

	METAL MEAN CONCENTRATION AND STANDARD DEVIATION PARAMETERS					
	Plastic Barrel		Concrete tank		Polytank	
	Aluminum	Slate	Aluminum	Slate	Aluminum	Slate
<b>Fe(mg/l)</b>	0.04±0.04	0.037±0.06	0.018±0.01 6	0.04±0.03	0.053±0.06 7	0.46±0.29
<b>Mn(mg/l)</b>	0.002± 0.002	0.008±0.00 7	0.004±0.0	0.007±0.00 3	0.007±0.00 6	0.026±0.01 5
<b>As(mg/l)</b>	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
<b>Pb(mg/l)</b>	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
<b>Cd(µg/l)</b>	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
<b>Cu(mg/l)</b>	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
<b>Zn(mg/l)</b>	0.016±0.00 6	0.02±0.01	0.004±0.0	0.016±0.00 8	0.018±0.01 6	0.015±0.00 8
<b>Hg(µg/l)</b>	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

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