UNIVERSITY OF EDUCATION, WINNEBA

# RAINWATER QUALITY ASSESSMENT IN SEFWI DWINASE, WESTERN NORTH REGION OF GHANA

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# RAINWATER QUALITY ASSESSMENT IN SEFWI DWINASE, WESTERN NORTH REGION OF GHANA

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# DECLARATION

I, FAVOUR WORLALI FIATI, declare that this thesis, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE: …………………………………

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**SUPERVISOR'S DECLARATION**

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of Thesis as laid down by the University of Education, Winneba.

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SIGNATURE: …………………………..……………………………………

DATE: ………………………………………………………………………..

# DEDICATION

To my parents; Amos Agbo and Ivy Constance Eghan, my siblings; Levina, Joanna, Juliet, Nyamekye, Ezekiel and Gyan. And also, to my grandparents Emmanuel Eghan and Rose Kesse.

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| | | |
|---|---|---|
| **AAS** | – | Atomic Absorption Spectroscopy/Spectrometer |
| **Ca** | – | Calcium |
| **DOC** | – | Dissolved organic carbon |
| **EC** | – | Electrical conductivity |
| **FAAS** | – | Flame Atomic Absorption Spectroscopy/Spectrometer |
| **Fe** | – | Iron |
| **Mg** | – | Magnesium |
| **Pb** | – | Lead |
| **pH** | – | Power of hydrogen |
| **RWH** | – | Rainwater harvesting |
| **RWHS** | – | Rainwater harvesting system |
| **TC** | – | Total coliform |
| **TDS** | – | Total dissolved solids |
| **TH** | – | Total hardness |
| **WHO** | – | World Health Organization |

# ABSTRACT

Rainwater is considered to be one of the reliable means of water supply to sustain life. In Ghana, there have been efforts to create awareness and interest in RWH to achieve national water coverage. However, atmospheric and other pollutions threaten its usage. This study analyzed the impact of different roofing materials on the physico-chemical, trace metals and microbial quality of rainwater in Sefwi Dwinase and how it can be efficiently put to use. Using descriptive design, twenty-one samples were taken from open environment, plain aluminium, flat concrete and colour-coated galvanized roofs. The samples were tested at the laboratory for concentrations of Total hardness, pH, TDS, DOC, EC, Calcium, Magnesium, Lead, Iron and Total coliform. The result revealed that, the physico-chemical parameters of the rainwater in the study area fell within the WHO guideline value for potability except pH which had some samples to be slightly acidic. Iron, Lead and TC had higher concentrations above WHO guideline. Plain aluminium roof is slightly advantageous over the others for RWH. Also, anthropogenic and biological factors increase trace metals and Total coliform in the rainwater. I concluded that, while the physico-chemical quality of the rainwater is good, it has trace metal and bacterial contamination. Meanwhile, with proper treatment, it can be used for potable and non-potable purposes. RWHS should be efficiently installed by authorities in institutions such as schools and hospitals in the town to augment water supply from the other sources, amidst regular cleaning of roof catchments, treatment of water and testing to monitor contaminations.

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background to the study

Water is one of the most essential elements of life. Water supply continues to be a challenge due to population growth and industrialization. Rainwater is one of the reliable means of water supply serving as alternative to the dependence on other sources of water, because it precipitates throughout the year especially in humid regions (Muhamad & Abidin, n.d). Some people therefore rely on the ancient practice of capturing rain runoff from surfaces, mostly, roofs and storing them for later use (Despins, Farahbakhsh, & Leidl, 2009). This is termed as rainwater harvesting (RWH) and it is now a widely used technique for the provision and supply of potable and non-potable water to cater for the rapid population growth and industrialization of mostly developing countries (Olaoye & Olaniyan, 2012). According to Muhamad & Abidin (n.d), rainwater is mostly collected to serve outdoor purposes such as gardening, washing car and flushing toilet. They continued that 'clean water' is seen as very precious to be wasted on such purposes hence the need to collect rainwater and utilise it rather than let it go waste.

Rainwater is regarded as the purest natural source of water (Ebong, Etuk, Ekong, & Dan, 2016). This source of water is however contaminated by pollutants in the atmosphere such as suspended particulates (dust, ash), aerosols and gases which significantly affect the pH of rainwater (acid rain) (DeBusk & Hunt, 2012). The quality of rainwater has been a concern to many in the world since it reflects the composition of the atmosphere from which it falls, and serves as a means of cleansing the atmosphere (Ebong, et al., 2016). The quality of rainwater to some extent is affected by particulate deposited on surfaces especially roof surfaces from which raindrops are washed and the roof materials (DeBusk & Hunt, 2012). Electrical conductivity, ph, total dissolved solids, dissolved oxygen, turbidity and hardness are some of the common physico-chemical parameters in precipitation studies. Traces of microbial and heavy metal contaminants such as total and faecal coliform, iron ($Fe^2$), lead, nickel, cadmium and zinc have also been tested in several rainwater studies (Olaoye & Olaniyan, 2012; Despins, Farahbakhsh, & Leidl, 2009; Muhamad & Abidin, n.d; Cobbina, Michael, Salifu, & Duwiejua, 2013). The quality of these parameters however differs from one geographical region to the other. While Friedler, Gilboa, and Muklada, (2017) indicated in their study that the measured quality of inorganic compounds of roof-yard harvested rainwater met drinking water standards, Ebong, et al., (2016) found out that the mean concentration of power of hydrogen (pH), Iron, Lead, Cadmium and Nickel were above their WHO acceptable limits. This means that, environmental conditions and other factors permeating in the local setting affect the quality of rainwater regardless of the roof type from which they are harvested.

The type of roofing material, location and weather conditions have effects on the quality of rainwater. Despins et al, (2009) posited that, total and fecal coliform are detected in higher quantities during summer while their growth decreases in colder seasons, basically due to the changes in temperature which decreases the activities of plants and animals (residues and faecal droppings that increses coliform counts) during winter. Poorer rainwater quality in terms of physicochemical indicators are often recorded in summer and other warmer months. This was attributed to lowerlevels of atmospheric pollutants present during colder especially winter months. Cold climate conditions, including the presence of snow on the ground and decreased animal and plant activity, is a possible cause or the reduced transfer of particulate matter and organics on to rainwater catchment surfaces. Metal roofs are reported to often leach trace elements which are dissolved in rain run off. Van Metre & Mahler, (2003) in their study of comparing rainwater washed from asphalt, shingle and galvanized metal roofs found out that, galvanized metal roofing was a source of cadmium and zinc while asphalt produced higher level of lead in rainwater. In contrast, Mendez, Afshar, Kinney, Barrett, and Kirisits, (2010) did not find metal roofs leaching higher concentration of metals. However, they indicated in their report that green roofs are not best for rainwater harvesting for indoor domestic use, because they contained higher values of DOC (dissolved organic carbon) which can lead to high concentrations of disinfection by-products if the rainwater were to be chlorinated. Also, the level of rainwater quality to some extent depends on proximity of the collection site to source of pollution. Rainwater collected or harvested in areas close to point source pollution are likely to be of low quality than rainwater far away from the point source.

Rainwater can be harnessed for both potable and non-potable use in most countries especially where rainfall is abundant in some parts of the year. Stored rainwater (harvested rainwater) supplements surface and underground sources of water in dry seasons or when there are shortages. Effective harnessing of rainwater in developing countries also ‘reduces the pressure on public water supply system which in most cases is not functional due to inadequate logistic and infrastructure’ (Aladenola & Adeboye, 2010). According to Thamer, Ghazali, & Mohd Noor, (2014) rainwater must be treated to remove pollutants for some potable uses such as drinking, cooking and bathing whereas non-potable uses do not require treatment of the rainwater and this include flushing toilets, watering garden and washing floor.

In Ghana, coverage for urban drinking water has increased consistently in recent years through the effort of government and other agencies. However, issues of quality of the water still remains a challenge. Reliability of most improved sources of water is sometimes low. Water supply is often intermitent which increases the risk of contamination (World Health Organisation, 2013). Access to potable water supply is a challenge, 50 percent of the populates uses unimproved sources of drinking water (Amponsah, Bakobie, Cobbina, & Duwiejuah, 2015). Drilling of boreholes in communities on higher grounds and those located on geological formations such as the Voltaian and Dahomayan has achieved little success (Siabi, Van-Ess, Engmann, Mensah, & Tagoe, 2015). Siabi, et al., (2015) report that, 56 percent of the total drilled boreholes in the eastern region of Ghana have the required yield and quality. The others are either dry or of low quality. Most people in these communities rely on rainwater stored in either small quantities or in large rainwater harvesting systems (RWHS) for domestic and commercial purposes. Atmospheric pollutants resulting from both natural and anthropogenic means ( heavy traffic, agricultural activities and minning) can pollute rainwater as it travels through the atmosphere, roof runoffs to the collection points. This study therefore analyses rainwater to examine its quality based on some physico-chemical, heavy metals and microbial parameters and also determine potential uses of it in other to improve public health.

### 1.2 Statement of the problem

Harnessing rainwater is ideal for augmenting water supply in hilly places where rainfall is abundant but ground water supply is insufficient (United Nations Human Settlements Programme, n.d.). Rainfall picks up contaminants that settle on roofs which affects its quality. These include faeces from birds and lizards, and falling parts of trees mainly around buildings. Also, research indicates that dust particles, other particulate matter and trace metals dissolve in rainwater as it falls from the sky and or come into contacts with roof materials. Pollutants emanate from industrial activities, dusty roads, heavy human and vehicular traffic and mining activities (Amponsah, et al., 2015; Bharti, Singh, & Tyagi, 2017; & Mendez, et al., 2010). It is therefore important to give priority to conducting periodic test on the quality of rainwater in other to ascertain the materials and minerals dissolved in the water, their levels of concentration and extent to which they are toxic for human and animal consumption (Opare, 2012). This will help determine the potability as well as make effective and efficient use of rainwater as a resource. The study was conducted in Sefwi Dwinase, Western North Region of Ghana. Most part of Sefwi Dwinase is undulating with hills bordered by steep and gentle slopes. This makes construction of boreholes, wells and other sources of water difficult and expensive, and residents are mostly seen queuing up to fetch water from boreholes and wells, a situation which is normally accompanied by misunderstandings and fights. Most people therefore rely on harvested rainwater. However, the town has a busy market and a wood processing company which has been operating for the past 78 years and producing air pollutants continue to threaten the quality of rainwater in the study area. This study investigated the quality of rainwater in the study area.

Water quality studies in Ghana are mostly concentrated on groundwater and surface water. Therefore, few studies exist on rainwater quality. Meanwhile, for Ghana to meet water services delivery of improving access to potable water services in achieving the national water coverage of 100% by 2025, there have been concerns to create sustained awareness campaigns to stimulate interest in and promote support for Rainwater Harvesting (RWH) as part of the national water policy. This is embedded in the National Rainwater Harvesting Strategy (NRWHS) prepared by the Ministry of Water Resources, Works and Housing in 2011 "to promote and strengthen RWH for water conservation and as augmentation measure for conventional potable networks in peri-urban and rural communities" (Ministry of Water Resources, Works and Housing, 2011). Periodic analysis of rainwater quality will help in identifying the efficient ways to put these harvesting systems to use. Educating the community on the quality of rain in their geographical region will help in acceptability of the rainwater harvesting systems. Siabi, et al., (2015), investigated the potential of rainwater harvesting as a source of quality water supply to hilly communities in the Eastern region of Ghana. They found out that, rainwater harvesting system is a reliable source of water when properly managed as against groundwater sources which is highly threatened by pollution from municipal and industrial waste. Kretchy, (2014) concluded from her study of chemical and isotopic composition of precipitation in Akatsi (coastal area), Kpando (forest area) and Amedzofe (mountainous area) that, relief and the ocean affect rainwater quality. Cobbina, et al., (2013) and Amponsah, et al., (2015) studied the physico-chemical quality of direct (open space/environment) rainwater in Tamale metropolis and Ayanfuri a mining community in Ghana respectively. This study therefore focused on the impact of different roofing materials on the physico-chemical, trace metals and microbial quality of rainwater. The study was however restricted to a one-time season because the focus was on how roofing materials affect rainwater quality

## 1.3 Purpose of the study

The main purpose of the study was to create awareness, educate and inform individuals of the quality of rainwater over rooftop in Sefwi Dwinase so as to promote rainwater harvesting and improve public health.

## 1.4 Objectives of the study

The main objective of the study was to investigate the effects roof materials have on the quality of rainwater in the study area. The following specific objectives guided the study.

i. To analyse microbial, heavy metals and physico-chemical parameters of rainwater in Sefwi Dwinase.

ii. To compare the quality of rainwater from different roof materials and open environment.

iii. To examine potential usage of rainwater in Sefwi Dwinase.

## 1.5 Research questions

Based on the objectives, the study will seek to answer the the following research questions

i. What proportion of microbial, heavy metals and physico-chemical parameters are present in rainwater in Sefwi Dwinase?

ii. What is the difference in rainwater quality from different roof materials and open environment?

iii. What uses can rainwater in Sefwi Dwinase be put to?

## 1.6 Research hypothesis

$H_0$: There is no significant difference between rainwater quality from roof material and that from open space.

$H_1$: There is a significant difference between rainwater quality from roof material and that from open space.

## 1.7 Significance of the study

Most ground and surface water supply for drinking are extracted from the ground without proper chemical and biological treatment. The level of pollution for these sources have become a major concern as domestic, industrial and agricultural waste continue to leach and percolate into them through run-offs especially in the rainy seasons. Rainwater harvesting, one of the oldest means of providing water for human use is now recognised as an alternative to the other sources of drinking water supply. However, patronage of this reliable means of water supply is challenged by high level of air pollution and roofing materials. The roof from which rainwater is harvested can be a source of contamination through leaching of materials (Issaka, 2011). A study into the quality of rainwater focusing on microbial, physico-chemical and trace metal components is very crucial.

The result of this study will help residents know a better efficient use for rainwater. This study further investigated the extent to which roofing type affects the quality of rain run off. This will help residents who make use of rainwater determine the type of roof suitable for collecting rainwater for a particular purpose. The analyses of the differences in the quality of rainwater at different locations within the town, is very useful information for future rainwater harvesting project for especially commercial and industrial use. This study can also serve as a basis of estimating outdoor air pollution in Sefwi Dwinase by government and non-governmental sanitation and other agencies.

## 1.8 Scope of the study

The study was conducted in Sefwi Dwinase, a town in the Sefwi Wiawso municipality in the western north region of Ghana. Analysing the quality of rainwater in every part of Sefwi Dwinase was not time and cost effective because of its large land area, hence, it was restricted to some part of the town. Assessing the quality of rainwater using very large microbiological, physico-chemical and heavy metal parameters was not feasible and cost effective. Hence the study was limited to some parameters which were: Total coliform (bacteria), Total hardness, Power of hydrogen (pH), Total dissolved solids (TDS), Dissolved organic carbon (DOC), Electrical conductivity (EC), Calcium (Ca), Magnesium (Mg), Lead (Pb) and Iron (Fe). Additionally, different suburbs have distinct roofing materials depending on some factors such as income level of residents. Therefore, all roofing materials at one suburb might not be necessarily present in all the other areas. In view of this, rainwater was collected over three most common roofing materials in the study area.

# CHAPTER TWO

## REVIEW OF RELATED LITERATURE

### 2.0 Introduction

This section was aimed at putting the study in scholarly context by reviewing relevant related literature. The review is based on themes to reflect the objectives of the study. Major contaminants in rainwater were reviewed as well as physico-chemical properties of rainwater, heavy metals and bacteria in rainwater. The effects of roofing materials on rainwater quality and the implications of the quality of rainwater on its uses were also considered.

### 2.1 Theoretical perspective

The quality or value of a phenomenon usually depends on a set of attributes or components, their features and how they interact with each other. One theory that explains the value (quality) of a phenomenon is the hedonic price theory. The model associated with the theory (hedonic price model) is used to estimate the value of an economic good using the values of the good's attributes. This theory is especially used in the housing market. According to Rosen (1974) as cited in Owusu-Ansah, (2011), hedonic prices are the implicit prices of attributes that are revealed to economic agents from observed prices of differentiated products and the specific amounts of characteristics associated with them. This definition suggests that housing as a heterogeneous good could be viewed as a package of inherent characteristics relevant to location, housing structure and neighbourhood or environmental amenities.

The basic idea of the hedonic price theory is that the price of a marketed good is related to its characteristics, or the services it provides, rather than the good itself. For example, the price of a house reflects the characteristics of the house — land size, age, number of bedrooms, bathrooms etc. Therefore, the value of the individual characteristics of a house or other good can be estimated by looking at how the price people are willing to pay for it changes when the characteristics change. The hedonic price method (HPM) is most often used to value environmental services that affect the price of residential properties. It can be used to assess economic benefits or costs linked with: Environmental quality, including air pollution, water pollution, or noise Environmental amenities, such as aesthetic views or proximity to recreational sites Air, water, and noise pollution have a direct influence on property values. House value is a function of all of the elements relating to the house. Using HPM, data are analysed, which relates to the value of the property to its characteristics and the environmental characteristic of interest. Thus, the effects of different characteristics on value can be estimated. The regression results indicate how much property values will alter for a small variation in each characteristic, holding all other characteristics constant (Kanojia, Magar, & Jadhav, 2016).

A hedonic regression curve shows the relationship between a dependent variable (house price in this case) and an independent or explanatory variable (a housing characteristic like the number of bedrooms) (Owusu-Ansah, 2011). Gundimeda, (n.d) and Kanojia, Magar, & Jadhav, (2016) identified some parameters that constitute each characteristic of the housing unit which affect price. They are: structural, environmental and locational characteristics. These characteristics have several components, and each of these components affect the overall house value or price.

Structural characteristics refers to built up area, including number and size of rooms, availability of lift, parking, security arrangement, building age. In general, household facilities have positive relationship with house price and play major role in determining house prices. Structural attributes like kitchen, toilet and bath are the highest attributes that explains house value or price (Aluko, 2011). The higher the household facilities in a house, the higher its price.

Environmental characteristics includes noise pollution, air quality, traffic congestion, green area/space, water quantity and quality. Some studies have used the hedonic model in the housing sector for making inferences about non-observable values of different attributes like air quality and airport noise level to estimate households demand for the various housing characteristics and to construct housing price indices (Owusu-Ansah, 2011).

Locational characteristics such as distance to work and shopping centres, availability of public transport, distance to amenity, main road, school, and slum affect the price of a house. Economies of scale improve the productivity of industry located in the Central Business District (CBD) and proximity becomes attractive, and the demand for land and real estate increase, leading to an upward pressure on real estate prices in the CBD. This leads to a negative relationship between house value and distance to city center and other essential services. That is the closer the house is to the CBD, the higher its price (Karlsson, 2007; Kanojia, Magar, & Jadhav, 2016). However, in some areas/regions, distance to city center is not significant in determining house price. This is deviation from the hedonic theory has been explained that, some cities especially

African cities have many sub-centers and are originally polycentric in nature hence householders or residents can access amenities in these sub-centers (Igwe & Mbee, 2015). Consumers in these areas may not be willing to pay higher price for houses close to the Central Business District (CBD).

According to Gundimeda (n.d), the hedonic price function shown below assumes that the price of housing is a function of its attributes.

$P = f\,(s1.\ s2.\ s3.\ \ldots\ sj;\ n1,\ n2.\ n3\ldots\ nj;\ e1,\ e2,\ e3\ldots\ ej)$

where s1, s2, s3 are the structural variables of the house;

n1, n2, n3 are the neighbourhood variables and

e1, e2, e3 are environmental variables.

Therefore, the price (quality) of a house is usually described by the characteristics of its **structure (s)**, **neighbourhood (n)** and **environment (e)**

$$\Rightarrow \quad P = f(\vec{s}, \vec{n}, \vec{e})$$

The functional form can be linear or non-linear. Using regression analysis, it is possible to estimate the relationship between the level of any one housing characteristic and the price of the property. Differentiating the hedonic price function with respect to any one of the characteristics yields the implicit price function for that characteristic (Gundimeda, n.d).

Adopting the principle behind the hedonic method, DeBusk & Hunt, (2012) identified three attributes or factors that affect the water quality of rooftop runoff. These are: Wet deposition (i.e. the precipitation), Dry deposition (i.e. atmospheric deposition that has accumulated on the roof surface) and Roof materials (i.e. materials used in the construction of the roof). This could be illustrated by the function below.

$$\mathrm{P} = f(\vec{w}, \vec{d}, \vec{r})$$

Where P is rainwater quality, w = wet deposition, d = dry deposition and r = roof material.

Wet deposition reflects the quality of rainwater prior to its contact with a surface. Wet deposition varies substantially by location, because the chemical composition of rainwater is influenced by a multitude of factors, such as geographic location and influences, prevailing meteorological conditions and anthropogenic activities (agriculture, industry, motor vehicle emissions, etc.) (DeBusk & Hunt, 2012). Anthropogenic activities such as fossil fuel combustion through motor vehicle emissions, combustion in building heating systems and industrial processes (Cobbina, Michael, Salifu, & Duwiejua, 2013) lead to the concentration of pollutants such as suspended particulates (dust, ash), aerosols and gases in the atmosphere. Consequently, rainwater scavenges these pollutants which affects its quality, significantly the pH of rainwater (acid rain is the most well-known phenomenon that can be attributed to wet deposition) (DeBusk & Hunt, 2012). When rainwater absorbs sulfur and nitrogen oxides from the atmosphere, the pH decreases and the rain becomes acidic (Cerqueira, et al., 2014)

Dry deposition, is regarded as a process by which particulates in the atmosphere that are generated via automobile emissions, industrial processes and fertilizer applications settle out and accumulate on surfaces (DeBusk & Hunt, 2012). The surfaces include roofs, lands, plants and surface water bodies. Rainwater picks up these pollutants on the surfaces which they fall (Opare, 2012). Constituents that have been linked to atmospheric deposition include Total suspended solids (TSS), Lead (Pb) (due to heavy traffic or industrial emissions), Chloride (Cl), Copper (Cu), nitrates, nitrites, Zinc (Zn), Aluminium (Al), Iron (Fe), Calcium (Ca) and pathogenic contaminants such as E coli, Total and Faecal coliform (DeBusk & Hunt, 2012; Abulude, Ndamitso, & Abdulkadir, 2018). As rain falls onto a roof surface, it washes off the particulates that have accumulated on the surface since the prior precipitation event, thus adding these constituents to the roof runoff. A longer antecedent dry period results in a greater amount of accumulated deposition and, thus, a higher concentration of pollutants in runoff during the next rainfall (DeBusk & Hunt, 2012).

Atmospheric sources play important roles in dry and wet depositions (Abulude, Ndamitso, & Abdulkadir, 2018).

Roof materials often leach traces of metals in harvested rainwater. All roofing types cannot be used to collect rainwater for drinking because of the coatings and the materials with which they are made of (Apraku & Adu-Kumi, 2014). Galvanized metal roofing has been found to be a source of cadmium and zinc while asphalt produces higher level of lead in rainwater (Van Metre & Mahler, 2003). In a study conducted by Olaoye & Olaniyan, (2012) on the quality of rainwater from different roofing materials, aluminium, asbestos, concrete and corrugated plastic roofs were found to contain diffferent levels of physico-chemical and bacterial concentrations. However, aluminium roof was found to be completely free from bacterial contamination while the others were not. Therefore, roof materials play a role in the quality of harvested rainwater.

Rainwater is mostly collected to serve outdoor and non-potable purposes such as gardening, flushing toilet, washing clothes, car and floor. However, according to Thamer, Ghazali, & Mohd Noor (2014), when rainwater is treated to remove pollutants, it can be used for some potable uses such as drinking, cooking and bathing.

## 2.2 Water quality

Water quality is a term generally used to denote the suitability of water to sustain various uses or processes. That is, the characteristics of a particular source of water or sample, determines what it will be used for. Any particular use will have certain requirements for the physical, chemical or biological characteristics of water. Consequently, water quality can be defined by a range of variables which limit water use. Although many uses have some common requirements for certain variables, each use will have its own demands and influences on water quality (Meybeck, Kuusisto, Mäkelä, & Mälkki, 1996).

Dissolved materials and many particulates are discharged directly to water bodies, while the particulate and volatile materials that pollute the atmosphere are picked up by rain and then deposited on land or in water (DeBusk & Hunt, 2012). Specific locations where pollution resulting from human populations and human activities occurs, such as discharges from sewage treatment works, industrial wastewater outlets, solid waste disposal sites, animal feedlots and quarries, can be described as point sources. The effect of a point source on the receiving water body is dependent on: the population, or size and type of activity, discharging the waste, the capacity of the water body to dilute the discharge, the ecological sensitivity of the receiving water body, and the uses to which the water may be put. Pollutants may also be derived from diffuse and multipoint sources. Diffuse sources are often of agricultural origin and enter surface waters with run-off or infiltrate into groundwaters (particularly pesticides and fertilisers) (Meybeck, Kuusisto, Mäkelä, & Mälkki, 1996).

Water quality depends on the composition of dissolved or suspended constituents of water. Natural processes and human activities that affect water determines the composition of water and its quality. Chemical composition of water is the commonest factor known to affect the quality of water. Agricultural activities (usually from the application of pesticides and weedicides) and other human activities such as mining releases chemical contaminants onto the ground and water bodies. These chemicals are later leached into underground aquifers and surface water bodies to contaminate these waters. All these factors can pose a serious health threat to consumers. However, especially (micro) biological factors are of main importance when considering water quality. There are also physical factors that affect water quality (RAIN, 2008). These include industrial and agricultural activities which decrease air quality.

Drinking-water should be suitable for human consumption and for all domestic purposes. That is, it must meet a national or the World Health Organization (WHO) drinking-water quality guideline (WHO, 2006). Water that is to be directly consumed by humans and animals, is expected to be of high quality because of the health implications involved. A reliable, safe water supply plays an important role in disease prevention, especially by facilitating personal, domestic, and food hygiene. These diseases may include; Diseases transmitted by the faecal–oral route (the diseases transmitted by consumption of faecally contaminated water are called “faecal-oral” diseases such as hepatitis A, bacillary dysentery, and many diarrheal diseases and also infections of the skin and eyes, such as trachoma, skin infections, and fungal skin diseases. Provision of water for domestic purposes in adequate quantities and quality will contribute to reducing the incidence of diseases transmitted by the faecal– oral route and other transmissible diseases (World Health Organisation, 2013).

## 2.3 Rainwater quality

Rainwater is regarded as the purest natural source of water but the presence of contaminants in the atmosphere has rendered untreated rainwater unsafe for human consumption (Ebong, Etuk, Ekong, & Dan, 2016). Rainwater is an important means of scavenging pollutants from the atmosphere and its composition actually reflects the composition of the atmosphere through which it falls (Cerqueira, et al., 2014). Rainwater picks up minute airborne dust and other particulate matter and dissolves various oxides which affect its quality. Possible atmospheric contaminants that could harmfully affect the quality of rainwater are dust particles emanating from nearby road and building construction activities, particulate matter carried by winds, dust generated as a result of vehicular movements on untarred roads covered with laterite soils and emissions from industrial activities in urban center (WHO, 2011; Opare, 2012). According to Opare (2012), rainwater picks up various other contaminating materials that settle on the roofs which affect its quality. They include faeces of birds and lizards, falling plant parts especially from trees located near homes, atmospheric dust and other materials blown by winds that settle on roofs.

Rainwater is slightly acidic and very low in dissolved minerals; as such, it is relatively aggressive. Rainwater can dissolve heavy metals and other impurities from materials of the catchment and storage tank. In most cases, chemical concentrations in rainwater are within acceptable limits; however, elevated levels of zinc and lead have sometimes been reported. This could be from leaching from metallic roofs and storage tanks or from atmospheric pollution (WHO, 2011).

Rainwater quality differs or varies from one geographical place to the other because of different atmospheric conditions (pollution) permeating in different regions. In modern and recent times, there has been increasing and consistent emission of harmful chemicals and materials that pollute the atmosphere due to urbanization and industrialization. These particulate and volatile materials that pollute the atmosphere are picked up by rain which are then deposited on land and or in water. Hence, rainwater is mostly found to contain pollutants such as suspended particulates (dust, ash), aerosols and gases. These pollutants significantly affect the physiochemical characteristics of rainwater especially the pH (acid rain) which compromise the quality of rainwater regarded as the 'purest natural source of water' (DeBusk & Hunt, 2012). The quality of rainwater has been a concern to many in the world since it reflects the composition of the atmosphere from which it falls, and serves as a means of cleansing the atmosphere (Ebong, et al., 2016). The quality of rainwater to  some extent is affected by particulate deposited on surfaces especially roof surfaces from which raindrops are washed and the roof materials (DeBusk & Hunt, 2012).

Rainwater lacks minerals, but some minerals, such as calcium, magnesium, iron and fluoride, in appropriate concentrations are considered very essential for health. Although most essential nutrients are derived from food, the lack of minerals, including calcium and magnesium, in rainwater may represent a concern for those on a mineral-deficient diet. The absence of minerals also means that rainwater has a particular taste or lack of taste that may not acceptable to people used to drinking other mineral-rich natural waters (WHO, 2011).

## 2.4 Major water contaminants

Rainwater contains chemical contaminants in Domestic rainwater harvesting tanks can originate from: raindrops that traverse through polluted air, catchment areas, and storage tanks (Kwaadsteniet, Dobrowsky, Deventer, Khan, & Cloete, 2013).

### *2.4.1 Microbial contaminants*

The most common contaminants in water sources obtained from roof or surface catchments is microbial (biological and microbiological) contamination, especially enteric pathogens. Squirrels, birds, possums, and rats may deposit fecal matter on the roof surface, which implies that undesired bacteria, viruses, and protozoan pathogens can filter into the rainwater tank. Pathogens that occur in the faeces of birds, insects, mammals, and reptiles can contaminate the water collected from rooftops. The rain then allows pathogens associated with animal droppings and other organic debris to be flushed into the tanks via the gutters and inlet tank system (Kwaadsteniet, Dobrowsky, Deventer, Khan, & Cloete, 2013). According to RAIN (2008), Enteric pathogens are "micro-organisms (bacteria, viruses, and protozoa) that cause gastrointestinal illness". Faecal materials from humans, animals, dead animals introduce these microbial contaminants into drinking water supplies. The most important indicator of faecal contamination in water is E-Coli (RAIN, 2008). "Species of protozoa known to have been transmitted by the ingestion of contaminated drinking-water include *Entamoeba histolytica* (which causes amoebiasis), *Giardia* spp., and *Cryptosporidium*" (WHO, 2006). A single mature larva or fertilized egg can cause infection, and such infective stages should be absent from drinking-water.

### *2.4.2 Chemical contaminants*

Chemical contamination results from air pollution, runoff and leaching of chemical substances and toxic material use. Industrial activities and heavy traffic often result in the emission of chemical pollutants into the atmosphere which affect the chemical constituent of especially rainwater (RAIN, 2008). Rainwater that traverses through the air in areas with high industrial or agricultural activities can result in the water being contaminated with concentrations of chemicals above the respective countries' and the WHO's drinking water standards. The health concerns associated with chemical constituents of drinking-water differ from those associated with microbial contamination and arise primarily from the ability of chemical constituents to cause adverse health effects after prolonged periods of exposure (WHO, 2006).

According to WHO (2011) in rural areas of developing countries, a significant number of very serious health-related water-quality problems may occur as a result of the chemical contamination of water resources (usually pesticides and fertilizers) though the great majority of health-related water-quality problems result from bacteriological or other biological contamination. The occurrence of methaemoglobinaemia in some areas is usually related to nitrate which has been derived from extensive use of nitrate fertilizers (Meybeck, Kuusisto, Mäkelä, & Mälkki, 1996).

### *2.4.3 Physical contaminants*

Physical contamination includes inorganic and organic sediments like sand, silt, clay, or plant material. Odour in water is due mainly to the presence of organic substances. Some odours are indicative of increased biological activity, while others may originate from industrial pollution. According to RAIN (2008), "physical contamination affects the colour, odour or taste of the water, but it poses no direct health risk". However, consumers may find physically contaminated water (bad colour, odour and taste) less attractive. For instance, turbidity in excess of 5 NTU (5 JTU) may be noticeable and consequently objectionable to consumers. Consumers may turn to more pleasant alternatives, but perhaps unsafe or less wholesome sources, when their water displays aesthetically displeasing levels.

Although guidelines for drinking-water quality are based on the best available public health advice, there is no guarantee that consumers will be satisfied or dissatisfied by water supplies that meet or fail to meet those guidelines based on the physical or aesthetic quality of the water. Hence water should be free of taste, colour and odour that would be objectionable to the majority of consumers (WHO, 2006).

## 2.5 Water quality parameters

Rainwater is tested to ensure its quality for drinking. However, water contains many elements and any one of them can be a reason for its rejection for human consumption. This section explains these water quality parameters: pH, Total dissolved solids, Electrical conductivity, Dissolved organic carbon, Total hardness, Calcium, Magnesium, Iron, Lead and Total coliform.

### *2.5.1 Power of hydrogen (pH)*

The pH of water is the effective concentration of hydrogen ions (H+) in solution. The balance hydrogen ions (H+) and hydroxide ions (OH-) in water determines the acidicity or basicity of water. The pH value generally assumed as neutral or unpolluted rainwater is 5.6. It is the pH of unpolluted cloud water equilibrated with atmospheric $CO_2$ (Khan & Sarwar, 2014; Zhao, et al., 2013). Hence acid rain has a pH level of less than 5.6. Human activities, significantly industrial production of pollutants such as sulfur dioxide emissions from power plants are the main causes of acid rain (Issaka, 2011). The presence of natural $H_2SO4$, weak organic acids, or anthropogenic emission of $H_2SO4$ and/or HNO3 can result in a rainwater pH below 5.0. Rainwater samples with pH values above 6.0 may suggest certain inputs of alkaline species into the precipitation in the study area (Wang & Han, 2011).

pH values govern the activity of many other important parameters of water quality. This makes pH one of the most important operational water quality parameters even though it does not directly affect human health (WHO, 2011). For example, NH3 toxicity, chlorine disinfection efficiency, and metal solubility are all influenced by pH. Rainwater pH is an important parameter in predicting the nature of anthropogenic activities on atmospheric pollution. At the extreme, pH value may affect the taste and quality of rainwater (Abulude, Ndamitso, & Abdulkadir, 2018).

The WHO recommends that, the optimum pH required is in the range of 6.5 – 9.5. A pH of 6.5 - 8.5 is the ideal range with the maximum environmental and aesthetic benefits (WHO, 2006).

### *2.5.2 Total dissolved solids*

Total dissolved solids is the sum of the silica plus the major ions (inorganic salts) in the water as well as a small amount of organic matter. Common inorganic salts that can be found in water include calcium, magnesium, potassium, sodium, carbonates, nitrates, bicarbonates, chlorides and sulfates (Safe Drinking Water Foundation, 2017). A close approximation of its value may be obtained by the measurement of electrical conductivity (Issaka, 2011). The amount of total dissolved solids in rainwater indicates the concentrations of minerals and soluble substances in the atmosphere (Apraku & Adu-Kumi, 2014). Total Dissolved Solids (TDS) may vary based on the presence of solid particles in the weather of that particular location, topography, climate and pollution levels.

Alone, a high concentration of dissolved solids is usually not a health hazard (WHO 2003). Safe Drinking Water Foundation, (2017) reports that, many people buy mineral water, which has naturally elevated levels of dissolved solids, however, while TDS itself may be only an aesthetic and technical factor, a high concentration of TDS is an indicator that harmful contaminants, such as iron, manganese, sulfate, bromide and arsenic, can also be present in the water

WHO, (2011) reports that the palatability of water with a total dissolved solids (TDS) level of less than about 600 mg/l is generally considered to be good; drinking-water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 mg/l. The presence of high levels of TDS produce hardness and may be objectionable to consumers, owing to excessive scaling in water pipes, heaters, boilers and household appliances. However, a very low concentration of TDS has been found to give water a flat and insipid taste, which is undesirable to many people (WHO, 2003).

### *2.5.3 Dissolved organic carbon (DOC)*

Dissolved organic carbon (DOC) is a general description of the organic material dissolved in water. Organic carbon occurs as the result of decomposition of plant or animal material. Organic carbon present in soil or water bodies may then dissolve when contacted by water. This dissolved organic carbon moves with both surface water and ground water (Government of Saskatchewan, 2009).

DOC is a biological important variable to human. Organic material (including carbon) results from decomposition of plants or animals. Organic carbon (OC) is emitted to the atmosphere as primary pollutants by the combustion of fuels and human activities. OC is also formed as a secondary pollutant from precursors emitted by both natural and anthropogenic processes (Torres, Bond, Lehmann, Subramanian, & Hadley, 2014). According to Iavorivska, Boyer, and Dewalle (2016), primary sources of OC are directly emitted into the atmosphere in the form of both gases and particles. They are further divided into biogenic (emitted by natural systems) and anthropogenic (emitted by human activities). Biogenic primary sources are related to emissions of volatile organic compounds from vegetation, wind-lifted biological particles (pollen, plant debris, soil, dust, bacteria, and viruses), forest fires, emissions from marine environments (degassing from ocean and bursting of ocean bubbles enriched in organic material from plankton activity), volcanoes, etc. Anthropogenic primary sources include: combustion and production of fossil and ethanol fuels (motor vehicle exhaust, electric generation units), biomass burning, domestic heating and cooking, tire and asphalt wear, solvent use, emissions from agriculture (such as pesticides), and natural gas exploration.

Carbon aerosols influence the global climate by changing the way that sunlight is scattered and absorbed. Organic aerosol reflects light and serve as seeds for the formation of clouds droplets (Torres, Bond, Lehmann, Subramanian, & Hadley, 2014). DOC concentrations in rain water are generally very low but increase as the water passes through the canopy and forest floor (Kolka, Weisbarnpel, & Froberg, 2008).

Carbon in the atmosphere affects air quality and climate. Atmospheric organic carbon oxidized to inorganic forms of carbon dioxide and carbon monoxide, or to be removed from the atmosphere and deposited to the landscape through deposition. Transfers of OC from the atmosphere to land occur as wet deposition (via precipitation) and as dry deposition (via surface settling of particles and gases) (Iavorivska, Boyer, & Dewalle, 2016).

The WHO gives no guideline value for Dissolve organic carbon concentration in water. However, according to Government of Saskatchewan (2009), DOC concentrations greater than 5 mg/L will complicate water treatment and may result in disinfection by-products, such as trihalomethanes, to be formed in amounts exceeding the standards. DOC will also increase colour in the finished water. Although there is no concentration limit for DOC, water treatment costs will dramatically increase as DOC increases. Source water with less than 2 mg/L of DOC tend to be easily treated for disinfection by-products and do not increase finished water colour.

DOC does not pose health risk itself but may become potentially harmful when in combination with other aspects of water. When water with high DOC is chlorinated, harmful byproducts called trihalomethanes may be produced. Trihalomethanes may have long-term effects on health and they should be considered when chlorinating drinking water which is high in DOC (Government of Saskatchewan, 2009). DOC can interfere with the effectiveness of disinfection processes such as chlorination, ultraviolet and ozone sterilization.

### *2.5.4 Electrical conductivity*

Solids can be found in nature in a dissolved form. Salts that dissolve in water break into positively and negatively charged ions. Conductivity is the ability of water to conduct an electrical current, and the dissolved ions are the conductors (Clean Water Team, 2004). It is a measure of the ability of water to pass current. Electrical conductivity is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulphate and phosphate anions (ions that carry negative charge) or sodium, magnesium, calcium, iron and aluminium cations, that is ions carrying positive charges. Higher amount of these inorganic solids present higher possibility of increasing the electrical conductivity of raindrops. Rainwater that is able to dissolve more inorganic solids have higher conductivity. Hence, EC can be looked as a good indicator for the total concentrations of soluble ions (Zhao, et al., 2013).

Conductivity is also affected by temperature: the warmer the water, the higher the conductivity (Issaka, 2011), and ocean spray: where sea spray salts and other minerals into the air, which is then dissolved by rainfall (Clean Water Team, 2004). An electrical conductivity of 300 μs/cm is the ideal for consumption according to the World Health

Organization (WHO, 2006). Electrical conductivity of rainwater reflects the impact of atmospheric particulate matter on the precipitation chemistry (Cobbina, Michael, Salifu, & Duwiejua, 2013).

### 2.5.5 Total hardness

Hardness is a natural characteristic of water which can enhance its palatability and consumer acceptability for drinking purposes. Total hardness of water refers to the total concentration of $Ca^{2+}$ and $Mg^{2+}$ ions in the water. Hard water is caused by dissolved calcium and magnesium as it passes through soil and rock formations. Other minerals, such as iron, may also contribute to water hardness. The equations below show the formation of these insoluble carbonates (Issaka, 2011).

$$Ca^{+2}_{(aq)} + 2HCO_3^- \xrightarrow{heat} CaCO_{3(s)} + H_2O_{(l)} + CO_{3(g)}$$

$$Mg^{+2}_{(aq)} + 2HCO_3^- \xrightarrow{heat} MgCO_{3(s)} + H_2O_{(l)} + CO_{3(g)}$$

(Issaka, 2011).

Hardness in water has a wide impact on households. Health studies in several countries in recent years indicate that mortality rates from heart diseases are lower in areas with hard water (Environmental Protection Agency, 2001). Depending on pH and alkalinity, hardness above about 200 mg/l can result in scale deposition, particularly on heating. Soft waters with a hardness of less than about 100 mg/l have a low buffering capacity and may be more corrosive to water pipes (WHO, 2006).

Water hardness can either be temporary or permanent. Temporary hardness of water refers to the amount of Ca2+ and Mg2+ ions that can be removed as insoluble carbonates by boiling the water. Hard water is caused by dissolved calcium and magnesium as it passes through soil and rock formations. Other minerals, such as iron, may also contribute to water hardness (Issaka, 2011). Originally taken to be the capacity of a water to destroy the lather of soap hardness was determined formerly by titration with soap solution. Nowadays, the analysis comprises the determination of calcium and magnesium which are the main constituents of hardness. Although barium, strontium and iron can also contribute to hardness, their concentrations are normally so low in this context that they can be ignored. Thus, total hardness is taken to comprise the calcium and magnesium concentrations expressed as mg/l CaCO3.

According to (WHO, 2006), no health-based guideline value is proposed for hardness. A guideline value of 500 mg/l based on consumer acceptability (WHO, 2011). However, the degree of hardness in water may affect its acceptability to the consumer in terms of taste and scale deposition. Public acceptability of the degree of hardness vary from one community to another, depending on local conditions. Depending on the interaction of other factors, such as pH and alkalinity, water with a hardness above approximately 200 mg/l may cause scale deposition in the treatment works, distribution system and pipework and tanks within buildings. It will also result in high soap consumption and subsequent "scum" formation. On heating, hard waters form deposits of calcium carbonate scale. Soft water, but not necessarily cation exchange softened water, with a hardness of less than 100 mg/l may, in contrast, have a low buffering capacity and so be more corrosive for water pipes (WHO, 2011).

Hard water has been noticed to affect laundry by requiring extra detergent use. Excessively hard water can cause cooking problems as it produces scale on pots usually above 500mg/l. Also, some vegetables cooked in hard water lose colour and flavor, beans and peas may become tough and shriveled when cooked in excessively hard water. Hard water may affect the performance of household appliances and increase cost of fuel (Issaka, 2011). Table 1 shows how the result of hardness in water can be interpreted.

**Table 1: WHO basis of hardness of water**

| Category of hardness (mg/l) | Grading / description |
|---|---|
| 0 to 50 | Soft |
| 51 to 100 | Moderate soft |
| 101 to 150 | Slightly hard |
| 151 to 200 | Moderate hard |
| 201 to 300 | Hard |
| 0ver 300 | Very hard |

**Source:** Adopted from Amponsah, Bakobie, Cobbina, & Duwiejuah, (2015)

### *2.5.6 Calcium*

Calcium is the most important and abundant element in the human body and an adequate intake is essential for normal growth and health (Environmental Protection Agency, 2001). It is very abundant and occurs in rocks, bones, shells etc. The maximum daily requirement is of the order of 1 - 2 grams and comes especially from dairy products. Calcium has a chemical symbol of ‘Ca’ and is measured in mg/l Ca. The common methods of analysis are Titration (Calcium Hardness) and Atomic Absorption Spectrometry (AAS).

High levels of calcium may be beneficial and waters which are rich in calcium (and hence are very hard) are very palatable. Also, incidence of heart disease is reduced in areas served by a public water supply with a high degree of hardness, the primary constituent of which is calcium, hence the presence of the element in a water supply is beneficial to health (Environmental Protection Agency, 2001). However, despite the potential health benefits of calcium abundance, there are problems associated with hardness.

WHO recommends a guideline value of 200 mg/l and a desirable limit of 75mg/l. The desirable level is more appealing to consumers with respect to taste and aesthetic value (Khan & Sarwar, 2014). Water low in calcium and magnesium, is associated with increased morbidity and mortality from cardiovascular diseases (CVDs) compared to water high in magnesium and calcium (WHO, 2006).

### *2.5 7 Magnesium*

Magnesium is mostly tested at the laboratory using titration or Atomic Absorption Spectrometry. Soil and roadside dust are the main anthropogenic sources of Ca and Mg, (Khan & Sarwar, 2014). Like calcium, magnesium is abundant and a major dietary requirement for humans (0.3-0.5 g/day). It is the second major constituent of hardness and it generally comprises 15-20 per cent of the total hardness expressed as CaCO3. Magnesium sulphate is used medicinally as "Epsom Salts," a laxative (Environmental Protection Agency, 2001).

The WHO recommends a permissible limit of 150 mg/l (Cobbina, Michael, Salifu, & Duwiejua, 2013). According to Khan & Sarwar, (2014) a limit of 30 mg/l is desirable and acceptable to consumers with regards to taste and asthetic value (Khan & Sarwar, 2014).

### *2.5.8 Heavy metals*

Exposure to heavy metals has been linked with developmental retardation, various cancers, kidney damage, and even death in some instances of exposure to very high concentrations. Exposure to high levels lead has also been associated with the development of autoimmunity, in which the immune system starts to attack its own cells, mistaking them for foreign invaders (Brooks, Bahadory, Tovia, & Rostami, 2010).

### *2.5.9 Iron*

Chemical symbol is Fe and unit of measurement/result is mg/l Fe, Colorimetric (o-PhenanthroIine) and Atomic Absorption Spectrometry are the common method of analysis. Iron is one of the most abundant metals in the Earth's crust (WHO,2006). 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 (Issaka, 2011). It is found in natural fresh waters at levels ranging from 0.5 to 50 mg/litre. Iron may also be present in drinking-water as a result of the use of iron coagulants or the corrosion of steel and cast-iron pipes during water distribution.

Iron is an essential element in human nutrition. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability and range from about 10 to 50mg/day (WHO, 2006). However, as a precaution against storage in the body of excessive iron, in 1983 Joint FAO/WHO Expert Committee on Food Additives (JECFA) established a Provisional Maximum Tolerable Daily Intake (PMTDI) of 0.8 mg/kg of body weight, which applies to iron from all sources except for iron oxides used as colouring agents and iron supplements taken during pregnancy and lactation or for specific clinical requirements. An allocation of 10% of this PMTDI to drinking-water gives a value of about 2 mg/l, which does not present a hazard to health (WHO, 2006). The taste and appearance of drinking-water will usually be affected below this level.

No health-based guideline value for iron in drinking-water is proposed in the WHO Guidelines, but it was mentioned that a value of about 2mg/l can be derived from the PMTDI established in 1983 by JECFA as a precaution against storage in the body of excessive iron. Iron stains laundry and plumbing fixtures at levels above 0.3 mg/l. There is usually no noticeable taste at iron concentrations below 0.3 mg/l (WHO, 2006). Laundry becomes stained if washed in water with excessive iron, and vegetables likewise become discoloured on cooking. When waters rich in iron are used to make tea (in which tannins are present) there may be a reaction giving rise to off-colours which may in severe cases resemble that of ink. Problems have been reported also with the addition of such waters to whiskey (Environmental Protection Agency, 2001).

### *2.5.10 Lead*

Chemical symbol for lead is Pb and it is measured in mg/l Pb. Normal method of analysis is the Atomic Absorption Spectrometry (AAS). Lead naturally occurs from the leaching from ores and effluent discharges. However, most Lead concentrations in the air are usually as a result of human activities such as production and use of lead-acid batteries, lead containing additives in petrol, solder and alloys. The application of lead in gasoline, has led to an unnatural lead cycle. In automobile engines, lead is burned, so that lead salts (chlorides, bromides, oxides) originate. These lead salts enter the environment through exhausts of automobiles. The larger particles will drop to the ground immediately and pollute soils or surface waters, the smaller particles will travel long distances through air and remain in the atmosphere. Part of this lead will fall back on earth when it is raining (Sharma & Rai, 2018). WHO, (2006) posit that, lead may be present in tap water primarily from household plumbing systems containing lead in pipes, solder, fittings or the service connections to homes depending on the pH, temperature, water hardness and standing time of the water.

Lead is one of the most commonly determined heavy metals. This is because it is a metal (poison) which accumulates in body tissue and it is especially dangerous for infants and children (Environmental Protection Agency, 2001). Lead also interferes with calcium metabolism, both directly and by interfering with vitamin D metabolism. Lead is toxic to both the central and peripheral nervous systems. It can also cause several unwanted effects, such as disruption of the biosynthesis of haemoglobin and anaemia, a rise in blood pressure, kidney damage, miscarriages and subtle abortions, declined fertility of men through sperm damage, diminished learning abilities of children and behavioural disruptions of children, such as aggression, impulsive behavior and hyperactivity (WHO, 2006; Sharma & Rai, 2018).

The WHO recommends a guideline value 0.01 mg/l for lead in drinking water (WHO, 2006). Because lead is a cumulative poison in the human body, strict limits on its presence in raw and finished drinking waters must be imposed.

### *2.5.11 Total coliforms*

Total coliforms are a large group of bacteria with several similar characteristics. They indicate the presence of other bacteria in water and are more or less related to faecal contaminants. The total coliforms represent the whole group, and it is bacteria that multiply at 37°C (Vilane & Simiso, 2017). Total coliforms include organisms that can survive and grow in water and species that may inhabit the intestines of warm-blooded animals or occur naturally in soil, vegetation, and water. Coliform is able to ferment lactose at 35–37°C with the production of acid, gas, and aldehyde within 24 - 48 hours. They are also oxidase-negative and non-spore-forming and display β-galactosidase activity (WHO, 2011; WHO, 2006). They are usually found in faecally-polluted water and are often associated with disease outbreaks. Although they are not usually pathogenic themselves, their presence in drinking water indicates the possible presence of pathogens (U.S. EPA, 2002).

Coliform organisms have long been recognized as a suitable and universal microbial indicator of drinking-water quality, largely because they are; easy to detect and enumerate in water, of the same origin as the pathogens (i.e. from the human or animal intestine), present in far greater numbers than the pathogens, and present whenever the pathogens are likely to be present (Environmental Protection Agency, 2001). Environmental Protection Agency, (2001) adds that, they show the same or better survival characteristics than the pathogens and, they must not be in themselves pathogenic.

Total coliforms are generally measured in 100ml samples of water. A variety of relatively simple procedures are available based on the production of acid from lactose or the production of the enzyme b-galactosidase (WHO, 2006). Two distinct analytical procedures are used to test for total coliform; that is the Multiple Tube Technique and the Membrane Filtration technique (Environmental Protection Agency, 2001).

The reasoning behind the use of the coliforms as indicators is to give a very high margin of safety which actually depends on the ratio of coliforms to pathogens, in practice this is never quantified. However, experience has shown this approach to be satisfactory (Environmental Protection Agency, 2001).

Coliform bacteria should not be detectable in treated water supplies and, if found, suggest inadequate treatment, post treatment contamination, or excessive nutrients. The coliform test can therefore be used as an indicator both of treatment efficiency and of the integrity of the rainwater distribution system. Although coliform organisms may not always be directly related to the presence of faecal contamination or pathogens in drinking-water, the coliform test is still useful for monitoring the microbial quality of treated piped water supplies (WHO, 2011). The presence of total coliforms in distribution systems and stored water supplies can reveal regrowth and possible biofilm formation or contamination through ingress of foreign material, including soil or plants (WHO, 2006).

### 2.6 Rainwater over rooftops

At the roof catchment level, wind-blown dirt, leaves, faecal droppings from birds and animals, insects and contaminated litter can be accumulated on roof materials and these can be sources of contamination of rainwater, leading to health risks from the consumption of contaminated water.

Rainwater is slightly acidic and very low in dissolved minerals; as such, it is relatively aggressive and can dissolve heavy metals and other impurities from materials of the catchment. In most cases, chemical concentrations in rainwater are within acceptable limits; however, elevated levels of zinc and lead have sometimes been reported. This could be from leaching from metallic roofs and  from atmospheric pollution (WHO, 2011).

The quality of roof catchment rainwater depends on the type of roof material (Olaoye & Olaniyan, 2012), and this makes roofing material an important consideration when designing a rainwater catchment (Mendez, et al., 2011). Roof materials and coating may cause adverse taste or odour in harvested rainwater, and more importantly some metals can dissolve or be leached to give high concentrations in water (WHO,2011). Different roofing materials yield varying values of rainwater parameter concentrations. For instance, Van Metre & Mahler, (2003) in their studies on the contribution of particles washed from rooftops to contaminant loading to urban streams focusing on galvanized metal roofs and Asphalt shingle roofs in Austin, Texas, noticed that metal roofs yielded significant particle-bound zinc, cadmium, and nickel. On the other hand, asphalt shingle roofing was found to be a source of lead and possibly mercury.

Also, a research by Mendez, et al., (2011) concluded that, Metal roofs are commonly recommended for rainwater harvesting applications, because they tend to have lower concentrations of fecal indicator bacteria as compared to other roofing materials. However, concrete tile and cool roofs produced harvested rainwater quality similar to that from the metal roofs, indicating that these roofing materials also are suitable for rainwater harvesting applications. Although the shingle and green roofs produced water quality comparable in many respects to that from the other roofing materials, their dissolved organic carbon concentrations were very high, which might lead to high concentrations of disinfection by-products after chlorination. They further indicated that, the concentrations of some heavy metals in rainwater harvested from the green roof suggest that the quality of commercial growing media should be carefully examined if the harvested rainwater is being considered for domestic use.

Moreover, Olaoye and Olaniyan, (2012) acknowledged aluminium roofing sheet to be most suitable for rainwater harvesting. While coliform as bacterial indicator was present in samples from asbestos, concrete and corrugated plastic roofs, aluminium roof was free from pathogenic contamination. In their study all the physical and most of the chemical parameters analyzed conformed to the recommended standard value apart from chloride and total hardness. However, to ensure that the rainwater harvested satisfies health requirement for consumption, they recommended that, all the harvested rainwater should be given some level of treatment.

Further, Poor hygiene in water storage and abstraction from storage containers or at the point of use are some of the factors that can cause poor rainwater quality and can also represent a health concern. But risks can be minimized by good design and maintaining good practice. For instance, Faecal contamination in rainwater samples can be minimized by good practice (WHO, 2011).

However, rainwater harvested over roofing materials may contain less acid than rain collected directly from the sky. Apraku and Adu-Kumi, (2014) noticed pH values in direct or open space rainfall to be less than roof catchment as well as storage tanks. They attributed the more acidic pH experienced from the direct fall to be the interaction between the rainwater and lower levels of effluents from industrial activities and vehicular emissions in the atmosphere. The lowest pH values suggest that alkaline particles in the atmosphere were not high enough to neutralize acidic species available in the water (Abulude, Ndamitso, & Abdulkadir, 2018).

### 2.7 Efficient uses of rainwater

Water quality and its potential impact on human health is a consideration when using rooftop rainwater capture. While rooftop runoff may contain pollutants, these pollutants are generally found in significantly lower concentrations and without many of the toxic contaminants that may be picked up by the rooftop runoff after it mobilizes off-site and flows over other impervious surfaces such as streets and parking lots (Garrison, Kloss, & Lukes, 2011). Anthropogenic activities have been identified as the main pollutants, but biological factors such as leaves, faecal droppings from birds and animals can lead to health risks from the consumption of such water when it is not treated.

Rainwater can be harnessed for both potable and non-potable use in most countries especially where rainfall is abundant in some parts of the year. Stored rainwater (harvested rainwater) supplements surface and underground sources of water in dry seasons or when there are shortages. Non-potable uses could be either for indoor uses or outdoor uses. Non-potable indoor uses include Clothes washing/ laundry usage, Toilets/urinals flushing, washing floor and Cooling. While non-potable outdoor uses are garden watering, washing floor, replenishing domestic pools or spas, car washing, supplying the hot water system, thermal buffers to insulate houses, ventilation for buildings and protecting homes from bushfires. The potable uses includes drinking, Showers/Bathing, Dishwashing, faucets, cooking and other kitchen activities (Garrison, Kloss, & Lukes, 2011; enHealth, 2011). According to Thamer, Ghazali, & Mohd Noor, (2014) rainwater must be treated to remove pollutants for it to be put to potable uses whereas non-potable uses do not require treatment of the rainwater. Boiling water or exposing it to solar energy for about six hours may destroy pathogens in it (Debusk, Hunt, Osmond, & Cope, 2011).

Overall, limiting rainwater use to non-potable applications such as toilet or urinal flushing, or hose bibs (or wall spigots) for irrigation water presents little human health risk. With proper care, rooftop rainwater capture can be a useful part of a holistic 21st Century water policy (Garrison, Kloss, & Lukes, 2011). In some parts of Ghana, the predominant potable uses of rainwater is for bathing and cooking as noted by Owusu & Asante, (2020). However, appropriate filtration and disinfection practices should be employed before it can be used for such purposes (Mohammed, Mohd Noor, & Ghazali, 2006). According to Debusk, Hunt, Osmond, & Cope, (2011), a maximum filtration of 1 micron may remove particulate matter and dissolved solids (such as lead), as well as most parasites and bacteria. Different types of filters exist for filtration. It could be a combination of sediments, ceramic and activated carbon/activated charcoal or a combination of gravel, mollusk sand and activated carbon/activated charcoal (Debusk, Hunt, Osmond, & Cope, 2011; Khayan, Husodo, Astuti, Sudarmadji, & Djohan, 2019) the choice of filters depend on local materials and advice from water resources expects.

In many locations, the use of rainwater is prohibited or is limited to outdoor non-potable uses, such as residential irrigation, for which it is generally accepted that little or no treatment of the rainwater is required. However, with proper treatment, the use of rainwater for indoor non-potable uses, such as toilet flushing, represents a substantial opportunity for the more efficient use of water resources (Garrison, Kloss, & Lukes, 2011).

## 2.8 Studies on rainwater quality

Cerqueira, et al., (2014) conducted a study on rainwater analysis in order to investigate trace elements in wet precipitation of Juiz de Fora City Brazil. Rainwater pH mean was found to be acidic (5.77) and this showed that samples had on their majority acidic properties. This acidity was directly associated with $SO4^{2-}$ and $NO3^{-}$, where $NO3^{-}$ was found to be the main contributor to this characteristic. Zinc and copper were within the range of other studied areas while cadmium and lead were below detection limit.

In Ghana, Amponsah, Bakobie, Cobbina, & Duwiejuah, (2015) analyzed the physico-chemical properties of rainwater collected in open environments in Ayanfuri, central region. The physico-chemical values recorded were within World Health Organization limits for potability except pH and turbidity. The mean concentrations of the trace metals, that is iron (0.51 mg/l), lead (0.28 mg/l) and cadmium (0.12 mg/l) in the rainwater samples exceeded WHO permissible limits for potability except manganese (0.28 mg/l). They identified anthropogenic activities especially mining to have increased the concentration of pollutants in the atmosphere and influenced the compromised rainwater quality.

Also, Apraku & Adu-Kumi, (2014) conducted a study in Akwapim, Ghana where they compared the quality of rainwater from direct source, roof catchment and storage tank.

The results showed higher levels of total coliform in the analyzed samples to the prescribed guidelines and the least pH value was experienced from the direct fall. They concluded that both the physical and chemical parameters are very much within the limits for drinking water standards specified by WHO and are unlikely to cause any chemical-related problems if drunk. However, the colony counts were quite significant in all the samples tested and makes the rainwater vulnerable to cause health implication. However, because of its closeness to being safe for drinking, the water could be used for other purposes with or without some level of treatment.

In a similar study, Issaka, (2011) compared the quality of borehole, river, dam and rainwater in the Gonja district Ghana. Rainwater proved to be of higher quality because it showed absence of fluoride, iron, total hardness and faecal coliform. Turbidity and conductivity were within the WHO permissible limits for potability. The low parametric values of the rainwater were attributed to low levels of particulates such as smoke, dust, and soot suspended in the atmosphere, low levels of organic and inorganic ions in the atmosphere and frequent rainfalls combined with low temperature during the sampling period.

### 2.9 Conceptual framework

From the review of the theory and other research works, the conceptual framework shown in figure 1 is arrived. The conceptual framework shows how wet and dry deposition as well as roof materials affect the quality aspects of rainwater, being physico-chemical, trace metal and bacterial. The quality of the water in turn determines the use to which it will be put; this could be potable or non-potable.

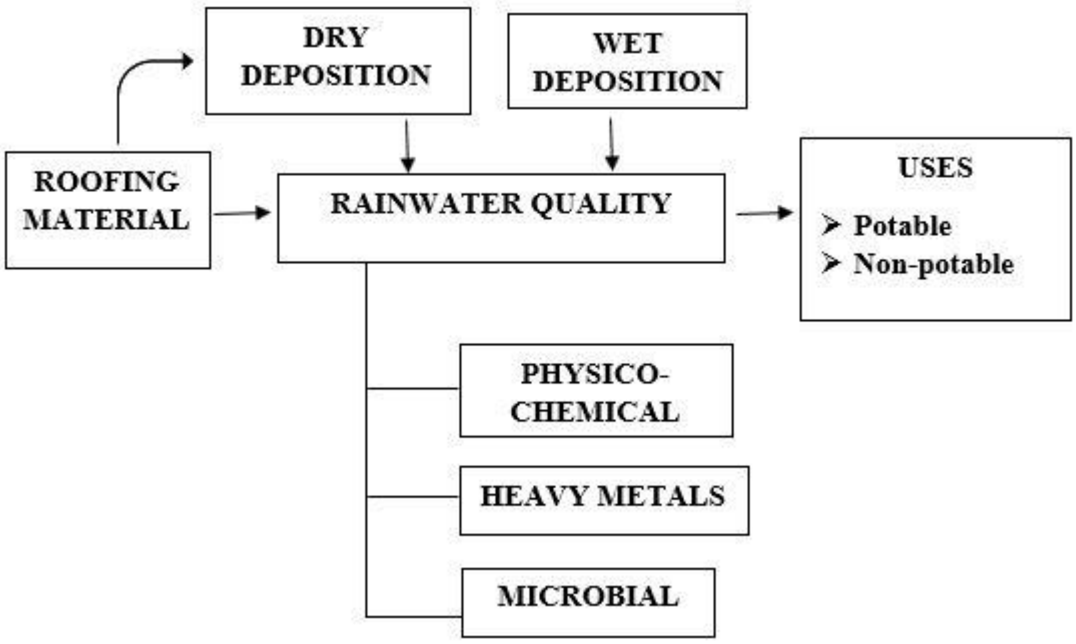

**Figure 1: Rainwater quality assessment framework**

**Source:** Author's construct, 2020

### 2.10 Summary

Rainwater quality which denotes the suitability of rainwater to sustain various uses or processes is mostly polluted by picking up pollutants in the atmosphere and also on surfaces on which it falls (this includes bacterials from leaves and animal droppings) . In addition, rainwater can dissolve heavy metals and other impurities from materials of catchments and storage tanks due to its relative aggresiveness arising from its slightly acidic nature. This adds to the quality issues of rainwater.

The physico-chemical properties of rainwater often do not give to health problems to consumers when their concentrations exceed the WHO guideline/permissible values. However, they lead to consumer rejection based on aesthetic value and most importantly, some of them influence the concentration and effects of other harmful substances. For example, higher concentration of DOC can lead to disinfection by-products such as Trihalomethanes which can be harmful. Exposure to heavy metals on the other hand has been linked with developmental retardation, various cancers, kidney damage, and even death in some instances of exposure to very high concentrations. Coliform bacteria found in rainwater samples also suggest the existence of pathogens which causes diseases.

While some studies indicate that the measured quality parameters of their rain samples were within the WHO standard values, others report higher values (or lower in the case of pH) above the guideline values. Again, most roofing materials such as galvanized, flat concrete, shingle, green roof and asphalts were found to be inappropriate catchments for rainwater harvesting since they leach heavy metals and other harmful metals. Some studies however recommend aluminium sheets for harvesting because it shows relative advantage over the other roofs in terms of the quality of rain run-off. Rainwater which is of low quality may be conviniently used for non-potable purposes such as gardening, flushing toilet, washing clothes, car and floor. However, with treated, rainwater can be used for cooking, bathing and even drinking.

# CHAPTER THREE

# RESEARCH METHODOLOGY

## 3.0 Introduction

This chapter highlights on the study area and how the study was undertaken. The research design, sample and sampling techniques adopted, data and its sources, and methods of data presentation and analysis are explained in this section. The chapter also gives a detailed account of laboratory analysis of the water samples.

## 3.1 Study area

This section gives a brief description of the study area in terms of location, relief and drainage, geology, climate, soil and vegetation, and roofing materials based on the (Ghana Statistical Service, 2014) District Analytical report of the Sefwi Wiawso Municipality.

### *3.1.1 Location and size*

The study was conducted in Sefwi Dwinase of the Sefwi Wiawso Municipality in the Western North region of Ghana. The Sefwi Wiawso Municipality lies in the North Eastern part of the Western Region between latitudes 6º N and 6º 3″ N and Longitudes 2º 45″ W and 2º 15″ W. The Brong Ahafo Region shares boundary with it to the North and Juabeso and Bia to the West, Aowin-Suaman to the South, Bibiani-Anhwiaso-Bekwai district to the East and Wassa Amenfi West to the South-East. The Municipality covers an area of 1,1011.6 sq.km, representing 7 per cent of land area of the then

Western Region and is roughly rectangular in shape. The Municipal capital is Sefwi Wiawso.

The study area is located within longitude 2°27'58.53"W and 2°29'11.12"W and latitude 6°13'49.05"N and 6°12'18.05"N in the Sefwi Wiawso Municipality. It shares boundary with Kokokrom to the north-east, Tanoso to the north, Sefwi Wiawso to the west, Wiase in the south, and the east with Aboduam. Figure 2 shows the study area.

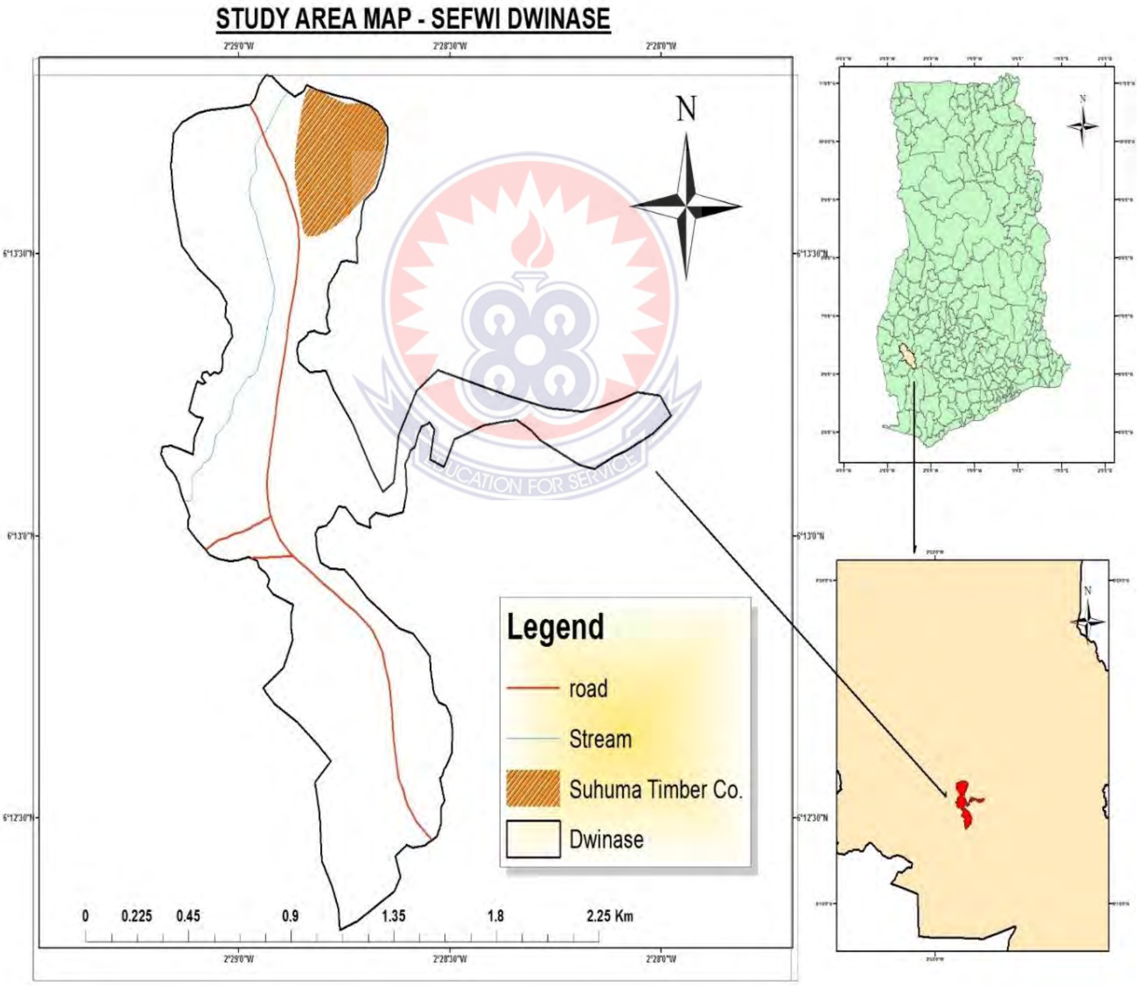

**Figure 2: Study area map in regional and national context**

**Source:** Author’s construct using Google Earth pro and ArcGis 10.1 (2019)

### *3.1.2 Relief and drainage*

Most part of the Municipality is generally undulating and lies between 152.4m – 510m above sea level. The highest point, the Krokoa peak which is 510m above sea level lies roughly to the South-West of Sefwi Wiawso. The main drainage feature is the Tano River and its tributaries. The Tano River runs roughly in a North-South direction and enters the sea in La Cote d'lvoire. The major tributaries include the Suhien, Kunuma, Sui and the Yoyo. This relief pattern (that is undulating land) can be clearly seen in Sefwi Dwinase (the study area).

### *3.1.3 Geology*

The geology of the Municipality is mainly the Lower and Upper Birimian types with the Lower Birimian formation to the East and North Eastern part of the Municipality. These are volcanic rocks, which have been solidified from molten materials (lava). The occasional granite intrusions give the Municipality its undulating nature and form part of the long hill ranges known as the Bibiani range. These are often steep and strongly dissected.

### *3.1.4 Climate*

Sefwi Dwinase falls within the tropical rainforest climatic zone with temperatures between 25˚C and 30˚C throughout the year and moderate to heavy rainfall pattern between 1524mm and 1780mm per annum. It comes with double maxima characteristics in June-July and September-October as its peaks. Humidity is relatively high, which is about 90% at night falling to 75 percent during the day.

The rainfall pattern of this area is unique and suitable for agricultural activities. It has two long wet seasons separated by relatively short dry season. The dry season is marked by relatively low humidity with hazy conditions occurring from December to February. The town often experiences concentrated downpours up to 178mm rainfall in a day which often causes flooding at some suburbs due to the nature of the soil in those areas.

### *3.1.5 Vegetation and soil*

The Sefwi Wiawso Municipality falls within the moist semi-deciduous forest zone of Ghana. The forest type consists of the Celtic triplochiton association. Common species found are Onyina, Odum, Wawa, Mahogany, Sapele, Emire Asamfina, Red cedar, among others. There is a high degree of depletion of the original forest as large sections of the forest are now secondary due to improper farming practices and logging. Due to this, a large section of the forest totaling 612.22 km$^2$ has been put under reserves. The Municipality has three (3) forest reserves which include Muro in Boako (167.8km$^2$), Suhuma in Old Adiembra/Amafie (359.8 km$^2$) and Tano Suhien in Punikrom (84.6km$^2$). These reserves surround Dwinase and influences its rainfall pattern.

The most widespread soil is the forest Ochrosols, which covers most of the Northern and Western parts of the Municipality. The forest Ochrosols is dominant in Sefwi Dwinase and it is a rich soil, which support the cultivation of cash and food crops, such as cocoa, palm tree, cola, coffee, cashew, plantains, cocoyam, cassava and maize, with high yields.

### *3.1.6 Roofing materials*

About 91 percent of households used metal sheet to roof their dwelling units, 95.9 percent and 87.5 percent in the urban and rural areas respectively. While 0.5 percent use cement/concrete (0.7 percent and 0.4 percent in the urban and rural areas respectively). In the urban areas, few of the households use Mud/Mud bricks/Earth as the material for the construction of roof, while in the rural areas few of the households use tile, slate and Asbestos.

## 3.2 Research approach

The study employed the quantitative research approach. Quantitative research relies on the collection and analysis of numerical data to describe, explain, predict or control variables of interest. Quantitative research focuses on objectivity that permits the researcher to generalize findings beyond a particular situation or setting (Mertler, 2016). In quantitative research, variables are related in the questions and hypothesis. Information is observed and measured numerically using unbiased techniques and statistical procedures (Creswell, 2014). Hence quantitative research approach employs statistical procedures to describe, explain and predict a situation, phenomena or problem. Some studies or researches warrant specific approach, Creswell, (2014) explains that, quantitative approach is best used when the research problem or question calls for the identification of factors that influence an outcome, the utility of an intervention, or understanding the best predictors of outcomes.

I used the quantitative research approach in the study to help me make meaningful analysis of the water quality parameters tested. The quality values of rainwater based on the selected parameters for the study were determined through laboratory testing. Statistical methods were used to determine how the different parameters affect the water quality and also to describe the dynamics of the water quality within the study area and among different roofing materials.

### 3.3 Research design

The study made use of the descriptive design. "Descriptive research refers to a research that describes a phenomenon or else a group under study" (Kim & Boyd, 2017). This involves describing the population under study through identified characteristics. Studies that use descriptive design observe, describe and document aspects of a situation or phenomena as it naturally occurs. Descriptive research design is a non-experimental quantitative design which means it does not involve influencing or the manipulation of natural variables or characteristics. "The accurate and systematic description of 'something' (event, phenomena or characteristics) or 'someone' is the cornerstone of this research design" (Dulock, 1993). This design was used in this study because it helped me to statistically describe and interpret the status of the quality of rainwater in the study area. This was done by testing some water parameters of the study materials in the laboratory, analyzing and interpreting the results in relation to guideline values stipulated by the World Health Organization. This also enabled me to describe the spatial condition of the rainwater quality in the study area.

### 3.4 Materials and procedures

The study area was divided into three strata and two suburbs selected from each stratum randomly using stratified random sampling technique. Eight points were established within each suburb based on the roofing material and open environment (that is open space, aluminum, flat concrete and galvanized roofing sheets) to collect the materials (rainwater). However, the two open space materials within each stratum were merged to produce one sample (this is further explained under 'rainwater sampling'). Therefore, there were seven collection sites in each stratum as shown in Figure 3. As shown in figure 3, the collection points were mainly on the left side of the road in the study area because, Suhuma timber company occupies larger part of the right side of the road, hence that side is seldom occupied by the residents. I used this procedure because the point and level of pollution in the study area differs spatially, which affects the quality of rainwater at these locations. The stratification also made it possible to compare variations in the quality of rainwater at different location and investigate the underlining causes of those variations. Stratified sampling according to Kothari, (2004) helps researchers to have higher statistical precision in obtaining data to analyze relationship between two or more subgroups. It is also convenient in obtaining homogenous data from a heterogeneous sample.

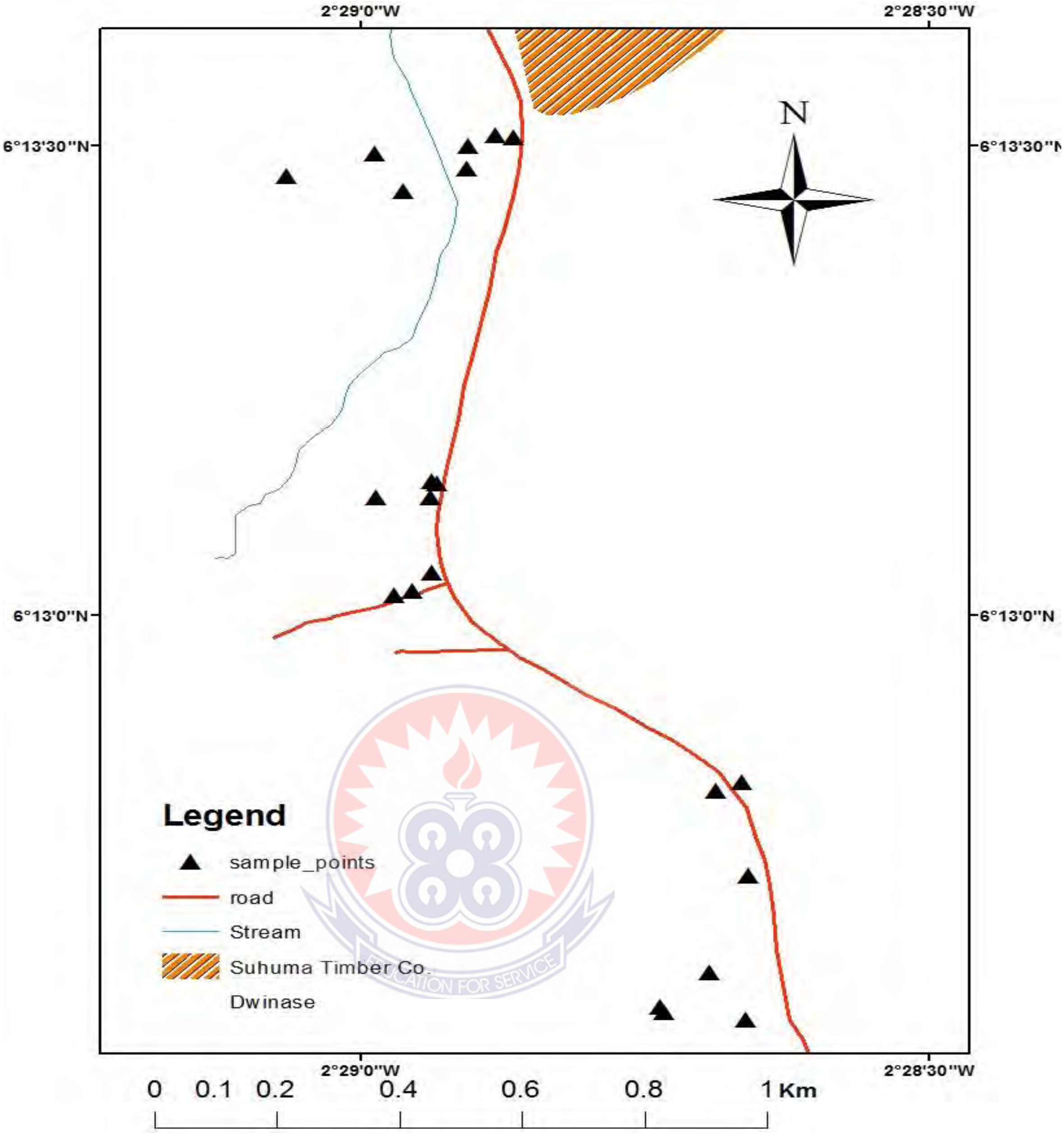

**Figure 3: Sampling points at Sefwi Dwinase**

**Source:** Field data, (2019)

### *3.4.1 Rainwater sampling*

The preliminary field work was to identify roof materials that are commonly used in Sefwi Dwinase, establish the collection points and to seek permission or consent from the inhabitants of those houses. Plain aluminum sheets, colour-coated galvanized sheets and flat concrete roofs were identified to be the three commonly used roofing materials in the study area. Rainwater was collected from the seven collection sites within each stratum, using collection containers placed above the ground. These were rainwater collected in open space/environments, over plain aluminum roofing sheets, colour-coated galvanized roofing sheets and flat concrete roofs. The materials were collected and labelled. Each label was given a prefix based on the stratum followed by the roof material label. A for the first stratum, B for the second stratum and C for the third stratum.

i. A for plain aluminum roof material: materials were taken from six sources, two from each stratum and designated as AA1, AA2, BA1, BA2, CA1 and CA2.

ii. G for colour-coated galvanized roof material: materials were taken from six sources, two from each stratum and designated as AG1, AG2, BG1, BG2, CG1 and CG2.

iii. C for concrete flat roof: materials were taken from six sources, two from each stratum and designated as AC1, AC2, BC1, BC2, CC1 and CC2

iv. O for open space/environment: materials were taken from six sources, two from each stratum. However, the two materials from each stratum were put together to produce one. This was done to ascertain the general quality of open space rainwater quality in each stratum. The materials were designated as AO, BO and CO.

### *3.4.2 Data and sources*

The study mainly made use of primary and secondary data. The data were obtained in two folds; through the collection of rainwater samples when it rained and secondary data primarily the WHO drinking water quality guideline to explain the result of the data collected. The primary data (materials) were collected in the September – October season, where there are considerable days of dry periods in between rainy days. This is in line with Chapman, Gardner, Huston, Chan, and Shaw (2006) who suggested that this helps to assess a worst-case scenario of how roofing materials affect the quality of rainwater.

### *3.4.3 Instruments for data collection*

Sterilized plastic containers and funnels were used to collect rainwater samples from the three strata within the study area.

### *3.4.4 Preparation of sample containers*

Before sample collection, the collection containers - bottles as well as funnels were cleaned daily by distilled water, this according to Bharti, et al., (2017) will avoid dry deposition of gaseous and particulate species in the containers. These small polythene/plastic bottles (containers) were labelled according to the sample site to enhance record keeping. Collected samples were then stored in these containers. The samples collected were duplicated; one to be tested for physiochemical characteristics and the other for heavy metal.

### *3.4.5 Handling samples*

Nitric acid was added to the heavy metal samples to prevent biological degradation of the samples (Bharti, Singh, & Tyagi, 2017). The samples were placed in ice chest (insulated containers), iced to keep the water samples at a proper storage temperature of 1-4°C and sent to the laboratory for the necessary tests. To ensure that sample bottles are not totally immersed in water from melted ice during transit, the ice were kept in polythene rubber. These precautions were necessary to ensure the production of valid data (U.S. EPA, 2002).

## 3.5 Laboratory test

The water samples were transported to the University of Ghana, Legon, Ecological laboratory of the Institute for Environment and Sanitation Studies for testing.

### *3.5.1 Determination of metals in water using AAS*

Flame Atomic Absorption Spectroscopy technique was used in the analyses of Calcium, Iron, Magnesium and Lead in all the water samples. Since the samples for the heavy metals testing contained nitric acid, the AAS was used to aspirate directly in an air/acetylene flame at specified wavelength. Atomic spectroscopy is the technique for determining the elemental composition of an analyte by its electromagnetic or mass spectrum. Atomic Absorption (AA) occurs when a ground state atom absorbs energy in the form of light of a specific wavelength and is elevated to an excited state. The amount of light energy absorbed at this wavelength will increase as the number of atoms of the selected element in the light path increases. The relationship between the amount of light absorbed and the concentration of analytes present in known standards can be used to determine unknown sample concentrations by measuring the amount of light they absorb. Performing atomic absorption spectroscopy requires a primary light source, an atom source (atomizer), a monochromator to isolate the specific wavelength of light to be measured, a detector to measure the light accurately, and electronics to process the data signal and a data display or reporting system to show the results.

The light source used was a hollow cathode lamp (HCL) or an electrodeless discharge lamp (EDL). the light source emits light at a specific wavelength. The trace metal concentration in the samples were determine one after using their respective HCL. In general, a different lamp is used for each element to be determined, although in some cases, a few elements may be combined in a multi-element lamp. The electrodeless discharge lamp (EDL) is used for volatile gases.

The monochromator (an optical device capable of transmitting a narrow band of the electromagnetic spectrum) transmits the light from the light source to the detector. The light passes through the monochromator which isolate specific wavelength for absorption by the atoms.

The atomizer/atom source creates a population of free atoms suitable for absorption of light. Atoms get excited at a higher temperature. The source of energy for free-atom production was heat, in the form of an air/acetylene flame. Whatever the system, the atom source used must produce free analyte atoms from the sample. The sample was introduced as an aerosol into the flame by the sample introduction system consisting of a nebulizer and spray chamber. The burner head was aligned so that the light beam passes through the flame, where the light is absorbed.

Detector measures the amount of light transmitted through the spectroscopy. Amount or output is sent to a computer (a data display or reporting system). In the past, photomultiplier tubes have been used as the detector. However, in most modern instruments, solid-state detectors are now used. Flow Injection Mercury Systems (FIMS) are specialized, easy-to-operate atomic absorption spectrometers for the determination of mercury. These instruments use a high-performance single-beam optical system with a low-pressure mercury lamp and solar-blind detector for maximum performance.

### *3.5.2 Preparation of standard solution for AAS*

Before analysis, the AAS had to be calibrated with standard solution. The standards are prepared in 1000 ppm and stepped down to lower concentration (2ppm, 10ppm). The preparations of 1000 ppm AA standard solution from the pure element or from one of its salt are outlined below. Deionized water was used and all solutions were stored in stoppered polythene bottles at room temperature.

#### *3.5.2.1 Calcium*

Dissolve 2.4973g of calcium carbonate ($CaCO3$) in 25ml. of 1M hydrochloric acid. This should be added dropwise to avoid losses during the vigorous effervescence. Dilute to 1litre in a volumetric flask with deionised water. Or Dissolve 2.7693g of calcium chloride ($CaCl2$) in 100ml. deionised water. Dilute to 1litre in a volumetric flask with deionised water

#### *3.5.2.2 Iron*

Dissolve 1.000g of iron wire or granules in 20ml. of 5M hydrochloric acid Dilute to 1 litre in a volumetric flask with deionised water. Or Dissolve 4.8400g of iron (111) chloride ($FeCl_3.6H2O$) in 200ml. of deionised water. Dilute to 1 litre in a volumetric flask with deionised water.

### 3.5.2.3 *Lead*

Dissolve 1.000g of lead metal in 50ml. of 2M nitric acid. Dilute to 1 litre in a volumetric flask with deionised water. Dissolve1.5980g. of lead nitrate ($Pb(NO_3)_2$) in 100ml. of deionised water. Dilute to 1 litre in a volumetric flask with deionised water.

### 3.5.2.4 *Magnesium*

Dissolve 1.000g of magnesium metal in 50ml. of 5M hydrochloric acid. Dilute to 1 litre in a volumetric flask with deionised water. Or Dissolve 3.9160g of magnesium chloride ($MgCl_2.6H2O$) in 200ml. of deionised water. Dilute to 1 litre in a volumetric flask with deionised water.

### 3.5.3 *Analysis*

The FAAS (pinAAcle 900t) is turned on, calibrated with the various calibration standards and the samples automatically run in triplicate. Mean concentration of the analyte is recorded on the software interface on a computer.

### 3.5.4 *Principle of the FAAS*

The spectrometer uses two primary light sources (i.e. hollow cathode lamp and electrodeless discharge lamp). Atomization of the sample analyte begins in the atomization chamber where the analyte is exposed to heat from a flame at a temperature of about 2000℃. At this temperature, the valence electrons of the analyte become excited and finally de-excited to the ground state. Upon atomization in a flame, metals absorb at well-defined wavelengths. The presence of other elements in an aqueous sample is not expected to interfere with the signal from the analyte because absorption peaks are discrete and non-overlapping.

A monochromator focuses a beam of monochromatic light onto the analyte at a specific wavelength where an amount is absorbed and another transmitted. The ground state is where maximum absorption of light from the source is achieved at their characteristic wavelength. By measuring the amount of light absorbed, a quantitative determination of the amount of analyte can be made.

### 3.5.5 *Total coliform*

Total coliform was tested in the laboratory using the membrane filtration method MI broth or MI agar. MI broth detects the presence of coliform bacteria by the production of β-galactosidase, which cleave the substrate MUGal to produce 4-methylumbelliferone, which fluoresces on exposure to UV light. It is easier to exclude non-coliforms since they do not produce this enzyme and therefore do not fluoresce on the medium (U.S. EPA, 2002).

In membrane filtration method using MI broth or MI agar an appropriate volume of a water sample (100 mL for drinking water) is filtered through a 47-mm, 0.45-µm pore size cellulose ester membrane filter that retains the bacteria present in the sample. The filter is placed on a 5-mL plate of MI agar or on an absorbent pad saturated with 2-3 mL of MI broth, and the plate is incubated at 35°C for up to 24 hours. The bacterial colonies that grow on the plate are inspected for the presence of fluorescence under longwave ultraviolet light (366 nm) from the breakdown of MUGal by the total coliform enzyme β-galactosidase.

## 3.6 Data presentation and analysis

Data generated from the laboratory test were analyzed quantitatively using the Statistical Package for Social Science (SPSS) version 20 and presented in tables, graphs, maps and diagrams. This helped to provide a visual description of the variations in the concentrations of the parameters in the study area. Principal component analysis was used to determine the factors that have the most effects on the rainwater quality and how much they could be explained by those variables.

## 3.7 Ethical consideration

Ethical consideration particularly informed consent was crucial in the study. I sought permission from landlords/landladies and or inhabitants of the houses which roofs were used in the study. This was done during the preliminary field work stage of the study. I explained the purpose of the rainwater collection to them to be for only academic purpose and not for any other reason as perceived by some of them (that is spiritual purposes). The inhabitants/owners consented before the water were collected.

# CHAPTER FOUR

# DATA PRESENTATION, ANALYSIS AND DISCUSSION

## 4.0 Introduction

This chapter deals with the presentation and analysis of data collected from the study area and laboratory analysis. The data is presented and analyzed based on the research objectives as a follow up to review of related literature presented in chapter two of this work. Data was reduced to means and ranges to facilitate interpretation.

## 4.1 Microbial, heavy metals and physico-chemical parameters of rainwater

In other to assess the quality of rainwater in Sefwi Dwinase; power of hydrogen (pH), electrical conductivity, Total dissolved solids, Total hardness, Dissolved organic carbon, calcium and magnesium were tested for physico-chemical quality, Iron and lead for trace metals and Total coliform for microbial quality. The results and analysis of these parameters are presented subsequently.

In order to assess a worst-case scenario sampling were undertaken for rainfall with considerable days of dry periods in between rainy days (Chapman, Gardner, Huston, Chan, & Shaw, 2006). As shown in figure 1, The rain samples were collected from the northern (‘eighteenmu’), central (‘main market’) and southern portion (‘Mpomam’) of the study area in other to find out the spatial variations in the parameter distribution.

**Table 2: Description of Physicochemical and microbial properties of rainwater**

| Parameters | Mean | Min | Max | Std deviation | Skewness | Kurtosis | WHO guideline value |
|---|---|---|---|---|---|---|---|
| pH | 6.738 | 6.000 | 7.400 | 0.361 | -0.250 | -0.513 | 6.5 to 8.5 |
| Electrical conductivity (µS/cm) | 28.759 | 2.330 | 114.90 | 30.365 | 1.549 | 2.020 | 300 |
| Total dissolved solids (Mg/l) | 14.402 | 1.355 | 57.450 | 15.162 | 1.554 | 2.033 | 1000 |
| Dissolved organic carbon (Mg/l) | 1.659 | 0.880 | 2.360 | 0.443 | 0.103 | -1.288 | - |
| Total hardness (Mg/l) | 13.311 | 0.428 | 42.176 | 14.855 | 0.918 | -0.769 | 500 |
| Calcium (Mg/l) | 5.236 | 0.162 | 16.580 | 5.929 | 0.906 | -0.793 | 200 |
| Magnesium (Mg/l) | 0.054 | <0.01 (BDL)* | 0.443 | 0.104 | 2.947 | 9.915 | 150 |
| Iron (Mg/l) | 0.505 | 0.024 | 1.251 | 0.326 | 0.365 | -0.363 | 0.3 |
| Lead (Mg/l) | 0.793 | <0.01 (BDL)* | 2.346 | 0.829 | 0.553 | -1.092 | 0.01 |
| Total coliform (CFU/100µL) | 96.330 | 0.000 | 10^3 x TMTC** | 300.436 | 2.974 | 7.561 | 0 |

***BDL – Below Detection Limit*** *****TMTC – Too Many To Count***

**Source:** Field data, (2019)

From Table 2, it can be noticed that, the distribution of pH, Dissolved organic Carbon and iron is quite symmmetrical given their low skewness values (less than 0.5). Total hardness, calcium and lead are moderately skewed while electrical conductivity, total dissolved solids, magnesium and total coliform are highly skewed to the right, which means they are nonsymmetrical. Except electrical conductivity, total dissolved solids, magnesium and total coliform which have much pointy distribution curves, the distribution curves of all the parameters are slightly flater than normal distribution curve, evidenced by their less and negative kurtosis values.

### *4.1.1 Power of hydrogen (pH)*

The pH of water is the effective concentration of hydrogen ions (H+) in solution and rainwater with a value of 5.6 is generally assumed as neutral or unpolluted. However, rainwater with pH value less than 5.6 is considered as acid rain. This is the pH of cloud water at equilibrium with atmospheric $CO_2$ (Khan & Sarwar, 2014). The pH values of rain samples from Sefwi Dwinase range from 6.0 to 7.4 with a mean pH value of 6.7 as shown in Table 2. Figure 4 indicates that majority of the samples (equivalent to 38.4%) recorded pH values of 7.0, 6.8 and 6.5. Few samples (equal to 19%) recorded pH values of 6.0, 6.2, 6.6, 7.2 and 7.4. It can be noted from Figure 5 that, apart from three materials that recorded 6.0, 6.2 and 6.3 pH values, all the others fell within the WHO optimum pH range of 6.5 – 8.5 (WHO, 2006) . The pH values that were below the WHO minimum value of 6.5 were located around the 'main market' and in 'Mpomam' which is far from the timber processing company. The higher pH values implies that rainwater in Sefwi Dwinase is generally alkaline.

pH is one of the most important operational water quality parameters (WHO, 2006) as it governs the activity of many other important parameters of water quality. It is also an important parameter in predicting the nature and impart of anthropogenic activities on atmospheric pollution (Abulude, Ndamitso, & Abdulkadir, 2018). I agree with Khan and Sarwar (2014) that, the general alkaline nature of rainwater in Sefwi Dwinase suggest that the influence of anthropogenic sources due to acidic gases is minor and the effect of particulate matter of alkaline nature like dust particles is dominant. As such, there are a certain inputs of alkaline species into the precipitation in the study area.

In similar studies, Khan and Sarwar, (2014) obtained rainfall data with wider pH range of 5.55 to 8.09 in Karachi, Pakistan. Abulude, Ndamitso and Abdulkadir, (2018) recorded pH values of 4.6 to 7.3 in Akure, Nigeria where as 6.26, 6.37 and 6.82 were recorded as mean values for Central Gonja, Ghana (Issaka, 2011). Also, Siabi, Van-Ess, Engmann, Mensah, and Tagoe, (2015) recorded higher pH values 7.4 – 7.5 in Akwapim north, Ghana an area with vegetation and rainfall pattern similar to the study area. A study in Ayanfuri, Ghana by Amponsah, Bakobie, Cobbina and Duwiejuah, (2015) observed lower pH value range of 5.88 to 7.01. The pH values were particularly found to be of high acidity in Obuasi, a mining town in Ghana (Akoto, Darko, & Nkansah, 2011). The lower values of 4.0 to 5.6 were attributed to anthropogenic sources, particularly mining activities in the town. The difference in rain pH can be attributed to spatial variations in atmospheric pollution and the composition of aerosols and gas in the atmosphere.

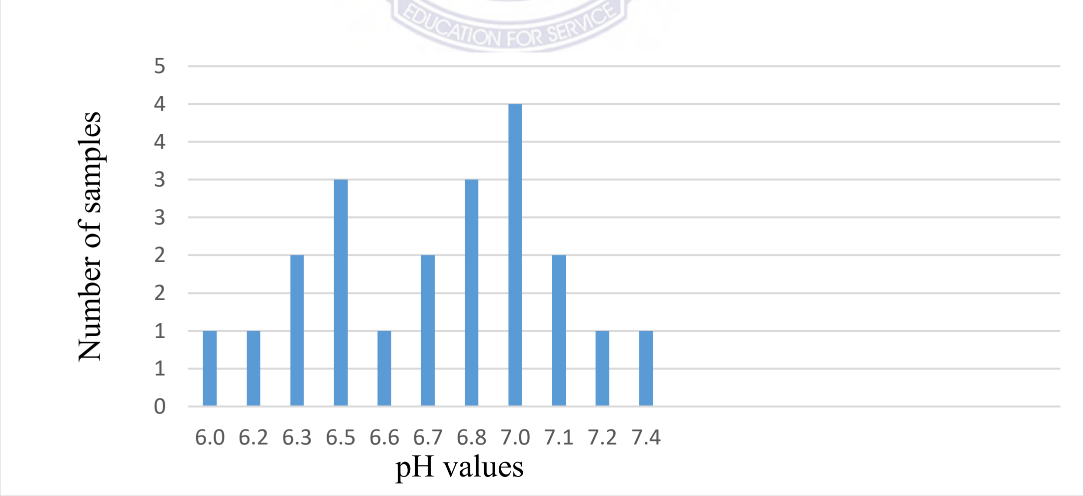

**Figure 4: Samples frequency distribution for pH**

**Source:** Field data, (2019)

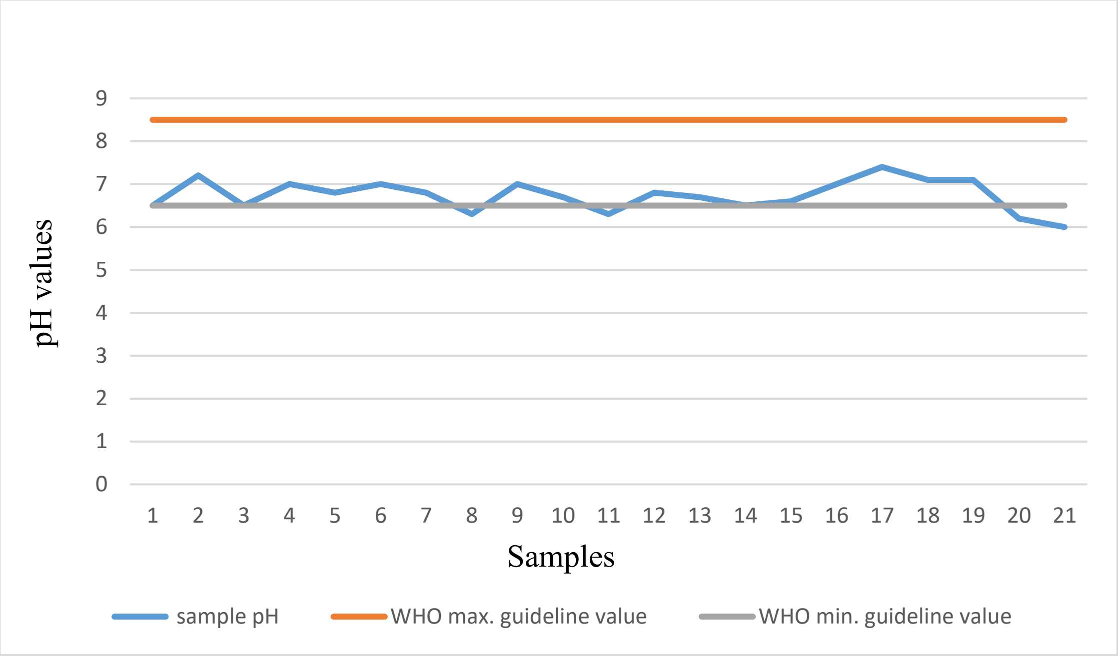

**Figure 5: pH values of samples against WHO optimum pH range**

**Source:** Field data, (2019)

### *4.1.2 Electrical conductivity (µS/cm)*

Conductivity is a measure of the ability of water to pass current (Issaka, 2011). The electric conductivity (EC) of rainwater ranged from 2.3 µS/cm to 114.9 µS/cm, with a mean of 28.759 µS/cm (and a standard deviation of 30.365, Skewness (1.549) and Kurtosis (2.02)) shown in Table 2. The highest value was observed in and around the 'main market' where busy activities aid in the vertical uplift of dust and other particulate matter in the atmosphere, whilst 'Mpomam' recorded the lowest value. The EC values were within the WHO suitability limit of 300 µS/cm. The mean conductivity in the study area was far above that of rainwater studied in Juiz de Fora City, Brazil 11.3 µS/cm ( a maximum of 35.2 µS/cm) (Cerqueira, et al., 2014) , Tamale metropolis, Ghana where the EC mean was 13.6±14.6 µS/cm (Cobbina, Michael, Salifu, & Duwiejua, 2013), Ayanfuri, Ghana  with a general mean of 15.75 µS/cm (Amponsah, Bakobie, Cobbina, & Duwiejuah, 2015). The EC values were however lower than the values 4.32 µS/cm to 866 µS/cm for samples harvested in Pakistan (Khan & Sarwar, 2014) and values observed by Abulude, Ndamitso, & Abdulkadir, (2018) for Akure in Nigeria with 44.75µS/cm mean and and a maximum of 325 µS/cm. The range 7.2 µS/cm to 59.6 µS/cm were recorded as conductivity values of rainwater in Obuasi, Ghana (Akoto, Darko, & Nkansah, 2011).

The EC values of the rainwater in the study area indicates the presence of soluble ions in the atmosphere and reflects the impact of atmospheric particulate matter on the precipitation chemistry (Zhao, et al., 2013; Cobbina , Michael, Salifu, & Duwiejua, 2013). Meanwhile, the soluble ions has low concentrations compared to the WHO guideline value of 300 µS/cm, hence rainwater will not interfere with domestic activities with respect to conductivity . The low electrical conductivity concentrations of rainwater therefore show less pollution of the atmosphere with particulate matter, this indicates good atmospheric environmental quality with respect to soluble ions.

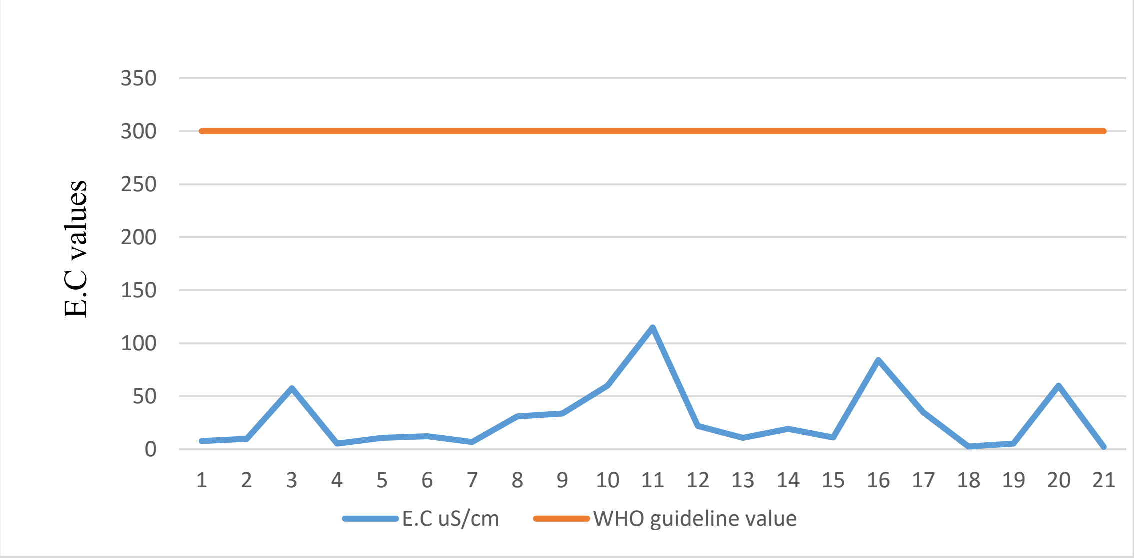

**Figure 6: EC values of rainwater samples**

**Source:** Field data, (2019)

### *4.1.3 Total dissolved solids*

With a mean value of 14.402 mg/l, the total dissolved solids of rainwater in the study area had a minimum of 1.355 mg/l and a maximum of 57.45 mg/l. Standard deviation 15.162 , skewness 1.554, Kurtosis 2.033. These figures were within the WHO limit for potability of 1000 mg/l. Figure 7 shows that the values are negligible to the WHO guideline value hence the rainwater has a very low possibility of causing health and other TDS related problems from its usage. The highest TDS values were recorded in the 'main market' area whilst the lowest values were recorded in Mpomam, which is far from the timber processing company and also away from the market. The general average value of TDS of rainwater in the study area is similar to 14.4 mg/l of Obuasi conducted by Akoto, Darko, and Nkansah, (2011). But the maximum value for the study 57.45 mg/l was higher than that of Obuasi 24.1 mg/l. Mean total dissolved solids is higher than observed mean values in Tamale, Ghana of 6.5 mg/l (Cobbina, Michael, Salifu, & Duwiejua, 2013) and 9.30 mg/l in Ayanfuri, Ghana (Amponsah, Bakobie, Cobbina, & Duwiejuah, 2015). But lower than recorded values in Malaysia, 30.2 mg/l (Muhamad & Abidin, n.d), Jordan, 38.47 mg/l (Radaideh, Al-Zboon, Al-Harahsheh, & Al-Adamat, 2009).

Comparing the Total dissolved solids (TDS) values for this study to the WHO's TDS palatable level of 600 mg/l, implies that, with respect to TDS, the rainwater from the study area is good and palatable for drinking and suitable for domestic use. I however disagree with the ascertion that, "Total dissolved solids in rainwater, originating from particulate matter in the atmosphere usually range from 2 mg/l to 20 mg/l" (Cobbina, Michael, Salifu, & Duwiejua, 2013). This is because about 24 percent of the sampled rainwater recorded values above 20 mg/l. Meanwhile, the concentration of particulate matter in the atmospheric air within Sefwi Dwinase have caused the relatively higher TDS values.

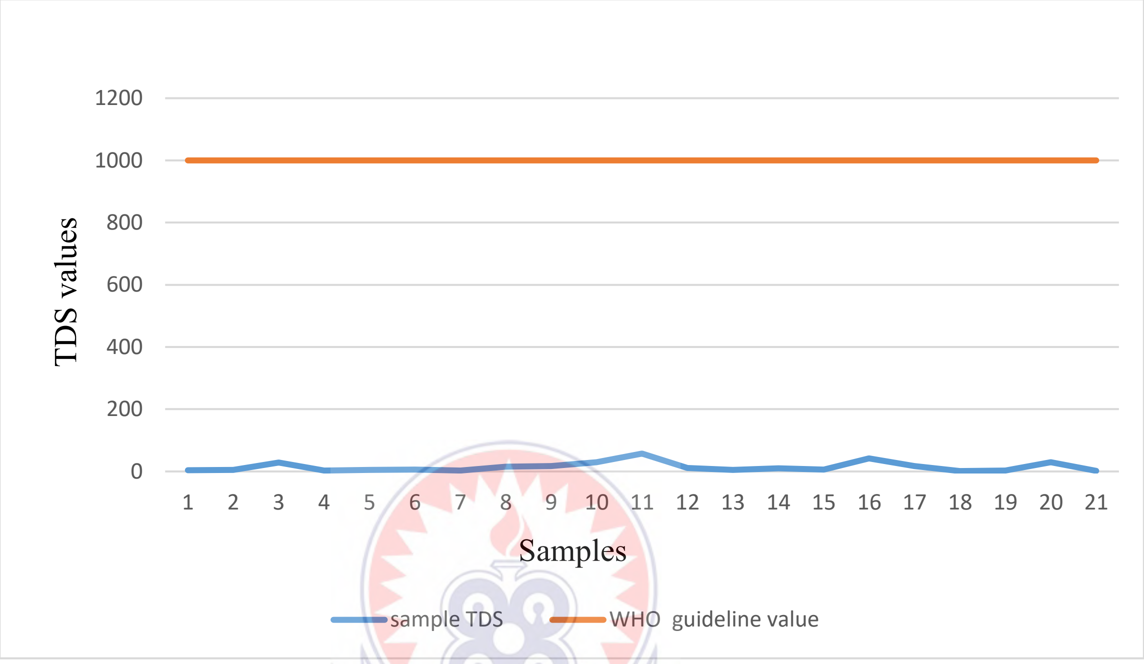

**Figure 7: TDS values of samples against WHO guideline value**

**Source:** Field data, (2019)

### *4.1.4 Dissolved organic carbon (DOC)*

Dissolved organic carbon (DOC) is a general description of the organic material dissolved in water. The dissolved organic carbon content of the rainwater from the study shown in Table 2, ranged from 0.88 mg/l to 2.360 mg/l. The mean value was 1.659 mg/l, standard deviation 0.443, skewness 0.103, Kurtosis -1.288. Figure 8 shows the concentration of DOC in the rainwater samples. This is consistent with the average value of 1.5 mg/l observed in Australia by Chapman, Gardner, Huston, Chan, and Shaw, (2006). Whereas Mendez, Afshar, Kinney, Barrett, and Kirisits, (2010) reports higher DOC values of up to 37.3 mg/l. From the results, DOC concentrations in the study area has no noticeable spatial significance, however, the highest value was recorded in 'Mpomam' where there is close proximity to vegetations. These vegetations may aid concentrations of DOC in rainwater through the emmisions of Volatile organic carbons (VOC) into the atmosphere. The WHO has not provided a health guideline value to dissolve organic carbon concentration in rainwater. However, higher values of DOC ( more than 5 mg/l) in water will produce high concentrations of disinfection by-products such as trihalomethanes, to be formed in amounts exceeding the standards, if the rainwater were to be chlorinated as a means of disinfection (Government of Saskatchewan, 2009). Hence rainwater in the study area may be safe for potable and non-potable use as far as DOC is concerned. However, rainwater in some part that exceeded 2mg/l may not be easily treated for disinfection by-products and the finished water colour may increase.

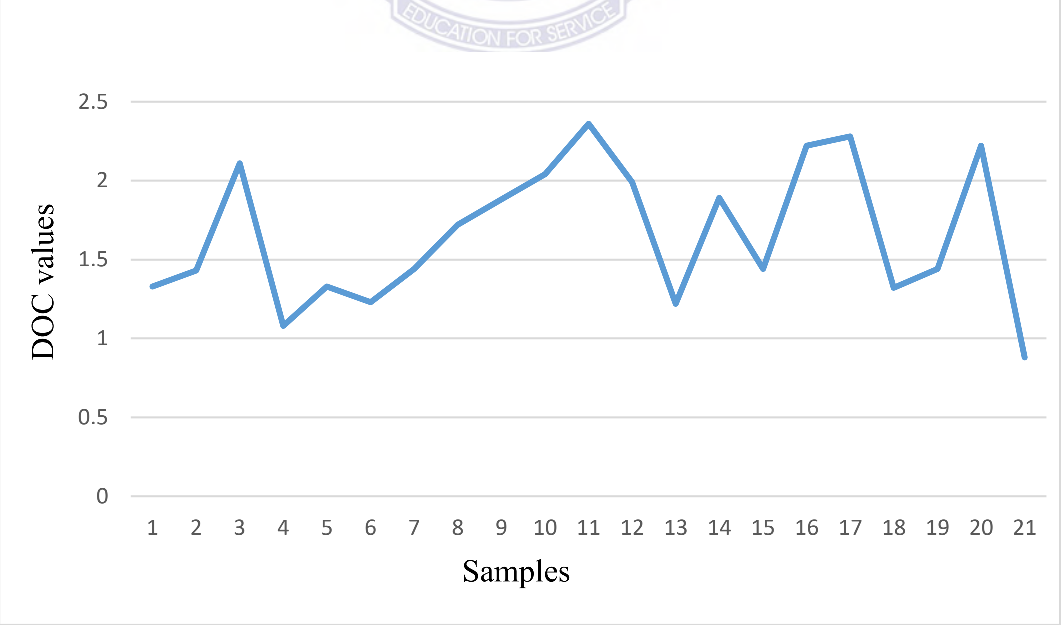

**Figure 8: DOC values of samples against WHO guideline value**

**Source:** Field data, (2019)

### *4.1.5 Total hardness*

From the study, the total hardness of the rain samples ranged from 0.428 mg/l to 42. 176 mg/l and a mean of 13.31mg/l. Standard deviation 14.855, skewness 0.918, Kurtosis -0.769. This is similar to the results found in other parts of Ghana: Amponsah, Bakobie, Cobbina, and Duwiejuah, (2015) 9.95mg/l ,and Cobbina, Michael, Salifu and Duwiejua, (2013) 10.64 mg/l. But it is lower that observed values in Israel (28.1 mg/l) by Friedler, Gilboa, and Muklada, (2017) and in Brazil (125 mg/l) by (Cerqueira, et al., 2014). However Issaka, (2011) recorded 0.00 mg/l mean total hardness in his study in the Central Gonja district in Ghana. A guideline value of 500 mg/litre was established for hardness by the WHO, based on taste and household use considerations (WHO, 2006). The results from the study indicates that the total hardness of rainwater in the study area falls within the WHO guideline value which makes it suitable for consumption as shown in Figure 9. The low total hardness recorded values reflect the low concentrations of calcium and magnisium ions in the atmosphere.

However, in as much as hard water (value of 500 mg/l and more) may cause scale deposition and high soap consumption, Soft water, with a hardness of less than 100 mg/l may, in contrast, have a low buffering capacity and so be more corrosive for water pipes (WHO, 2011). On the basis of hardness of water by WHO shown in table 1, it can be concluded that rainwater from the study is soft which implies that, it is potable for household use and indicate palatability of the water. However, the low concentrations of hardness in the rainwater have the tendency of causing disease and deficiencies (cardiovascular diseases) because very soft waters may have an adverse effect on mineral balance, especially when it is not suplemented with a balanced diet as posited by the WHO, (2006).

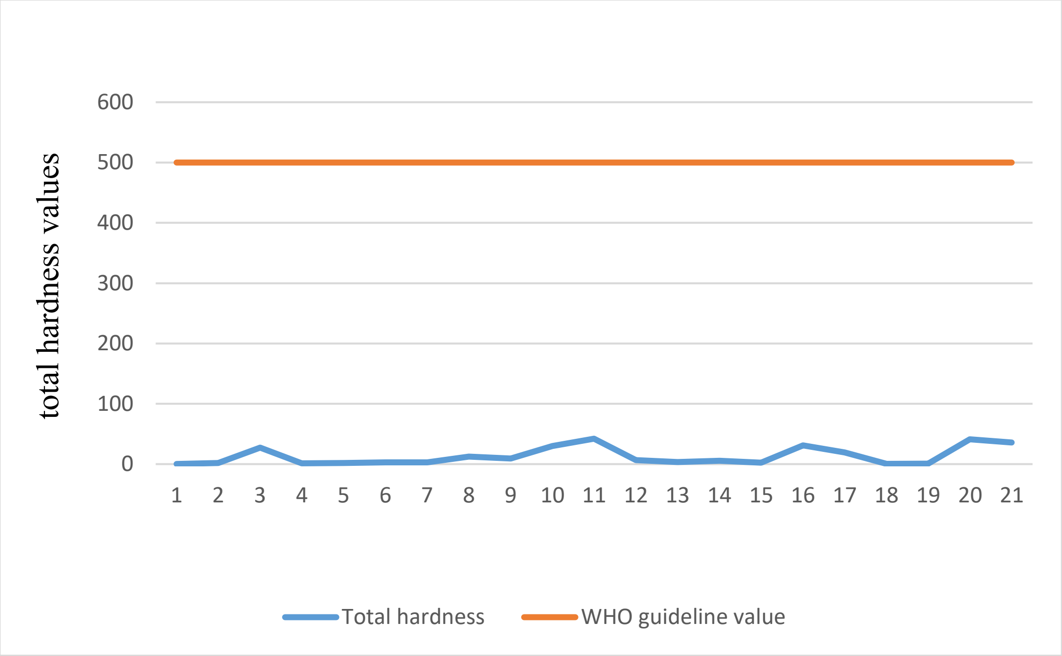

**Figure 9 : Total Hardness values of samples against WHO guideline value**

**Source:** Field data, (2019)

### *4.1.6 Calcium and magnesium*

5.236 mg/l was recorded as the mean calcium content of the rain samples from the study. The maximum and minimum values were 16.580 mg/l and 0.162 mg/l respectively. Standard deviation 5.929, skewness 0.906 and Kurtosis -0.793. Most of the highest calcium concentrations were within the central part of the study area, whilst the northern part recorded the lowest values. calcium concentration of 5.236 mg/l from this study was higher than the mean value of 2.14 mg/l recorded in Ayanfuri, Ghana and the mean of 2.38 mg/l for Tamale, Ghana (Cobbina, Michael, Salifu, & Duwiejua, 2013)

Magnesium concentration in the rainwater recorded a mean value of 0.054 mg/l, minimum of <0.01 (BDL), maximum 0.443 mg/l, standard deviation of 0.104, skewness 2.947 and Kurtosis 9.915. Fifty-seven percent (57%) of the samples were below detection limit (BDL). This indicates that magnesium concentration in the rainwater is very low almost negligible. The highest magnesium values were within the central part of the study area, whilst the southern part recorded more below detection limit values (almost zero values). The value of magnesium concentrations rom the study, is much lower than value range of 24.8 - 38.6 mg/l and a mean of 1.4 mg/l reported by similar studies in Ogbomoso, Nigeria and Haifa, Isreal (Olaoye & Olaniyan, 2012; Friedler, Gilboa, & Muklada, 2017).

The Calcium and Magnesium concentrations of rainwater in the study area is within the WHO guideline limit as well as the desirable limit of 75mg/l and 30 mg/l respectively, and may therefore be acceptable to consumers or residents with regards to taste and asthetic value. However, as noted by WHO, (2006) the low concentrations of these minerals in rainwater of the study area have the tendency of causing health problems since large number of the populace in the study area patronise rainwater. Water low in calcium and magnesium, is associated with increased morbidity and mortality from cardiovascular diseases (CVDs) compared water high in magnesium and calcium (WHO, 2006). Although most essential nutrients are derived from food, the lack of minerals, including calcium and magnesium, in rainwater may represent a concern for those on a mineral-deficient diet (WHO, 2011). Also, the intake of soft water (water low in calcium and magnesium) may be associated with high risk of fracture in children. A few months exposure may be sufficient consumption time effects from water that is low in magnesium and/or calcium (Cobbina, Michael, Salifu, & Duwiejua, 2013).

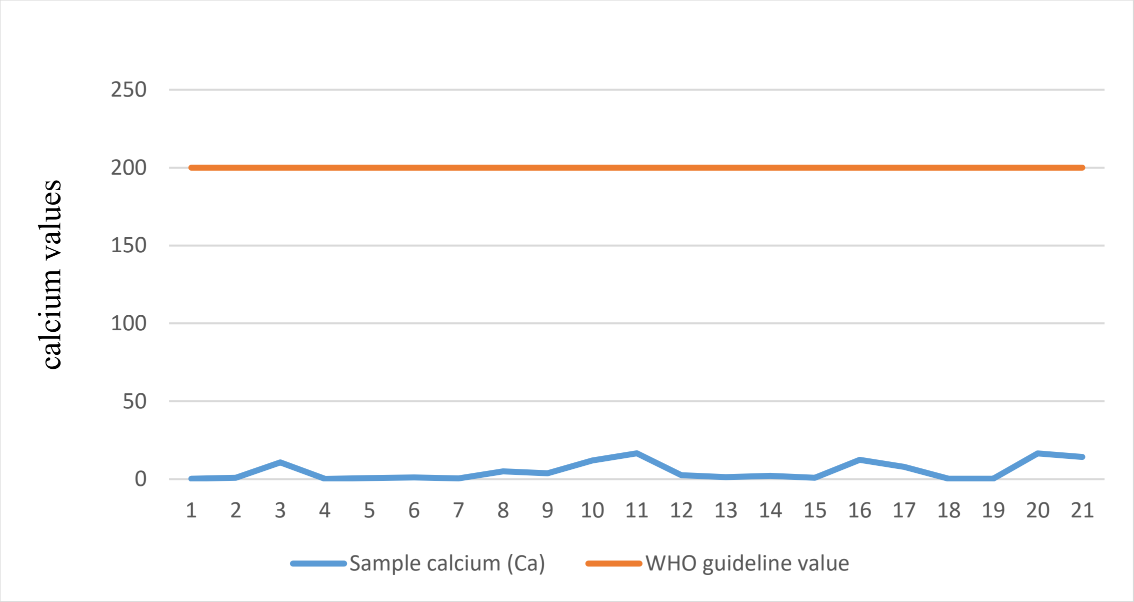

**Figure 10: Calcium values of samples against WHO guideline value**

**Source:** Field data, (2019)

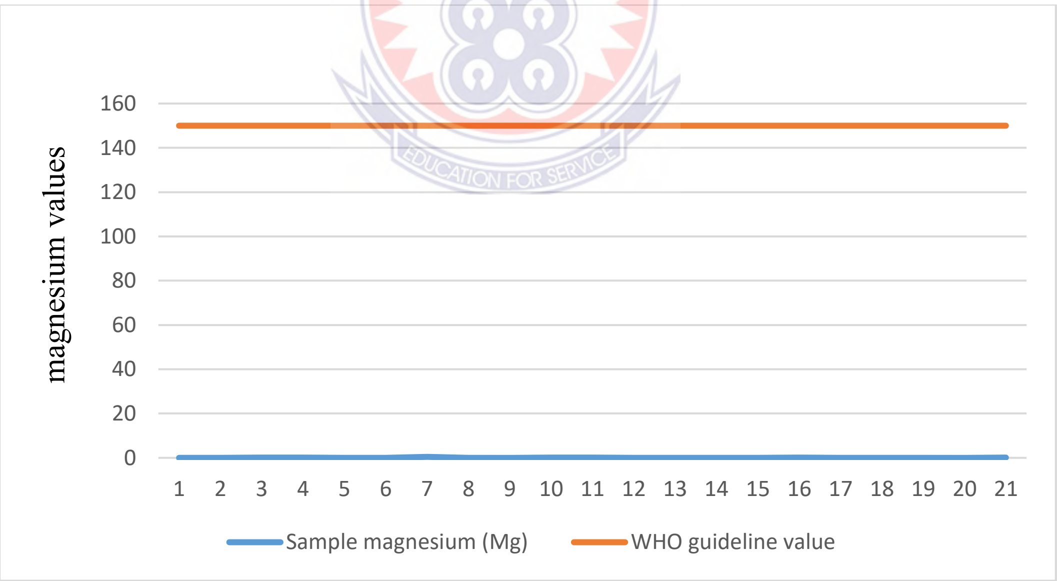

**Figure 11: Magnesium values of samples against WHO guideline value**

**Source:** Field data, (2019)

### *4.1.7 Iron*

The result of the laboratory analysis of mean concentration in rainwater yielded a mean value of 0.505 mg/l and a range range 0.024 mg/l to 1.251 mg/l , standard deviation 0.326, skewness 0.365, Kurtosis -0.363. With respect to distribution, higher values of Iron concentration were recorded around the 'main market' that is the central portion of the town. The southern part of the town ('Mpomam') followed, and then the northern part recorded the lower values. The mean concentration of iron is similar to observed values in Akwa Ibom, Nigeria (0.54 mg/l) (Ebong, Etuk, Ekong, & Dan, 2016) and in Ayanfuri, Ghana 0.51 mg/l (Amponsah, Bakobie, Cobbina, & Duwiejuah, 2015). This is unlike reported values of 0.00 mg/l from similar studies conducted by Issaka, (2011) in Central Gonja, Ghana, and Olaoye and Olaniyan, (2012) in Ogbomoso, Nigeria due to the absence of iron in the atmosphere. Radaideh, Al-Zboon, Al-Harahsheh, and Al-Adamat, (2009) and Akoto, Darko, and Nkansah, (2011) also recorded low values of 0.01 mg/l in Jordan and 0.11 mg/l in Obuasi, Ghana respectively.

The mean concentration of iron obtained and also recorded values of sixty-one percent (61%) of the samples were higher than the 0.3 mg/l (shown in Figure 12) recommended for potable water by WHO's guidelines for drinking-water quality (WHO, 2011). This implies that harvested rainwater has high concentration of iron which may be harmful for human consumption. The higher concentration of iron in rainwater of the study area could be attributed to anthropogenic activities such as burning of fossil and emissions from the timber company in the study area. From the literature review, high concentration of iron in water may result in iron toxicity and its attendants effects, stain laundry, dicolour vegetables upon cooking and cause reaction when added to tea (in which tannins are present) and whiskey (Ebong, Etuk, Ekong, & Dan, 2016;

Environmental Protection Agency, 2001; WHO, 2011). Thus, iron could be regarded as a pollutant in the study area, as the consumption of rainwater from these areas may interfere with household activities, result in iron toxicity and associated health implications in humans.

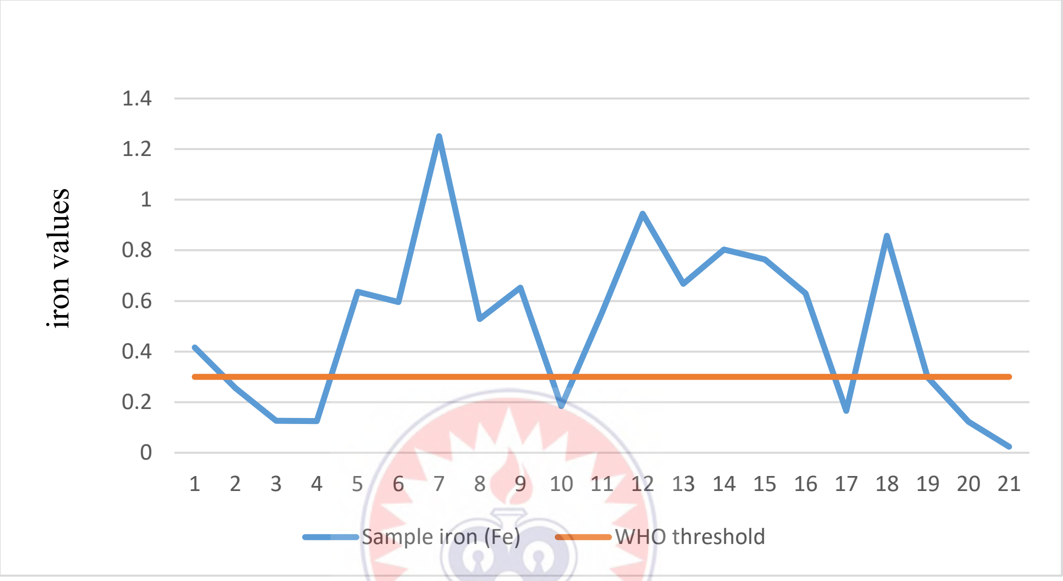

**Figure 12: Iron values of samples against WHO guideline value**

**Source:** Field data, (2019)

### *4.1.8 Lead*

Lead concentration had a mean 0.793 mg/l, minimum <0.01 (BDL), maximum 2.346 standard deviation 0.829, skewness 0.553 , and a Kurtosis of -1.092. In a similar study, Akoto, Darko, and Nkansah, (2011) recorded lower average lead values of 0.17 mg/l in Obuasi a mining community in Ghana, 0.05 mg/l by Ebong, Etuk, Ekong, and Dan, (2016) in Nigeria and 0.27 mg/l in Ghana (Amponsah, Bakobie, Cobbina, & Duwiejuah, 2015). The higher lead values were recorded in the roof catchments in the central and southern part of the study area, that is away from the Timber company in the study area. Twenty-nine percent (29%) of the sampled rainwater recorded below detection limit (<0.01, BDL) concentration, indicating that, lead concentration is negligible in some parts of the study area. Meanwhile over sixty percent (60%) of the recorded over 0.3 mg/l which exceeds the health guideline by the WHO. The mean concentration of 0.793 mg/l is far above the WHO threshold value of 0.01 mg/l for potability.

The higher lead concentration found in rainwater of up to 2.346 mg/l recorded in the study may be as a result of exhaust emissions from vehicles and other machines as well as the emissions of air pollutants from the timber company compounded wth the action of wind in entraining particulates into the atmosphere. Lead is a highly toxic and cumulative poison in the human body even at a very low concentration and exposure to it could result in problems of heart, kidney, liver and respiratory system in humans (WHO, 2006). Also, as noted by Ebong, Etuk, Ekong and Dan, (2016), it inhibits the essential functions of elements such as calcium, iron, copper and zinc in human body. I can therefore conclude form the result of the study that, rainwater in Sefwi Dwinase is lead polluted and not suitable for potable uses especially drinking and cooking.

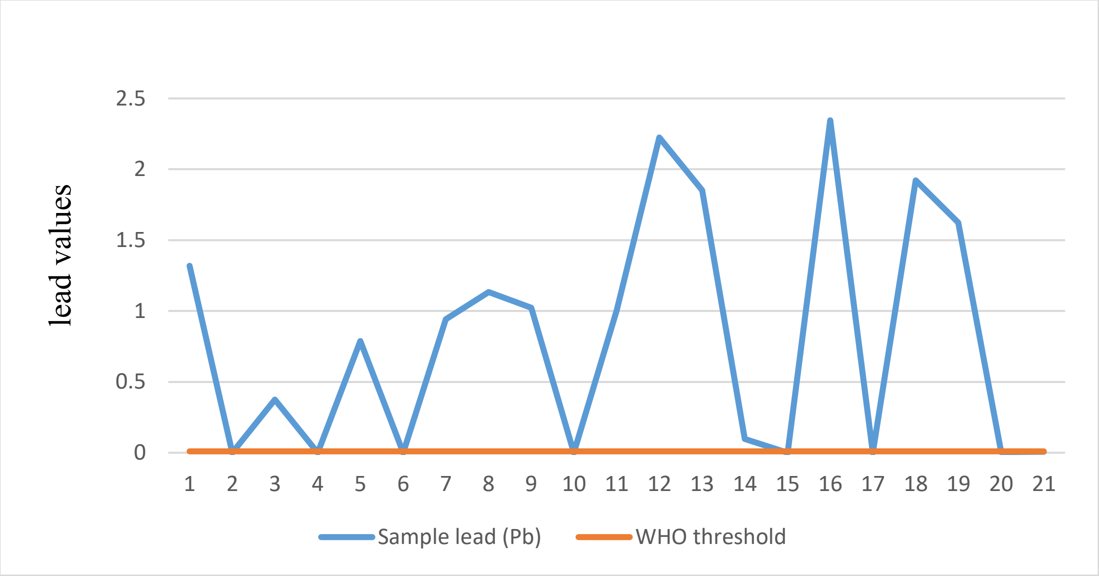

**Figure 13: Lead values of samples against WHO guideline value**

**Source:** Field data, (2019)

### *4.1.9 Total coliform (CFU/100 ml)*

Total coliform (TC) recorded for the study ranged from 0.00 CFU/100ml to 1000 x TMTC CFU/100ml (TMTC implies too many to count) a mean of 96.330 CFU/100ml standard deviation 300.436 , skewness 2.974, Kurtosis 7.561. The very high standard deviation value indicate that a lot of the sample values deviate from the mean value. This is confirmed by the high value of kurtosis explaining how pointed the distribution is. Figure 14 provides a visual presentation of the distribution of total coliform from the study. The distribution comprises extreme variations in TC values in the rainwater.

As shown in Figure 15, fifty-seven percent (57%) of the samples recorded zero values which means that they were within the WHO recommendation of not to be detected in a 100 ml of water (0 CFU/100ml). However, coliform baterials were present in the remaining samples, out of which two (2) recorded extreme values of over 1000 CFU/100ml. Most of the samples containing TC values were located in the southern part of the town where trees and birds are abudant. Interestingly, the open space rainwater in the northern part of the town contain TC counts. In similar studies, harvested rainwater were found to contain concentrations of Total coliform counts. Despins, Farahbakhsh and Leidl, (2009) observed lower values of Total coliform ranging from <1 (below detection limits) to 400 CFU/100ml and an average of 19.6 CFU/100ml in Ontario, Canada. Radaideh, Al-Zboon, Al-Harahsheh and Al-Adamat, (2009) also observed a mean total coliform value of 40 CFU/100ml in Jordan. However, higher mean TC of 129 CFU/100ml was reported by Vilane and Simiso, (2017) in Swatziland showing a possible high pathogenic pollution of rainwater and a range of 85 CFU/100ml to 205 CFU/100ml in Akwapim, Ghana.

The high concentration of total coliforms may be as a result of trees hanging in the vicinity with birds and other animals, which defecate on the roof catchment. Leaves and animal droppings contribute to organic loading of the rainwater samples, which in turn act as nutrient for bacterial growth (Olaoye & Olaniyan, 2012). The results from the study gives an indication that the rainwater could be pathogenically polluted which may lead to serious health problems, given the highly above WHO recommended figures recorded for coliform bacterials. Even though I did not test for the concentrations of pathogens, the presence of total coliforms, gives an indication of the general level of microbiological contamination of the rainwater as noted by Environmental Protection Agency, (2001).

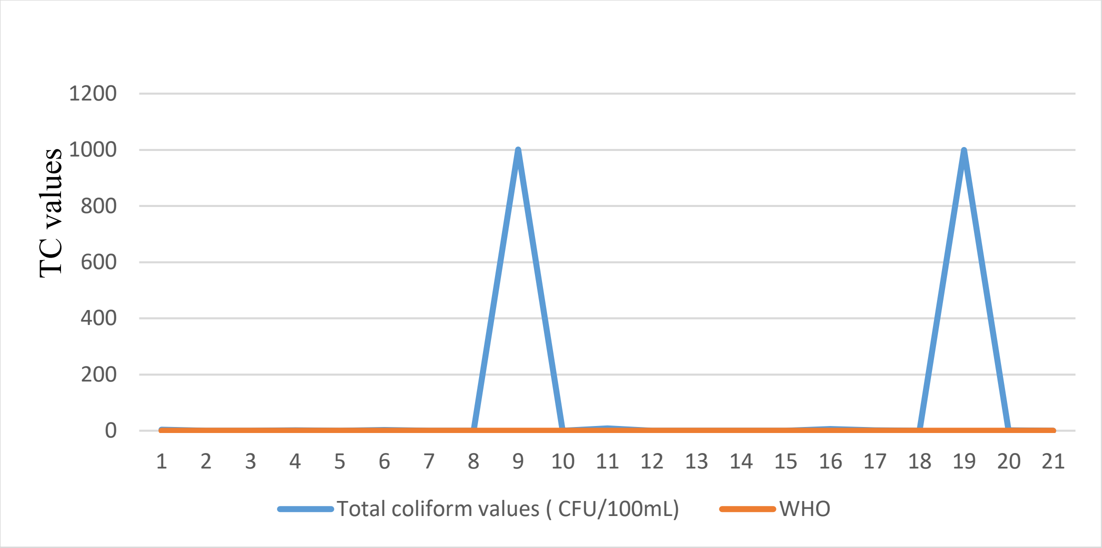

**Figure 14: Total coliform (TC) values of samples against WHO guideline value**

**Source:** Field data, (2019)

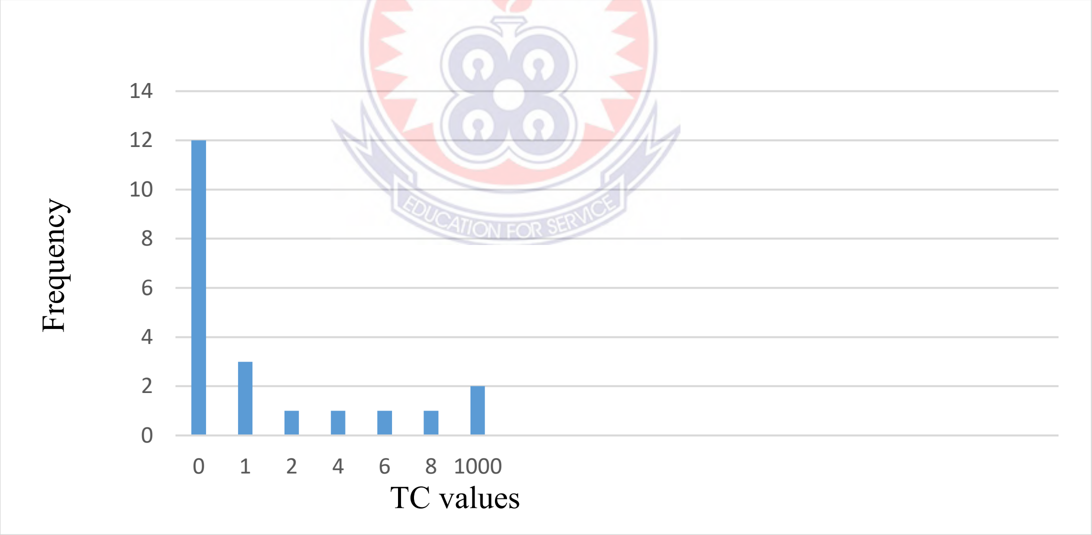

**Figure 15: Frequency distribution for Total coliform (TC)**

**Source:** Field data, (2019)

### *4.1.10 Correlation analysis*

Correlation analysis was done on the water quality parameters tested during the study. This was to ascertain the relationship of each parameter with the others and their implications. Table 3 shows the correlational values between the water quality parameters

**Table 3: Pearson correlation coefficient between the water properties studied**

*****. Correlation is significant at the 0.01 level (2-tailed).***

| **Para Meter** | **EC** | **TDS** | **pH** | **DOC** | **TH** | **Ca** | **Mg** | **Fe** | **Pb** | **TC** |
|---|---|---|---|---|---|---|---|---|---|---|
| EC | 1 | | | | | | | | | |
| TDS | 1.000** | 1 | | | | | | | | |
| pH | -.244 | -.248 | 1 | | | | | | | |
| DOC | .832** | .830** | -.028 | 1 | | | | | | |
| T H | .796** | .799** | -.518* | .595** | 1 | | | | | |
| Ca | .794** | .798** | -.517* | .597** | 1.000** | 1 | | | | |
| Mg | .154 | .155 | -.108 | .022 | .144 | .116 | 1 | | | |
| Fe | -.165 | -.168 | .140 | -.044 | -.463* | -.473* | .271 | 1 | | |
| Pb | .071 | .070 | .162 | .068 | -.179 | -.178 | -.061 | .504* | 1 | |
| TC | -.094 | -.095 | .287 | -.004 | -.181 | -.178 | -.128 | -.031 | .215 | 1 |

****. Correlation is significant at the 0.05 level (2-tailed)***

**Source:** Field data, (2019)

From Table 3, electrical conductivity and total dissolved solids have a perfect positive relationship ( r value 1.000) at significant level of 0.01. This proves that they are from the same source just as Abulude, Ndamitso, and Abdulkadir, (2018) noticed from their study. Again, EC and TDS each has strong positive relationship with dissolved organic carbon, total hardness and calcium. The parameters - electrical conductivity, total dissolved solids, dissolved organic carbon, total hardness and calcium are a measure of the ions and particulate matter in the atmosphere (Cobbina, Michael, Salifu, &

Duwiejua, 2013), therefore as the ions and particulate matter pollution increases, each of these variables increases. This is evident by their strong positive correlation with each other which is significant at the 0.01 level. Apart from magnesium, lead and total coliform total hardness had a very strong positive relationship with all the parameters significant at the 0.01 level (99%) significant. Total hardness had a perfect correlation with Calcium, that is an r value of 1.000 significant at 0.01 level. This indicates that the major constituents of hardness in the study area is calcium. Magnesium has less effect on the total hardness, and this is in line with WHO, (2006) report that “hardness in water is caused by dissolved calcium and, to a lesser extent, magnesium. It is usually expressed as the equivalent quantity of calcium carbonate”. Total hardness also had strong negative relationship with pH and iron, that is Total harness increases as pH and iron decreases. This shows that Total hardness increases as pH and Iron decreases. Hence the more acidic rainwater is, the harder it becomes since it is able to dissolve more calcium and magnesium content. Moreover, the result shows that, pH had significant negative relationship with all the physico-chemical parameters of the water. This is consistent with Ebong, Etuk, Ekong, and Dan, (2016) study in Akwa Ibom, Nigeria where pH had significant negative relationship with Total dissolved solids. pH correlated positively with the trace metals (Iron and Lead) and microbial aspect (Total coliform). But this relationship was not significant. This proves that the lesser the pH value of rainwater (the more acidic), the more polluted the water. The result is however not consistent with Abulude, Ndamitso, and Abdulkadir, (2018) who reported that, pH had significant positive relationship with the other physico-chemical properties of the water samples in Akure. The influence of crustal aerosols in neutralizng the acid content of rain was identified as the cause of the relationship.

Iron (Fe) has a significant positive relationship of 0.504 (significant at 0.05 level) with Lead (Pb). Iron and Lead each has weak relationships with the other parameters except for Total hardness and Calcium. Fe had a Strong negative relationship with Total hardness and Calcium having a correlation coefficient of - 0.463 and -0.473 (significant at the 0.05 level) respectively. This implies that, as one parameter increases, the other increases as well. This result is consistent with the correlational coefficeint between Iron and Lead observed by Ebong, Etuk, Ekong, & Dan, (2016) where a positive significant correlation coefficient of 0.903 was observed between Fe and Pb.Whereas Pb had an insignificant negative relationship with Total hardness and Calcium. Iron and Lead significantly increase as Total hardness and calcium decrease (indicated by their negative correlation). Finally, Total coliform has very weak negative correlation with almost all the water quality parameters tested except for pH and Lead which it has positive relationship with. As the water becomes more alkaline (pH increases), Total coliform icreases, because bacterials and pathogens do not thrive in acidic water.

### 4.3 Effects of Different Roof Materials on Rainwater Quality.

To analyse rainwater quality before it is stored in storage tanks and also the impacts of roof materials on rain quality, rainwater samples were collected in open space (direct rainfall) and over three common roofing materials in the study area. The roofing materials used in the study were plain aluminium, colour-coated galvanized and flat concrete roof. From the study, pH was higher in the colour-coated galvanized roof rainwater, this roofing type leached more alkaline water. Flat concrete roofs leached more acidic rainwater than the other roofing materials. For electrical conductivity, total dissolved solids, dissolved organic carbon, calcium and total hardness, flat concrete roof recorded higher values in all these physico-chemical parameters, followed by plain aluminium roof and colour-coated galvanized roof. However, plain aluminium roof recorded the least magnesium values, while flat concrete roof recorded the highest values. Similarly Olaoye and Olaniyan, (2012) in their study on ‘Quality of rainwater in different roofing materials’ observed magnesium values to be lowest in plain aluminium roofs where as concrete roofs recorded the highest magnesium values. It must however be noted that all the physico-chemical parameters except pH fell within the WHO standard guideline values for drinking water. Nonetheless, flat concrete roofing mateial recorded much higher parametric values (with pronounce difference/ margin with the other roofing materials) in rainwater in the study area. This conforms to Mendez, et al., (2011) who found out from their investigation of ‘The effect of roofing material on the quality of harvested rainwater’ in Austin, Texas that, metal roofs dissolves least concentrations of most physico-chemical features or parameters of harvested rainwater.

With regars to trace metals, plain aluminium roofing material proved to leach the highest iron concentrations in rainwater in Sefwi Dwinase, while flat concrete roof produced the least iron values. Colour-coated galvanized roof leached higher lead concentrations in rainwater than the other roofing materials. This is probably due to the paint/colour coatings of this roofing type. Flat concrete recorded the next higher values while plain aluminium recorded the least values. Lead is a very poisonous metal/substance and consumption of it leads to detrimental health implications. Plain aluminium roof was also noticed to leach the least lead concentrations by Ojo, (2019). The result is however, in contrast with Olaoye and Olaniyan, (2012) who noticed from their study that roof materials have no impact on iron content in rainwater since all the samples recorded zero (0) values for iron concentration.

Total coliform as a bacterial indicator of the water quality in Sefwi Dwinase was recorded in all the selected roofing materials for the study. But, though about 67 percent each of thier samples recorded zero values, colour-coated galvanized roof and aluminium roof recorded the highest mean values of total coliform in the study. Meanwhile, flat concrete roofs recorded the lowest mean value with total coliform present in about 67 percent of the samples recorded from flat concrete roof. This means that all the roofing types were not free from pathogenic contamination. This is in contrast with Olaoye and Olaniyan, (2012) who acknowledged aluminium roofing sheets to be the most suitable for rainwater harvesting in Ogbomoso, Nigeria because the samples taken from that roofing material had no coliform, indicating that it was free from pathogenic contamination. However, this contamination is closely associated with poor hygiene on roof catchments and water storage. But risks can be minimized by good design and maintaining good practice/hygiene as advised by WHO, 2011.

The average concentrations of all the parameters for each of the roof materials analyzed and presented in Table 4 to 7.

### *4.3.1 Plain aluminium roof*

The mean pH value of rainwater samples collected over plain aluminum roofs (6.7) was similar to the overall mean pH recorded for the study (6.738). This value is above that of rain over flat concrete roof and lower than rain over galvanized roofs. The pH value was within the WHO standard for potability. The other physico-chemical properties, that is electrical conductivity, total dissolved solids, dissolved organic carbon, calcium, magnesium and total hardness all recorded mean values that are below their corresponding overall mean values of the study. Again, these values are higher than rain collected over galvanized roofs, but lower than flat concrete rainwater. The mean values of the physico-chemical properties were within the WHO guideline values for the respective parameters. Mean value of 0.66mg/l for iron was higher than the general mean of the study, whereas lead recorded a lower mean of 0.507mg/l compared to the general mean of 0.793mg/l for the study. However, these Fe and Pb values were above the WHO standard of 0.3mg/l and 0.01mg/l respectively. Plain aluminum roof leached higher values of iron in the rainwater than the other roofing materials, while it leached the lowest mean lead. Total coliform had a mean of 167 CFU/100µL which is higher than the general mean and far above the WHO health guideline value of 0 CFU/100µL. Table 4 summarizes the studied physico-chemical, trace metal and microbial properties of the rainwater collected over aluminum roofs.

**Table 4: Rainwater quality properties average result for plain aluminum roofs**

| | **pH** | **EC (µS/cm)** | **TDS (mg/l)** | **DOC (mg/l)** | **TC (CFU/100µL)** | **Fe (mg/l)** | **Ca (mg/l)** | **Mg (mg/l)** | **Pb (mg/l)** | **TH (mg/l)** |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 6.7 | 19.807 | 9.897 | 1.582 | 167 | 0.663 | 2.297 | 0.005 | 0.507 | 5.76 |
| WHO standard | 6.5 to 8.5 | 300 | 1000 | - | 0 | 0.3 | 200 | 150 | 0.01 | 500 |

**Source:** Field data, (2019)

### *4.3.2 Colour-coated galvanized roof*

Rainwater samples collected over colour-coated galvanized roofs recorded mean pH of 6.98 which was above overall mean pH recorded for the study (6.738). This value is higher than the other roofing materials. The pH value was within the WHO standard for potability. All the other physico-chemical properties, that is EC, TDS, DOC, Ca, Mg and TH had mean values that are below their respective general mean values of the study. Colour-coated galvanized roof recorded the least mean values of the physico-chemical properties of the rain samples against rain collected over plain aluminium roofs and flat concrete roofs. All these values were within the WHO guideline values for the respective parameters. Mean value of Fe was similar to the general mean of the study (0.5), whereas Pb recorded a much higher mean of 1.27mg/l compared to the general mean of 0.793mg/l for the study. These values were above the WHO limit of 0.3mg/l and 0.01mg/l respectively. Colour-coated galvanized roof leached higher values of Lead in the rainwater compared to the other roofing materials. Total Coliform had a mean of 166.8 CFU/100µL which is higher than the general mean and far above the WHO health guideline value of 0 CFU/100µL. Table 5 summarizes the studied physico-chemical, trace metal and microbial properties of the rainwater collected over colour-coated galvanized roof.

**Table 5: Rainwater quality properties average result for colour-coated galvanized roofs**

| | pH | EC (µS/cm) | TDS (mg/l) | DOC (mg/l) | TC (CFU/100µL) | Fe (mg/l) | Ca (mg/l) | Mg (mg/l) | Pb (mg/l) | TH (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 6.983 | 9.432 | 4.693 | 1.413 | 166.833 | 0.525 | 0.899 | 0.027 | 1.27 | 2.358 |
| WHO standard | 6.5 to 8.5 | 300 | 1000 | - | 0 | 0.3 | 200 | 150 | 0.01 | 500 |

**Source:** Field data, (2019)

### *4.3.3 Flat concrete roof*

The maximum individual sample values of pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved organic carbon (DOC), calcium (Ca), total hardness (TH) and lead (Pb) (shown in Table 2) were recorded from rainwater colllected over flat concrete roofs. This means that rainwater collected over flat concrete may not be suitable for domestic uses. However, the lead maximum was an isolated case of a were carpentry where wood shavings and other waste are constantly burnt, which could contribute to the higher concentration of lead. Meanwhile, majority of the remaining samples recorded lower values up to zero. Flat concrete roof recorded the least mean pH values of rainwater (6.68) compared to the samples collected over the other roofs as well as the overall mean pH recorded for the study (6.738). The pH value was within the WHO standard for potability. The mean values of EC, TDS, DOC, Ca, Mg and TH exceeded their corresponding overall mean values of the study. Again, the values of these properties were higher than rain collected over colour-coated galvanized roofs and plain aluminium roofs. However, the mean values of the physico-chemical properties were within the WHO guideline values. Iron (Fe) recorded a mean of 0.297mg/l and lead (Pb) mean of 0.621mg/l which are all less than the general mean of 0.505mg/l and 0.793mg/l respectively. Flat concrete roof recorded the least mean Fe compared to the other roofing materials. The mean Fe was below the WHO threshold of 0.3mg/l, whilst Pb exceeded the threshold of 0.01mg/l. Total coliform (TC) had a mean of 2.667 CFU/100µL which is lower than the general mean but above the WHO health guideline value of 0 CFU/100µL. Table 6 summarizes the studied physico-chemical, trace metal and microbial properties of the rainwater collected over flat concrete roof.

**Table 6: Rainwater quality properties average result for flat concrete roofs**

| | **pH** | **EC (µS/cm)** | **TDS (Mg/L)** | **DOC (mg/l)** | **TC (CFU/100µL)** | **Fe (Mg/L)** | **Ca (Mg/L)** | **Mg (Mg/L)** | **Pb (Mg/L)** | **TH (Mg/L)** |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 6.683 | 68.633 | 34.317 | 2.205 | 2.667 | 0.297 | 12.643 | 0.074 | 0.621 | 31.91 |
| WHO standard | 6.5 to 8.5 | 300 | 1000 | - | 0 | 0.3 | 200 | 150 | 0.01 | 500 |

**Source:** Field data, (2019)

### *4.3.4 Open space*

Interestingly, rainwater collected in open environment recorded the highest individual values (maximum values) for iron and magnesium as well as lowest pH (most acidic). The minimum sample values of EC, DOC and fe (shown in Table 2) were recorded from open space. The iron and magnesium maximum values were isolated case around the main market where a lot of anhtropogenic activities that pollute the air take place. This sample influenced the mean values of the other properties of rainwater collected in open space. Meanwhile, the remaining samples recorded lower values for Fe and Mg (minimum for the study). The open space water samples had mean pH of 6.43 which falls outside the WHO guideline range of 6.5 to 8.5. This indicates that, rainwater is slightly acidic in the study area. This value is lower than rainwater collected over roofs from the study. The mean values of EC, TDS, DOC, Ca, Mg and TH were below their respective overall mean values of the study. The values of EC, TDS and DOC were lower than that of rain collected over roof materials. Ca, Mg and TH were however higher than some of the roof materials. The mean values of these physico-chemical properties were within the WHO guideline values. Fe and Pb recorded mean values which are similar to their respective general mean for the study. However, these values are higher than some of the values recorded from roof materials. The mean iron and lead exceeded the WHO threshold although some were below. Total coliform had a mean of 1.33 CFU/100µL which is lower than the general mean and the samples collected from the roof materials. But this value is above the WHO health guideline value of 0 CFU/100µL. Table 7 summarizes the studied physico-chemical, trace metal and microbial properties of the rainwater collected in open space.

**Table 7: Rainwater quality properties average result for open space**

| | pH | EC (µS/cm) | TDS (Mg/L) | DOC (Mg/L) | TC (CFU/100µL) | Fe (Mg/L) | Ca (Mg/L) | Mg (Mg/L) | Pb (Mg/L) | TH (Mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 6.433 | 5.657 | 2.993 | 1.217 | 1.333 | 0.564 | 4.973 | 0.167 | 0.756 | 13.119 |
| WHO standard | 6.5 to 8.5 | 300 | 1000 | - | 0 | 0.3 | 200 | 150 | 0.01 | 500 |

**Source:** Field data, (2019)

### *4.3.5 Relationship between rainwater collected over rooftop and open space rainwater*

An independent-sample T test was run between roof harvested rain and open space rain with alpha value of 0.05 and the result is presented in table 8. It can be noticed from the table that, apart from Magnesium and Iron, equal variances are assumed for all the parameters (that is significant value of F test is greater than the alpha value of 0.05). For Magnesium and Iron equal variances are not assumed since the significant value of F tests are less than the alpha value of 0.05.

**Table 8: Independent-sample T test between roof harvested rain and open space rain**

| | F | Sig. | T | Sig. (2-tailed) | Mean Difference | Std. Error Difference |
|---|---|---|---|---|---|---|
| **Ph** | .008 | .932 | 1.644 | .117 | .356 | .216 |
| **Total dissolved solids** | 4.045 | .059 | 1.446 | .165 | 13.311 | 9.207 |
| **Electrical conductivity** | 3.887 | .063 | 1.463 | .160 | 26.952 | 18.417 |
| **Dissolved organic carbon** | 2.197 | .155 | 2.001 | .060 | .516 | .258 |
| **Total hardness** | .409 | .530 | .024 | .981 | .224 | 9.504 |
| **Calcium** | .542 | .471 | .081 | .936 | .306 | 3.787 |
| **Magnesium** | 26.54 | .000 | -.948 | .442 | -.132 | .149 |
| **Iron** | 5.471 | .030 | -.186 | .868 | -.069 | .368 |
| **Lead** | 1.036 | .321 | .083 | .935 | .044 | .530 |
| **Total coliform** | 1.741 | .203 | .582 | .568 | 110.833 | 190.533 |

**Source:** Field data, (2019)

The significant value of the t test for all the parameters are above the the alpha value of 0.05. That is most of the water quality parameter concentrations of the direct or open space rainfall did not significantly differ from that of the roof harvested rainwater. This implies that, there is no statistically significant relationship between the properties of rain collected over roof materials and that of the rainwater collected in open space based on the analyzed parameters. This is supported by their smaller mean difference values (almost insignificant in some of the parameters ). Some of the parameters were higher or of low quality than the water collected over roofing materials. For instance, the open space rainwater recorded the most acidic values from the study (that is a range of 6.0 – 6.8 and a mean of 6.4.). This finding is in line with Apraku and Adu-Kumi, (2014) who noticed pH values in direct or open space rainfall to be less than roof catchment as well as storage tanks in their study conducted in Akwapim Ghana. They attributed the more acidic pH experienced from the direct fall to be the interaction between the rainwater and lower levels of effluents from industrial activities and vehicular emissions in the atmosphere. The lowest pH values recorded in my study for open environment rainfall suggest that, the presence of alkaline particles in the samples were not high enough to neutralize acidic species available in the water in line with Abulude, Ndamitso, & Abdulkadir,(2018). While roof surfaces may have alkaline particles settling on them from dry deposition, which neutralizes the slightly acidic rainwater to make them more basic.

Moreover, the result of the independent-sample T test is an evidence of accepting the null hypothesis that ‘there is no statistically significant relationship between the properties of rain collected over roof materials and that of the rainwater collected in open space’. Although there was a positive relationship between the properties of rain collected over roof materials and that of the rainwater collected in open space, it was not statistically significant, therefore the alternate hypothesis was rejected.

### 4.4 Efficient uses of rainwater.

The overall quality of rainwater in Sefwi Dwinase had some issues with trace metal concentrations, microbial concentrations in some cases and pH in few instances. The rainwater therefore requires treatment before it can be used for potable purposes. It is important to identify the primary factors and sources accounting for the low water quality in the time. This will help determine appropriate treatment to enhance the quality of the harvested water before usage. Principal components analysis (PCA) was performed on the water quality properties with a view to identify the major variables that affect the water quality in the study area and associate their possible sources. The analysis was done in other to better understand the underlying course of the water quality to be able to estimate the potential uses with respect to possible health risk. The factor loading matrix of the principal component analysis are presented in Table 9. Significant components were picked on the basis of an eigenvalue > 1. The PCA showed the most vital factors that affected the water quality of the study area. PCA yielded in total three significant factors, explaining about 76.5% of the total data variance. Loadings of the Direct Oblimin rotated factors are presented in Table 9.

**Table 9: Factor loadings matrix obtained from rainwater properties in Sefwi Dwinase**

| Variables | Factor 1 | Factor 2 | Factor 3 |
|---|---|---|---|
| Total dissolved solids | .980* | .091 | -.022 |
| Electrical conductivity | .980* | .094 | -.019 |
| Dissolved organic carbon | .900* | .173 | .177 |
| Calcium | .820* | -.330 | -.185 |
| Total hardness | .819* | -.317 | -.204 |
| Iron | -.187 | .890* | -.243 |
| Lead | .169 | .734* | .238 |
| Total coliform | .054 | .072 | .710* |
| Magnesium | .064 | .395 | -.657 |
| Ph | -.191 | .272 | .592* |
| Total variance | 45.4% | 17.6% | 13.5% |
| Probable origin | Soil | Anthropogenic | Biological and Anthropogenic |

***Factors >0.5 are considered significant***

**Source:** Field data, (2019)

Factor 1 explained about 45.4% of the total variance, with strong positive loadings for TDS, EC, DOC, Ca, and TH, showing a high influence of crustal contribution in the atmosphere of the study area, these ions were mostly provided by soil and road dust. Volatile organic compounds (VOC) from vegetation and forest fires also contributes to this factor owing to the higher DOC loading. Factor 2, which explained 17.6% of the total variance, showed strong positive loading for Fe and Pb. This factor is a loading of pollution mainly caused by anthropogenic sources, such as automobile exhaust, waste burning and industrial processes. The anthropogenic factor increases the impacts of trace metals (originating from anthropogenic activities) notably lead in Sefwi Dwinase poses health risk which may render the rainwater unsuitable for drinking and food preparation. Khayan, Husodo, Astuti, Sudarmadji and Djohan, (2019) posited that filtration and absorption is the best option for decreasing heavy metal content in rainwater especially Lead. With this method, filtration tube combined with gravel, mollusk sand and activated carbon or activated charcoal which are arranged systematically can be used for filtration. Factor 3 presented a strong positive loading for TC and pH, and a strong negative loading for Mg, explaining 13.5% of the total variance. This is commonly associated to both biological and anthropogenic origin. Mainly from animals defecates and leave droppings in roof catchments, dust particles from roads and markets, and other human activities. The biological factor presents health risks associated with pathogenic infection. Rainwater in Sefwi Dwinase may therefore cause illness upon consumption. It is however noticed that the risk of contracting illness from rainwater harvested from well-maintained roof catchments is very low, although it should be noted that the risk increases with less maintenance and cleaning, and in the absence of a first flush diverter (this prevents the polluted first rain after a long dry period from entering a harvesting container) (enHealth, 2011). Disinfecting or boiling rainwater will also render it pathogenically safe for both potable and non-potable uses.

Therefore, soil especially the regional rock formation contributes more to the water quality in the study area. This is followed by anthropogenic activities which mainly increase the trace metal concentration and then biological contributors which account for the presence of possible pathogen counts in some areas. However, the soil factor does not have negative health implication since the variables in that factor recorded values which fall within the WHO guideline values. Hence the main concerns are the anthropogenic and biological factors which have health implications on consumers.

This finding is consistent with Cerqueira, et al., (2014) who found out that, crustal source mainly soils and road dust was the main contributor of the water quality in Juiz de Fora City, Brazil, while anthropogenic source was the second contributor. However, the impacts of the soil factor on the concentrations of the physico-chemical properties does not pose any health risk upon consumption. Meanwhile the impacts of trace metals originating from human activities especially lead as well as pathogenic threat from biological factor in Sefwi Dwinase pose health risk which renders the rainwater unsuitable for drinking and other domestic activities. This situation according to enHealth, (2011) is especially dangerous for particular vulnerable groups, such as pregnant or breastfeeding women and young children.

Garrison, Kloss, & Lukes, (2011); enHealth, (2011), outline some potable and non-potable uses that rainwater could be used for. The potable uses of rainwater include drinking, showers/baths, dishwashing, cooking and other kitchen activities, faucets and other uses. Non-potable uses could be either for indoor uses or outdoor uses. Non-potable indoor uses include clothes washing/ laundry usage, toilets/urinals flushing and cooling. While non-potable outdoor uses are garden watering, replenishing domestic pools or spas, car washing, supplying the hot water system, thermal buffers to insulate houses, ventilation for buildings and protecting homes from bushfires. Washing floors, watering garden and grass are other non-potable uses and for such uses, treatment is not required (Mohammed, Mohd Noor, & Ghazali, 2006). Rainwater in Sefwi Dwinase can be used for both indoor and outdoor non-potable uses without treatment. This include toilet flushing, cleaning floor, washing clothes, car wash and agricultural and landscape irrigation. Even though such uses require little or no treatment, the higher concentrations of iron in the rainwater from the study may stain clothes when used for laundry as noted by WHO, 2011. Therefore, the water needs to be treated when it is to be used for continuous or long-term washing. Again, the concentrations of most of the properties of the rainwater detected in rooftop runoff are similar to the concentrations in open environment rainwater. As such, these contaminants are unlikely to result in intolerable residues in crop produce (such as edible plants, fruits, and vegetables), especially when they bind with soil particles and organic matter on the ground as observed by Debusk, Hunt, Osmond, and Cope, (2011).

As noted by Owusu & Asante (2020), the predominant potable uses of rainwater is for bathing and cooking. However, appropriate filtration and disinfection practices should be employed before it can be used for such purposes. The trace metal and bacterial contaminants renders rainwater in the study area unsafe for drinking and other potable uses like cooking, dishwashing and bathing. Meanwhile, harvested rainwater may be used for potable uses if it is appropriately treated. Debusk, Hunt, Osmond, & Cope, (2011) suggests that, filtration and ultraviolet light disinfection can be used to treat roof harvested rainwater for potable uses. A maximum filtration of 1 micron may remove particulate matter and dissolved solids (such as lead), as well as most parasites and bacteria. Different types of filters exist for filtration. For instance, it could be a combination of sediments, ceramic and activated carbon/activated charcoal or a combination of gravel, mollusk sand and activated carbon/activated charcoal (Debusk, Hunt, Osmond, & Cope, 2011; Khayan, Husodo, Astuti, Sudarmadji, & Djohan, 2019). With appropriate treatment, rainwater in Sefwi Dwinase can be harvested, stored and used for both potable and non-potable uses.

### 4.5 Summary of Empirical Evidence in relation to the Conceptual Framework

The results from the study shows that, the quality of rainwater from the study area is affected by wet and dry deposition resulting from human activities, soil and biological factors and also Aluminium, flat concrete and colour-coated galvanized roofing materials. Roofing materials in turn affect dry deposition as it stores some amounts of pollutants and particulate matter to be later washed by the rain. For instance, flat concrete roofs from the study had more ions which resulted in higher physico-chemical concentrations as compared to the other roofing types.

These factors lead to the low rainwater quality which is indicated by higher concentrations of trace metals (Iron and Lead) as well as higher levels of Total coliform an indication of pathogenic contamination. The physico-chemical concentrations are however low, that is they fell within the WHO value for potability. Based on its quality, the rainwater can be directly used for non-potable purposes such as irrigation, flushing toilets and cleaning floors. However, to be able to put the rainwater to potable uses such as drinking and bathing without possible health implications, it needs to undergo treatment such as the slow filtration method to get rid of the trace metal and pathogenic pollution. Figure 16 below summarizes this work in relation to the conceptual framework

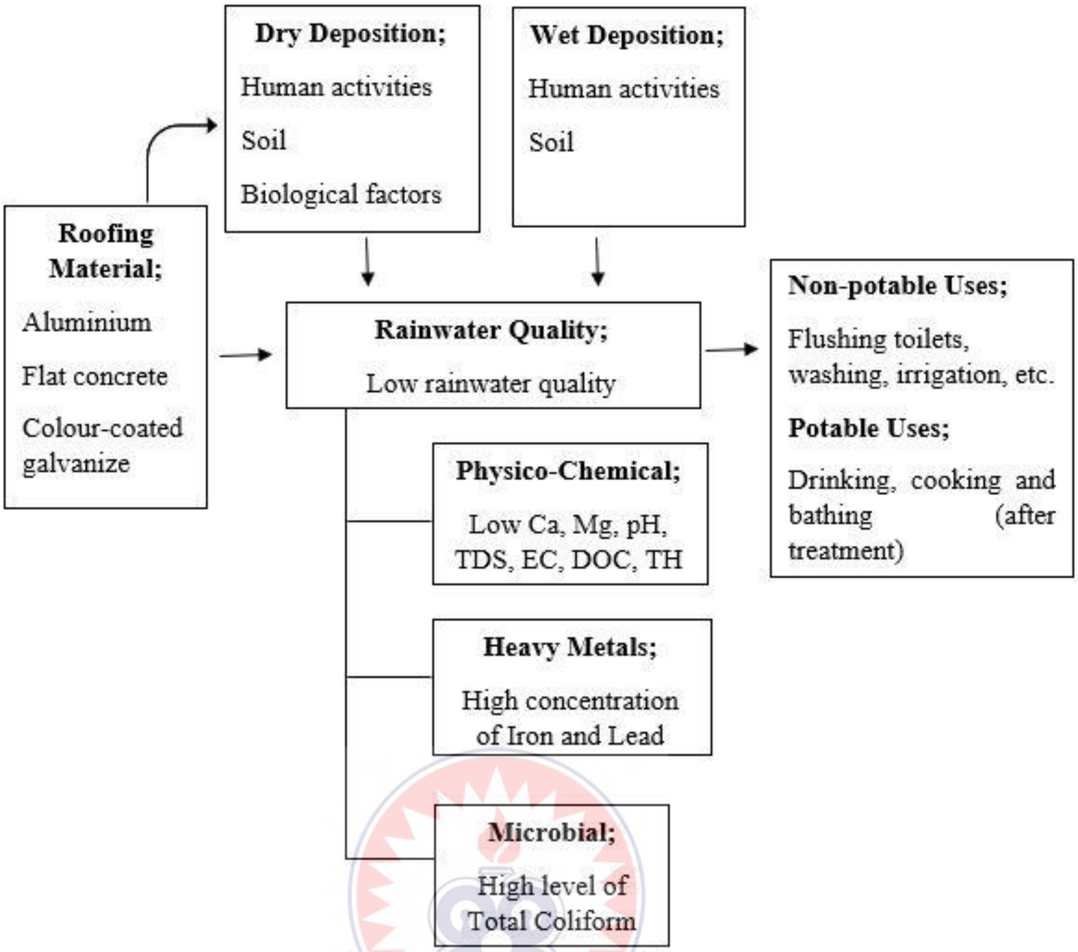

**Figure 16: Empirical evidence in relation to the conceptual framework**

**Source:** Author's construct, (2020)

# CHAPTER FIVE

# SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

## 5.0 Introduction

This chapter summarizes the findings derived from the analysis and discussions of the results. Conclusions are drawn on the rainwater quality of Sefwi Dwinase based on the findings. And finally, recommendations are made for the study.

## 5.1 Summary of findings

This section presents a summary of the major findings from the analysis and discussions of the study. The following are the major findings from the study.

- Almost all the parameters analyzed in the study had higher concentrations in the central and southern parts of the study area. The concentrations of the physico-chemical properties of rainwater (EC, TDS, DOC, T.H, Ca and Mg) in the study area fell within the WHO guidelines for potability indicating that, the particulate matter resulting from dust, sooth, and others does not affect the rain quality beyond limit. However, the pH of same samples was slightly acidic, that is, they fell below the WHO minimum value of 6.5. Again, Iron and Lead were found to be of higher concentrations above the guideline value of 0.3mg/l and 0.01 mg/l by the WHO this shows that anthropogenic activities such as exhaust emissions from vehicles and other machines are high and thus affect the air quality.

- All the three roofing materials recorded similar concentrations of physico-chemical and bacterial parameters. However, plain aluminium leached higher Iron, Colour-coated galvanized roof leached the highest Lead while Flat concrete roof recorded the more acidic concentration. The lowest pH values were recorded from open environment rainfall, suggesting that, the presence of alkaline particles were not high enough to neutralize acidic species available in the water. The result of the study and the T test between roof harvested rain and open space rain revealed that, though roof material affect water quality, the relationship was not statistically significant. This is because most of the water quality properties of the direct or open space rainfall did not significantly differ from roof harvested rainwater.
- Moreover, anthropogenic and biological factors increase the impacts of trace metals notably Lead and Total coliform in Sefwi Dwinase. These factors render the rainwater unsuitable for drinking and food preparation especially by particular vulnerable groups such as pregnant women and young children. However, with appropriate treatment, the rainwater could be used for potable uses such as; cooking and bathing, as well as non-potable uses including toilet flushing, cleaning floor, washing clothes, car wash and agricultural and landscape irrigation.

## 5.2 Conclusion

- The study focused on analyzing the rainwater quality of Sefwi Dwinase and how it can be efficiently put to use by householders. With the exception of pH, all the physico-chemical parameters of the rainwater in the study area fell within the WHO guideline value for drinking water and may be fit for drinking. The pH of some samples were slightly acidic, but it is not too low to be considered as acid rain, and as such may not directly cause health problems for consumers. The trace metals concentrations of rain in the study were however, higher than the WHO guideline value for drinking water, thus the rainwater is polluted with trace metals. Total coliform was present in half of the samples; an indication that rainwater could be pathogenically polluted, given the highly above WHO recommended value recorded for coliform bacterials.

- Further, none of the roofing materials investigated in the study proved to be best for rainwater harvesting. However, plain aluminium roof is slightly advantageous over flat concrete roof and colour-coated galvanized roof, because it leached the least Lead concentrations. Also, the results of the study revealed that, most of the water quality parameter concentrations of the direct or open space rainfall did not significantly differ from roof harvested rainwater. Hence the effect of roofing materials on the quality of rainwater is not statistically significant.

- Finally, although the rainwater can be promoted for subsistence, domestic and industrial purposes, the impacts of trace metals originating from human activities especially lead and pathogenic threat from biological factor in Sefwi Dwinase render untreated rainwater unsuitable for potable uses especially drinking. This is because of the health implications of these parameters. Meanwhile with with proper treatment, the use of rainwater for indoor non-potable uses, such as toilet flushing, washing clothes and cleaning floors represents a substantial opportunity for the more efficient use of water resources.

### 5.3 Recommendations

The following recommendations are suggested based on the major findings and conclusions of my study.

- Rainwater harvesting systems can be installed in the town by especially, public institutions such as schools and hospitals to augment water supply from the few boreholes and hand dug wells in the town. Since the northern part of the town (around Roman church and eighteen mu) recorded fewer concentrations of the parameter, it may be cost effective to install harvesting systems in those places. But the hilly areas could also be considered because rainwater harvesting could be the cheapest means of water supply. Rainwater from harvesting systems should be regularly tested to monitor heavy metals and pathogenic contaminations.
- Plain aluminium roofing materials could be used for rainwater harvesting by householders and institutions such as schools and hospitals. The roof catchment should be well cleaned regularly to reduce pathogenic contamination and accumulation of particulate matter from dry deposition.
- Also, individuals and householders can treat harvested rainwater by boiling or exposing it to the sun (when they are in polythene bottles) and disinfected by adding chlorine or alum prior to potable use either than drinking. Meanwhile the heavy metal content in water require further treatment before it can be used for drinking. The municipal assembly, Ghana water company, other public and private organizations should help treat rainwater through methods such as slow filtration using tubes of well-arranged filters such as gravel, mollusk sand and

activated carbon/activated charcoal to remove traces of heavy metals in harvested rainwater. This will go a long way to help ‘promote and strengthen rainwater harvesting for water conservation and as augmentation measure for conventional potable networks in peri-urban and rural communities’, as per the goal of the national rainwater harvesting strategy.

### 5.4 Areas for further studies

For further studies, the potential of rainwater harvesting in terms of yield, demand and cost/benefit can be assessed by students, researchers and institutions.

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# APPENDIX

| SAMPLE | Fe (Mg/l) | Ca (Mg/l) | Mg (Mg/l) | Pb (Mg/l) | TC CFU/100µL | pH | E.C uS/cm | TDS (Mg/l) | DOC (Mg/l) | TH (Mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| **AO I** | 0.416 | 0.196 | <0.01 | 1.319 | 4.0 x 10° | 6.5 | 7.72 | 3.86 | 1.33 | 0.49 |
| **AG 1 I** | 0.255 | 0.821 | <0.01 | <0.01 | 0 | 7.2 | 10.03 | 5.015 | 1.43 | 2.053 |
| **AC 2 I** | 0.126 | 10.76 | 0.108 | 0.374 | 0 | 6.5 | 57.6 | 28.8 | 2.11 | 27.343 |
| **AG 2 I** | 0.125 | 0.162 | 0.162 | <0.01 | 1.0 x 10° | 7 | 5.27 | 2.635 | 1.08 | 1.079 |
| **AA 1 I** | 0.636 | 0.775 | <0.01 | 0.788 | 0 | 6.8 | 10.95 | 5.47 | 1.33 | 1.938 |
| **AA 2 I** | 0.596 | 1.177 | <0.01 | <0.01 | 2.0 x 10° | 7 | 12.44 | 6.22 | 1.23 | 2.943 |
| **BO I** | 1.251 | 0.443 | 0.443 | 0.942 | 0 | 6.8 | 6.92 | 3.46 | 1.44 | 2.924 |
| **BA 1 I** | 0.529 | 5.047 | <0.01 | 1.134 | 0 | 6.3 | 31.1 | 15.55 | 1.72 | 12.618 |
| **BA 2 I** | 0.652 | 3.672 | 0.027 | 1.024 | 10^3 x TMTC | 7 | 33.9 | 16.95 | 1.88 | 9.291 |
| **BC 1 I** | 0.185 | 11.97 | 0.058 | <0.01 | 0 | 6.7 | 59.9 | 29.95 | 2.04 | 30.163 |
| **BC 2 I** | 0.554 | 16.58 | 0.177 | 1.004 | 8.0 x 10° | 6.3 | 114.9 | 57.45 | 2.36 | 42.176 |
| **BG 1 I** | 0.945 | 2.591 | <0.01 | 2.225 | 0 | 6.8 | 21.9 | 10.95 | 1.99 | 6.478 |
| **BG 2 I** | 0.668 | 1.302 | <0.01 | 1.853 | 0 | 6.7 | 10.92 | 5.46 | 1.22 | 3.255 |
| **CA 1 I** | 0.803 | 2.195 | <0.01 | 0.098 | 0 | 6.5 | 19.39 | 9.695 | 1.89 | 5.488 |
| **CA 2 I** | 0.764 | 0.913 | <0.01 | <0.01 | 0 | 6.6 | 11.06 | 5.53 | 1.44 | 2.283 |
| **CC 1 I** | 0.63 | 12.3 | 0.056 | 2.346 | 6.0 x 10° | 7 | 84.2 | 42.1 | 2.22 | 30.989 |
| **CC 2** | 0.166 | 7.808 | <0.01 | <0.01 | 1.0 x 10° | 7.4 | 35.1 | 17.55 | 2.28 | 19.52 |
| **CG 1** | 0.858 | 0.171 | <0.01 | 1.921 | 0 | 7.1 | 2.71 | 1.355 | 1.32 | 0.428 |
| **CG 2** | 0.298 | 0.346 | <0.01 | 1.623 | 1.0 x 10^3 | 7.1 | 5.49 | 2.74 | 1.44 | 0.865 |
| **AC1** | 0.122 | 16.44 | 0.044 | 0.004 | 1.0 x 10° | 6.2 | 60.1 | 30.05 | 2.22 | 41.280 |
| **CO** | 0.024 | 14.28 | 0.059 | 0.006 | 0 | 6 | 2.33 | 1.66 | 0.88 | 35.942 |