APPROPRIATE RAINWATER HARVESTING AND DOMESTIC WATER QUALITY
A CASE STUDY OF CENTRAL GONJA DISTRICT

by

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DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge, it contains no materials previously published by another person or material which has been accepted for the award of any other degree, except where due acknowledgement has been made in the text.

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ABSTRACT

Water is an essential resource for our well-being. The quality of water sources in the Central Gonja district of Ghana has been questioned due to activities that pollute water in the area. Therefore, there is the need to ascertain the quality of water from different sources in the area. One hundred and eight (108) samples were collected from boreholes, rivers, dam and rainwater in the wet and dry seasons. Sixty-three (63) storage samples from plastic, metal and concrete tanks were collected within 3 months of storage including *entry point water*. The samples were analysed for *p*H, total alkalinity, EC, turbidity, total hardness, nitrate, fluoride, iron, and FC. In addition, data was collected through a questionnaire survey and measurement of roof catchment areas of 60 households/houses in Buipe, Yapei and Mpaha townships. The dry-season water demand versus rainwater supply approach was used to determine the storage requirement. Analysis of the water sources showed that the boreholes, rivers and dams were seasonally affected in terms of the parameters measured except for iron and fluoride. Rainwater showed the absence of fluoride, iron and faecal coliform. The results from the storage tanks also showed that plastic and concrete tanks were within the WHO recommendation except for faecal coliform. The results showed that the type of storage tank has direct impact more on the physico-chemical quality of stored rainwater and care must be taken in the use of metal tanks. The results of the survey showed that a storage capacity of 30 m^3 is enough to meet household water demand during the 5 months dry period. Generally, rainwater can be recommended for drinking, cooking, bathing and washing for the people of Central Gonja district.

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DEDICATION

This thesis is dedicated to my lovely mother Mrs. Issaka Zeinab who has been my backbone in my achievements and the loving memory of my dear father Ex. Sgt. Issaka Patriba.

ACRONYMS

AAS	Atomic Absorption Spectrophotometer
APHA	American Public Health Association
CDC	Centre for Disease Control
CFU	Coliform Faecal Unit
CGDHD	Central Gonja District Health Directorate
CWQRB	California Water Quality Research Board
CSIR	Centre for Scientific and Industrial Research-
DES	Department of Environmental Services
DTU	Development Technology Unit
DRHS	Domestic Rainwater Harvesting System
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
EPA	Environmental Protection Agency
EDTA	Ethylene Diamine Tetraacetic Acid
FC	Faecal Coliform
IFM	International Fact-Finding Mission
NGOs	Non Governmental Organisations
NTU	Nephelometric Turbidity Unit
PVC	Poly Vinyl Chloride
TA	Total Alkalinity
TH	Total Hardness

TDS	Total Dissolved Solids
TSS	Total Suspended Solids
TWDB	Texas Water Development Board
UN	United Nations
UNICEF	United Nations International Children's Education Fund
UNEP	United Nations Environmental Programme
UNJMP	United Nations Joint Monitoring Programme
USEPA	United States Environmental Protection Agency
WRI	Water Research Institute
WHO	World Health Organisation
WHOLL	World Health Organisation Lower Limit
WHOUL	World Health Organisation Upper Limit
WRC	Water Resources Commission
WRI	Water Resources Institute

CHAPTER 1

INTRODUCTION

1.1 Background to the study

Water that is easily available and affordable is a prerequisite to good hygiene, sanitation and is central to the general welfare of all living things. In addition, access to safe water and sanitation is fundamental to gender equity with 71 % of household water collected by women or girls (UN, 2008a). Several factors affect water supply. For instance, divisions in wealth, class and socio-economic status is correlated with the degree of planning and provision of adequate infrastructure for water.

The World Health Organisation (WHO) estimates 1.8 million deaths each year due to lack of access to safe water, sanitation and hygiene. Out of these deaths, 99.8 % occur in developing countries and 90 % are children (Nath *et al.*, 2006). The WHO and United Nations International Children's Education Fund Joint Monitoring Programme for water supply and sanitation estimated 1.5 million deaths of children from diarrheal diseases resulting from lack of access to safe water and sanitation (UN, 2008b). These deaths could have been avoided, if proper water supply systems and educational programmes were put in place. The United Nations Millennium Development Goals (MDGs) have as its target to "halve by 2015 the proportion of people without sustainable access to safe drinking water and sanitation" (UN, 2008a). Since the implementation of the MDGs, about 1.6 billion people have gained access to safe drinking water (UN, 2008b).

However, about 784 million people worldwide still need to gain access to safe drinking water (UNJMP, 2008).

The United Nations Environmental Programme (UNEP) estimates that 250 million people in Africa will be at risk of water stress, less than 1700 m^3 of water available per person per year by 2020 and up to 500 million by 2050 (Falkenmark *et al*., 1989). Sub-Saharan Africa is making the slowest progress in meeting the MDGs target, one-third of the population still need safe drinking water (UNJMP, 2008). In Ghana, 22 % of the population and over 30 % of the rural population lack access to safe drinking water (Allison, 2007). Ghanaians still suffer from water shortages, 50 % of the population uses unimproved sources of drinking water. This figure is 10 % higher than the average for the African continent, where 40 % lack access to improved drinking water supply (Murcott *et al*., 2008). In the Northern Region of Ghana, 56 % of the population uses unimproved water supplies for drinking. This problem is exacerbated by lack of improved sanitation in the region where 92 % lack sanitation access to improve (vanCalcar, 2006).

The water supply situation in the Central Gonja District is grim and water scarcity is regarded as one of the root causes of water related diseases and poverty in the area. Residents of the district rely on boreholes, unprotected streams, dams, rivers, dug-outs and impounded reservoirs for their domestic water needs. Some of these water sources serve as drinking places for animals as well, and the health risks posed by this situation are endless and far reaching. However, one of the most growing domestic water resources is harvesting of rainwater and the major harvesting source is rooftop (Engmann, 1993). In view of this, the Ghana Science Association (GSA) has advocated for a building code, which makes it mandatory for all designs of buildings to incorporate rainwater harvesting systems (Barnes, 2008). The interest in rainwater harvesting is growing in the district, and the use of rainwater has changed from its function as mere water augmentation to ultimate water source for domestic activities (UNICEF, 2008). Rainwater harvesting presents a promising alternative for supplying fresh water in the face of the traditional water supplies which are conceived to be polluted in the area. The increasing interest in rainwater harvesting has necessitated research into the appropriateness of rainwater harvesting system and domestic water quality in the Central Gonja District.

1.2 Statement of problem

Rainwater as it falls from the sky is soft, and is among the cleanest of water sources. However, contamination may result from the environment, roof materials and containers which are used for rainwater storage (Polkowska *et al*., 2001). The effectiveness of storage tank for preserving water quality depends on preventing sunlight, organic matter and macro-organisms from entering the tank (Barnes, 2009; Ziadat, 2005).

The storage tank materials can also impact on the quality of the water stored. Research has shown that the type of storage tank material has some effect on the quality of drinking water (Jawas *et al*., 1988). There are reports that rainwater collected from metal roofs can react with steel tanks to cause corrosion. For instance, high concentrations of heavy metals in storage tanks could be significant if corrosion is evident, and when the tank has not been cleaned for a long time (Ziadat, 2005). The situation is worsened by wear and tear conditions of metal tanks which increase the concentration of heavy metals such as iron, which can be toxic to humans if it exceeds certain concentrations. Pier and Bang (1980) indicated a positive correlation between high concentrations of trace metals in drinking water and human health risk causing diseases such as cancer, sudden infant death and cardiovascular syndrome.

1.3 Study objectives

The general objective was to determine an appropriate rainwater harvesting and domestic water quality for Central Gonja District. The specific objectives under the study were to:

- Determine the quality of water sources: *p*H, total alkalinity, electrical conductivity, turbidity, total hardness, nitrite, fluoride, iron, and fecal coliform,
- Determine the impact of storage tank material on the quality of stored rainwater,
- Determine the appropriate rainwater storage capacity for households.

1.4 Justification

The material for constructing rainwater harvesting and water storage system components is related to the efficiency of rainwater harvesting and can be a source of contamination through leaching of materials. Water quality from roof catchment is a function of the type of roof material, climatic conditions, and the environment (Vasudevan, 2002).

Ground and surface water supply for drinking is often directly sourced from ground without biochemical treatment, and the level of pollution has become a cause for major concern. Water hardness is caused by dissolved polyvalent metallic ions, predominantly Ca^{2+} and Mg^{2+} cations. High concentration of total hardness in water may be due to dissolution of polyvalent metallic ions from sedimentary rocks, seepage and run-off from soil (Gupta and Saharanb, 2009). In the rainy season, run-offs from the surroundings wash and pesticides and fertilizers from farmlands into the surface water bodies and underground water sources. As a result of flooding, faecal waste can mix with river water or other protected water sources (Corwin, 1996). This has obvious health implications with regard to the spread of water related diseases in the Central Gonja District.

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

CHAPTER 2

LITERATURE REVIEW

In this Chapter an extensive literature was reviewed in the areas of water supply in developing countries, rainwater harvesting around the world, components of domestic rainwater harvesting system, rainwater consumption and health related issues.

2.1 Water supply in developing countries

Water is life and a valuable natural resource that sustains the environment and supports livelihood. Water scarcity is severe in developing countries, with about 1.2 billion people in 20 "water-scarce" developing countries without access to "safe water" (WHO, 1997). According to WRI (2000) more than one billion people in developing countries do not have access to clean water whilst two billion lack adequate sanitation. Africa is noted to be the poorest of the world continents in terms of annual fresh water renewal. In Ghana, rural areas depend on rivers, streams, hand dug-wells and rainwater for their water needs. Most of these water supplies are polluted and serve as the main sources of water-borne and water-related diseases (Gyau-Boakye and Dapaah-Siakwan, 1999). About 70 % of diseases in Ghana are linked to insufficient water supply and sanitation coverage (IFM, 2002).

The sources of water supply in rural areas include conventional communal sources and self supply sources. According to Carter *et al.* (2005) the conventional communal water sources are justified for improved water quality and use of high level technology like drilled boreholes, collection tanks and protected springs (see Table 2.1). Locating improved water supplies within reasonable distances to households saves time and increases total water consumption. The WHO considers 200 m as a convenient distance (Sharma *et al.*, 1996). For instance, women in Oyo State, Nigeria spent about 58 minutes daily to collect water at an average distance of 537 m (Sangodoyin, 1993) which is too long. Conventional communal facilities in most rural areas have proved unsustainable because of poor operation and maintenance, congestion, difficulty in operating the pumps and long distances, since the sources are few with many scattered households (Brett *et al.*, 2007). Self supply initiatives have evolved as an alternative approach to water supply in developing countries. This is based on locally available and easily affordable technologies to the users in the rural communities (Alford, 2007). Through rainwater harvesting, women in Sri Lanka saved 2 hours daily by reducing the number of trips made to wells and springs from 8 to 3 times per day. Rosen and Vincent (1999) indicated that the time saved by women can be used for cooking, hygiene, rest, social and personal activities.

Table 2.1: Definitions of "improved/unimproved" water supply

Intervention	Improved	Unimproved
Water supply	Piped water into dwelling, plot or yard Public tap/standpipe Tube well/ borehole Protected dug well Protected spring Rainwater collection	Unprotected dug-well Unprotected spring Cart with small tank/drum Tanker truck Bottled water Surface water (river, dam, lake, pond, stream, irrigation channels)

Source: Guy and Jamie (2008)

2.2 Introduction to rainwater harvesting

The challenges to the adoption and implementation of domestic rainwater harvesting as a source of water supply in developing countries is enormous and varying. Highlighted is the history and application of rainwater harvesting technology around the World.

2.2.1 Rainwater harvesting in Asia

Rainwater harvesting is wide spread phenomenon in Asia. India is leading in rainwater capture for domestic use in South Asia, where rainwater harvesting has been used for over 8000 years (Pandey *et al.*, 2003). In 2001, India approached a level of water stress with 1,820 m^3 of annual renewable fresh water per capita which is estimated to decrease to 1,341 m^3 by 2025 (Tripathi and Pandey, 2005). The Indian government has created subsidies that encourage the adoption of rainwater harvesting in many parts of the country.

Sri Lanka has practiced rainwater harvesting since the 5th Century, and has gained popularity over boreholes and pipe system (Ariyananda, 2003). Population growth, urbanization and deforestation have increased competition for water in the country. The Sri Lankan government in collaboration with the World Bank established the Community Water Supply and Sanitation Project that provides water and sanitation infrastructure to communities. Later, rainwater harvesting was introduced as a solution to the challenge of providing water to the uphill settlements (Ariyananda, 2003).

In northern China, there are many water quantity and quality limitations. The high levels of fluoride in the groundwater have led to the rejection of many wells. Though the annual precipitation is between 300 mm and 450 mm, rainwater harvesting is considered a viable option for water supply (Thomas, 1998). Several large-scale programmes have been established in the Hebei province to provide low-cost water from a variety of rainwater harvesting methods, and with political and technological collaboration, such efforts will soon spread to other provinces.

Indonesia has also utilised rainwater harvesting to supply water as a solution to the water quality problems in some parts of the country. Tsunami and earthquakes have resulted in contamination of groundwater and surface water sources in Indonesia (Pudyastuti, 2006).

2.2.2 Rainwater harvesting in the Americas, Europe and Australia

In Western Europe, the Americas and Australia, rainwater was the primary water source for isolated homesteads. About 100,000 residential rainwater harvesting systems are in use in the United States and its territories (Lye, 1996). Germany is one of the countries currently investigating rainwater harvesting models in urban areas (Gould and Nissen-Petersen, 1999). The decentralisation of water supply in Germany has been accepted and in many cases, subsidized by the City Councils. There have been efforts by the local government to encourage households to capture rainwater for domestic use and divert excess amount to recharge groundwater. Up to 100,000 tanks have been provided for rainwater storage of over 600,000 m^3 of rainwater in Germany (Herrmann, 2007).

The widespread use of rainwater harvesting in Australia and New Zealand, is mainly for the purpose of water supply in the rural and drier regions. In semi-arid and arid Australia, rainwater collected is used in farming and domestic activities, and more than one million people rely on rainwater as water supply (Gould and Nissen-Petersen, 1999). Large rainwater catchments are utilised in Western Australia to provide water for livestock farms and small settlements. In Brazil, several NGOs and local associations like the Brazilian Rainwater Catchment Systems Association have focused on the supply of drinking water using rainwater harvesting, and the irrigation in small-scale agriculture using sub-surface impoundments (UNEP, 2006). Rainwater harvesting and utilisation is now an integral part of educational programs for sustainable livelihood in Brazil.

2.2.3 Rainwater harvesting in Africa

In Africa, rainwater harvesting projects have increased in recent years due to the increased number of polluted or dried-out boreholes and wells or neglected water supplies in rural communities (Gould and Nissen-Petersen, 1999). In Kenya, several rainwater harvesting projects have been established by the UN and the Catholic diocese. However, according to Kahinda *and* Mwenge (2008) the growing aridity and unpredictable climate in South Africa makes rainwater harvesting unsuitable; therefore only 1 % of domestic water is supplied through rainwater harvesting.

Sub-Saharan Africa is close behind Asia in embracing research and implementation of rainwater harvesting (Patrick, 1997). Majority of rainwater harvesting projects are upgraded to be more efficient for the capture and storage of rainwater for local demand than other systems (Gould and Nissen-Petersen, 1999). Although rainwater harvesting is gaining popularity in sub-Saharan Africa, it faces some challenges. First, rapid population growth in urban areas make it difficult for the government and NGOs to meet the high water demand (Thomas, 1998). Second, the roof types and sizes of many rural houses are not suitable for rainwater harvesting and can compromise the system's efficiency and even the quality of water. Lastly, due to high installation and storage costs, low income households are more likely to invest in materials that are within their budgets and not those that are optimum for the system (Thomas, 1998).

2.3 Studies on rainwater quality

Several international studies have been performed to study the quality of harvested rainwater. However, some of these include studies cited by Fuller *et al.* (1981), Abdul-Hameed *et al.* (2008). Some studies done in Africa include:

Gould and McPherson (1987) described the bacteriological analysis of water samples from 13 roof tanks and 8 ground catchment tanks in Botswana. The results showed that rainwater collected from corrugated iron roofs and stored in covered tanks is of high quality compared with wells and rivers.

Hammad *et al.* (2008) studied the quality of drinking water in storage tanks in Khartoum state. Out of 92 storage tank samples analysed, 51 tanks showed the presence of thermotolerant coliform and *E. coli*. The degree of microbial contamination of water stored in iron tanks was greater than that stored in fiberglass tanks. Contamination in public tanks was greater than that in household tanks. Turbidity ranged between 7.4 and 8 NTU. The *p*H was between 7.7 and 7.9. Iron and copper were found to increase in water stored in tanks compared to that from taps. Iron and copper were also common in water stored in metal tanks. Covered tanks showed less degree of contamination compared with uncovered ones.

Mayo and Mashauri (1991) studied the bacteriological (faecal coliform and faecal streptococci), chemical (*p*H and total hardness) and physical (turbidity and colour) analyses from rainwater cisterns at the University of Dar es Salaam in Tanzania. The results showed that 86 % of the samples were free from faecal coliform. Faecal streptococci were obtained in 53 % of the samples and 45 % of the samples tested for total coliforms were positive. The *p*H was 9.3 - 11.7 which is above the recommended limits. Fifty four percent of the consumers raised objections over the taste of water.

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

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

2.4 Components of Domestic Rainwater Harvesting System (DRHS)

Domestic rainwater harvesting systems are conceptually made of five basic components: roof catchment area, conveyance system, first flush diverters, delivery mechanism and storage area (DTU, 1999). Plate 2.1 shows schematic presentation of a domestic rainwater harvesting system.

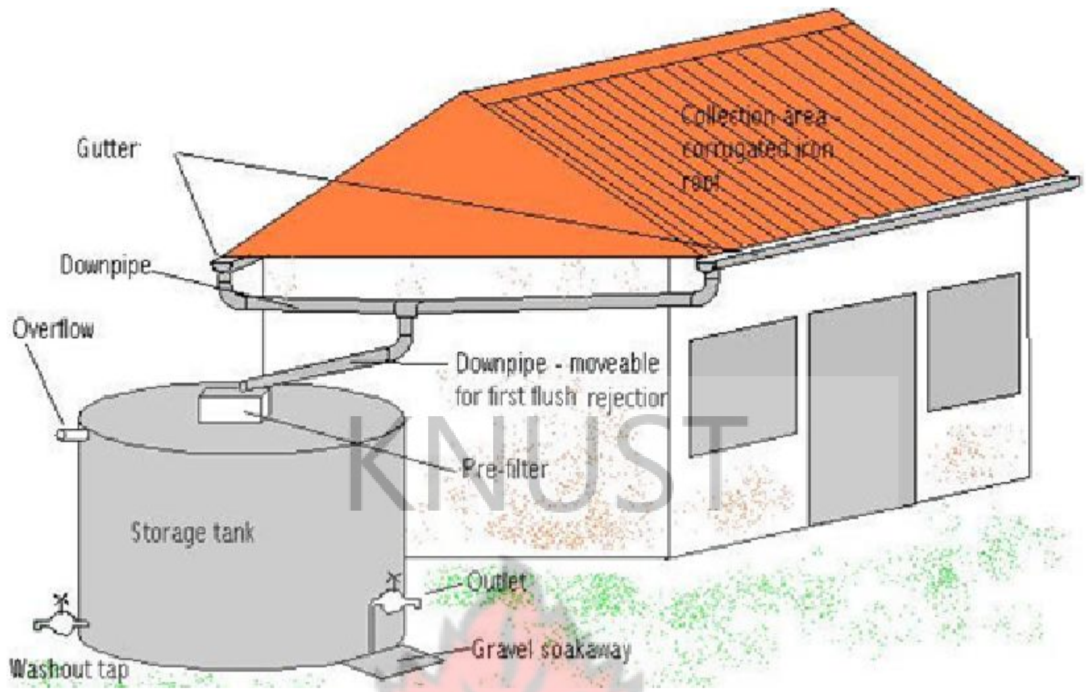

Plate 2.1: Main components of DRHS (DTU, 1999)

2.4.1 Roof catchment

The collecting surface for domestic rainwater harvesting is the roof of a dwelling. Roof materials include corrugated, galvanised, iron sheet, aluminium, asbestos sheet, tiles, slate, and thatch. Water quality from different roof catchments is a function of the type of roof material, climatic conditions, and the surrounding environment (Vasudevan, 2002). Many roofs consist of "roof valleys" which occurs where two roof planes meet, and is common for houses with 'L' or 'T' configurations. Run-off coefficient is the ratios of the volume of water that runoff a catchment surface to the volume of rainfall that falls on the catchment surface. The volume of runs-off from a catchment depends on spillage, leakage, wetting and evaporation from the catchment surface (Cresti, 2007). Table 2 gives types of roof materials, run-off coefficient and quality of harvested water.

Table 2.2: Roof material, run-off coefficient and water quality

Roof material	Run-off coefficient (K)	Remarks
Galvanised iron	> 0.9	i) Excellent water quality ii) Smooth surface and high temperatures sterilise bacteria
Tile	0.6 - 0.9	i) Good quality water when glased ii) Unglased tiles harbour mould
Asbestos	0.8 - 0.9	i) New sheets give quality water. ii) Older roofs can harbour moulds. iii) Poor water quality (>200 FC/100 ml)
Thatch	0.2	i) Little first flush effect ii) High turbidity due to organic material

Source: DTU (2000)

2.4.2 Conveyance system

The conveyance system channels rainwater from the roof to the storage tank. The main components include downpipes/downspouts, first flush diverters and filtering devices.

Gutter size and installation

Gutters are designed by balancing between slopes to convey enough rainwater without lowering it far to prevent interception of water flowing off the rooftop. The cost and performance of DRHS depend on the size of the gutter. A slope of 1:100 increases conveyance. However, the capacity of a gutter to convey flow is more sensitive to increase in area than slope. It is appropriate to size at least 1 cm^2 of gutter cross-sectional area per 1 m^2 of roof area (Gould and Nissen-Petersen, 1999). Gutter materials include half-round PVC, seamless aluminum, and galvanized steel. Common gutter shapes are shown in Plate 2.2.

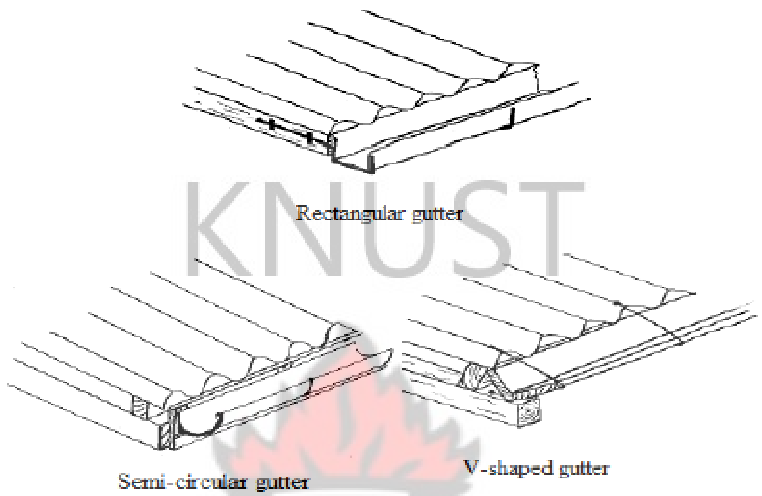

Plate 2.2: Examples of gutter shapes (Gould and Nissen-Peterson, 1999)

The flow capacity (*Q*) of a gutter without over-topping depends on the following: Cross-sectional area (A), hydraulic radius (R), slope (S) and roughness coefficient of the gutter material (n).

$$R = \frac{A}{P} \quad [2.1]$$

Where; P is length of perimeter of the wetted cross-section when full (For a square gutter, R = 0.33 x width, for a semi-circular gutter, R = 0.67 x depth of water, and for a semi-circular gutter running full, R = 0.25 x diameter).

The flow performance of gutters varies along its length resulting in a spatially varying flow. For long gutters, the flow (Q is approximated by Manning's formula as given in Equation 2.2.

$$Q = \frac{1}{n} A R^{2/3} S^{1/2}, \text{ m}^3/\text{s} \qquad [2.2]$$

Gutters are installed with the slope towards the downpipe, the outside face should be lower than the inside face to encourage drainage away from the building wall. A gutter with cross-sectional area of 200 cm^2 with a diameter of 16 cm is appropriate for most designs (Pacey, 1986). The procedure for installing gutters is given below:

1. Splash guard is nailed to the roof.
2. A gutter hanger is tied to the splash-guard at each end of the roof.
3. Wire gutter brackets are applied and gutter is fitted into the gutter-hangers.
4. Gutter is attached to facia board.
5. Gutter continues to the tank inlet in place of downpipe.

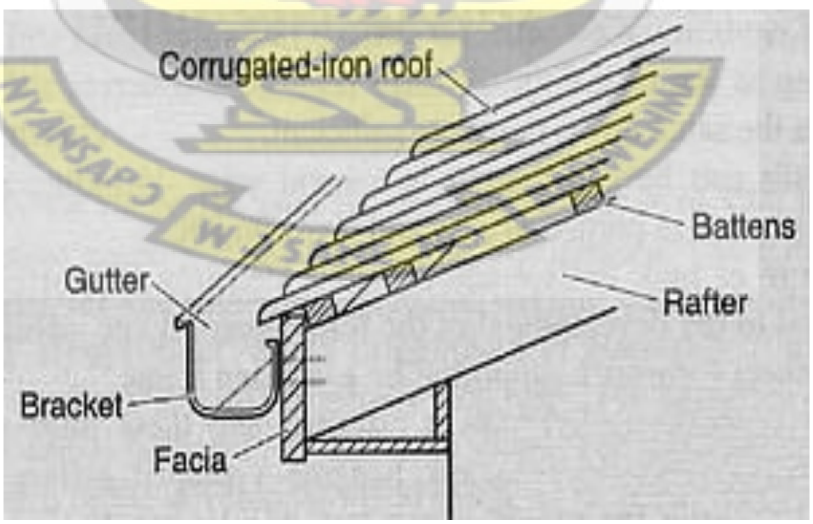

Plate 2.3: Gutter installation (Pacey, 1986)

Downpipes/Downspouts

The downpipe channels rainwater from the gutter to a tank for storage. Downpipes constructed of 3” PVC pipes, and often of lengths ≥10 ft, and not sufficiently supported may sag below the level of the tank inlet (Barnes, 2009). Below the downpipe, drop outlets are connected to route water downward and at least two 45^0 elbows which allow the downspout to snug to the side of the house.

First flush and filtering devices

The volume of water to divert depends on slope and smoothness of collection surface, rainfall intensity, time between rain events and nature of contaminants. The TWDB (2005) recommends 1 to 2 gallons of the first rainfall per 9.23 m^2 of roof catchment area should be diverted. Simpler ideas for diverting first flush are based on a manually operated arrangement where the inlet pipe is moved away from the tank inlet and then replaced again once the initial first flush has been diverted. This method requires a person present to move the pipe. Tipping gutters also can be used to achieve the same purpose or a floating ball that forms a seal once sufficient water has been diverted (TWDB, 2005). An automatic diverter is one that without any human intervention diverts run-off corresponding to the volume of rainfall on a roof; then slowly it resets itself (Thomas and Martinson, 2007). The volume of water diverted is dependent on the capacity of the pipe. A simple method is to add an extra closed off section of downpipe before the tank inlet (Plate 2.4)

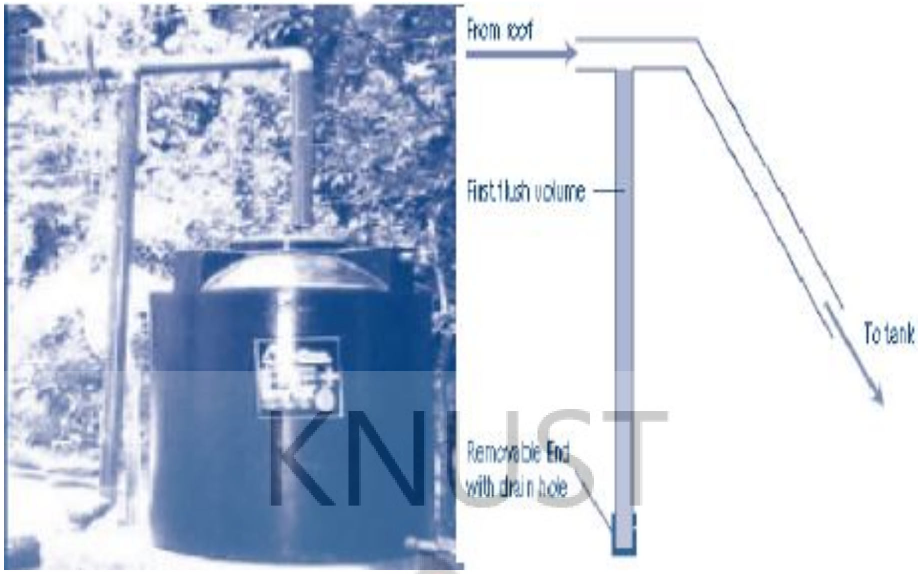

Plate 2.4: A pipe first-flush diverter (Thomas and Martinson, 2007*)*

Filters remove dirt and debris before rainwater enters the storage tank and should be easily removable for periodic cleaning. Filters are installed over the gutter, at or inside downpipe and over tank entrance as indicated below (DTU, 2000; 2003).

- **Screen over gutter length:** Screen are placed at angles to prevent the build-up of leaves in gutters, which can cause blockage and potential overflow.
- **Screen at downpipe:** Filter is placed where the gutter conveys water to downpipe but the location of the filter makes it difficult in cleaning.
- **Screen in downpipe:** This requires a more complex design and too expensive for most people in developing countries. This solution uses more than 10 % water to clean.
- **Screen at tank entrance:** A common type of filter is a plastic bucket filled with coarse rocks with holes punched at the bottom to allow water through. Another

type of filter is a plastic bucket with holes at the bottom and the inlet covered with “guinea worm filter” (Plate 2.5).

Plate 2.5: Examples of storage tank inlet with pre-filterings: bucket with guinea worm filter covering inlet (left), rough gravel in bucket (right)

2.4.3 Storage tanks

Storage tanks are the most expensive part of DRHS and may be located above or below the ground (Lundgren and Akerberg, 2006). Storage tanks are installed to make for later use of water and aid self-sufficiency. The size of rainwater tank is dictated by rainwater supply, water demand, and length of dry spell, the roof surface area, aesthetics, personal preference, and budget (TWDB, 2005). The cost of rainwater tanks depend on size, make, installation, additional fittings and supplies. There are many types of rainwater storage containers in different geographical regions. Earthenware cisterns, large pots, metal and plastic drums in Africa. The next section focused on plastic, galvanised metal and concrete tanks.

Plastic tanks

Polyethene tanks are available, relatively inexpensive and durable, lightweight, and long lasting. Polyethylene tanks are available in capacities from 50 - 15,000 gallons. Rainwater collected and stored in plastic water tanks remains naturally acidic and can react with the copper pipes that carry the water to your household taps (TWDB, 2005). The naturally acidic rainwater can corrode the copper pipe which causes gastric problems and headaches, and in severe cases cirrhosis of the liver. A bag of limestone chips added to a plastic tank to make the water alkaline.

Metal tanks

Metal tanks are available in sizes from 150 - 2,500 gallons, and are lightweight and easy to relocate (TWDB, 2005). Most metal tanks are corrugated galvanized steel dipped in hot zinc for corrosion resistance. They can be lined with polyethylene or coated inside with epoxy paint.

Concrete tanks

Concrete is a composite material consisting of a cement binder in which an inert aggregate is embedded. One advantage of concrete tanks is their ability to decrease the corrosiveness of rainwater by allowing the dissolution of calcium carbonate from the walls (Lundgren and Akerberg, 2006). Cement is subject to deterioration on prolonged exposure to aggressive water, due to the dissolution of lime or chemical attack by aggressive ions such as chloride or sulfate, and this may result in structural failure.

Cement contains a variety of metals that can be leached into the water. Concrete is prone to cracking and leaking. The advantage of concrete tanks is a desirable taste imparted to the water by calcium in the concrete being dissolved by the slightly acidic rainwater.

Plate 2.6: Examples of rainwater tanks, top left (polyethylene tank), top right (concrete tank) and bottom (metal tank)

Maintenance of rainwater tanks

Rainwater tanks should not be allowed to become breeding sites for mosquitoes. For most types of tanks mosquito breeding can be stopped by adding a teaspoon (5 ml) of domestic kerosene (Barnes, 2009). However, kerosene should not be used in plastic tanks. Tanks should be examined for accumulation of sludge at least every 2 - 3 years (Barnes, 2009). Aspiration of kerosene can cause respiration irritation, convulsion, drowsiness, coma, ataxia and restlessness. The most common health implication of kerosene is dermatitis (Roberts, 2006).

2.5 Water consumption and health

Water is essential for life and is a basic human need. Water borne diseases are a result of consuming water contaminated by human, animal or chemical waste. These diseases cause an estimated 12 million deaths worldwide each year (Buor, 2004). About 1.9 million children die, 20 % from diarrheal disease per year in India. Globally, one person dies from water-related disease every minute (UNICEF, 2005). Polluted water is the source of viral hepatitis, cholera, leptospirosis, typhoid fever, amoebiasis, schistosomiasis, dracunculiasis, echinococcosis, malaria and onchocerciasis. In Ghana, prominent diseases directly linked to water pollution include diarrheal, intestinal worms and typhoid infections (Buor, 2004).

The quality of rainwater in tanks has been the subject of much controversy. Good quality drinking water is "free from disease-causing organisms, harmful chemical substances and radioactive matter, is aesthetically appealing and is free from objectionable color or odor" (Life Water Canada, 2007). Common health concerns for rainwater quality in developing countries are related to bacteria, particularly *E. Coli* and to aesthetic properties, such as colour, taste, smell and hardness (Zhu, 2004). According to Moe *et al.* (1991) the incidence of diarrheal in children was significantly related to drinking water containing high levels of bacterial contamination (>1000 *E. coli* per 100 ml) but little difference was observed between illness rates of children using either good quality drinking water (<1 *E. coli*/100 ml) or moderately contaminated drinking water (2 - 100 *E. coli* per 100 ml). The quality of rainwater collected depends on when it is collected, how it is stored as well as method of use (Ariyananda, 2003). The quality of rainwater also depends on the atmospheric pollution of the individual area, the proximity to pollution sources and the level of cleaning and attendance (Zhu, 2004). Microbial contamination and other water quality problems associated with rainwater harvesting systems are most often derived from the catchment area, conveyance or storage components (Lye, 1996).

2.5.1 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. The following are water quality parameters are usually determined: *p*H, total alkalinity, electrical conductivity, turbidity, nitrite, fluoride, iron and faecal coliform.

Water *p*H

The *p*H of water is the effective concentration of hydrogen ions (H^+) in solution. Acid rain has a *p*H level of less than 5.6 (Radojevic and Harrison, 1992). Industrial pollutants such as sulfur dioxide emissions from power plants are the main causes of acid rain (Eby, 2004). Human activities are responsible for the production of these atmospheric pollutants. The chemical reactions that lead to acid rain begin as energy from sunlight in the form of photons which hit ozone molecules to form free oxygen and single reactive oxygen atoms in the atmosphere. These oxygen atoms react with water molecules to produce electrically charged, negative hydroxyl radicals which are responsible for oxidizing SO_2 and NO_2 to sulfuric and nitric acids respectively (Radojevic and Harrison, 1992). The balance hydrogen ions (H^+) and hydroxide ions (OH^-) in water determines the acidicity or basicity of water. Therefore, when analysts measure *p*H, they are determining the balance between these ions (USEPA, 2006). A *p*H of 6.5 - 8.5 is the ideal range with the maximum environmental and aesthetic benefits (Environmental Protection Agency, 2008). Initial *p*H is usually high in the tanks; it gradually decreases during the rainy season and increase again after the rain stops. Low *p*H values of 6.1 - 9.2 can accelerate corrosion problems in domestic appliances while high *p*H is an indication of undesirable biological activity in the tank (Fuller *et al*., 1981).

Total alkalinity

There is no health guideline value for total alkalinity. Alkalinity is the total measure of the substances in water that have "acid-neutralizing" ability (USEPA, 2006). Alkalinity indicates a solution’s power to react with acid and neutralize it. The main sources of natural alkalinity are rocks, which contain carbonate, bicarbonate, and hydroxide compounds. Borates, silicates, and phosphates may also contribute to alkalinity (CWQRB, 2005). The alkalinity is reduced during the rainy season when water inside the tank is diluted and increases again during the dry season (Lundgren and Akerberg, 2006).

Electrical conductivity

A conductivity of 300 µs/cm is the ideal for consumption (WHO, 2006). Conductivity is a measure of the ability of water to pass current (CWQRB, 2005). Conductivity in water is affected by the presence of chloride, nitrate, sulfate, and phosphate anions or sodium, magnesium, calcium, iron, and aluminum cations. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. For this reason, conductivity is reported as conductivity at 25 °C in µs/cm. Pushard (2005) indicates that distilled water has conductivity in the range of 0.5 - 3 µs/cm and industrial water is as high as 10,000 µs/cm.

Turbidity

Turbidity does not have a health guideline, but the recommended value is below 5.0 NTU for effective disinfection (WHO, 2006). Turbidity measures the fine suspended matter and its ability to impede light passing through water, mostly caused by colloidal matter (Shelton, 2000). It is measured in Nephelometric Turbidity Unit (NTU). Excessive turbidity in water causes problems with water purification processes such as flocculation and filtration, which may increase treatment cost (DWAF, 1998). The level of total coliform bacteria and the grade of turbidity in rainwater collected from the rooftop are affected by dry spell, and intensity of rainfall. The longer the dry period in between rainfall events, greater is the amount of turbidity in the rainwater (Shelton, 2000).

Total hardness

Total hardness of water refers to the total concentration of Ca^{2+} and Mg^{2+} ions in the water. Temporary hardness of water refers to the amount of Ca^{2+} and Mg^{2+} ions that can be removed as insoluble carbonates by boiling the water (Suffredini, 1994). 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. Equations 12.5 and 2.6 below show the formation of these insoluble carbonates.

$$Ca^{+2}(aq) + 2HCO_3^{-} \xrightarrow{heat} CaCO_3(s) + H_2O(l) + CO_3(g) \quad [2.5]$$

$$Mg^{+2}(aq) + 2HCO_3^{-} \xrightarrow{heat} MgCO_3(s) + H_2O(l) + CO_3(g) \quad [2.6]$$

Hardness minerals in water have a wide impact on households. Soap scum is composed $CaCO_3$, $Mg(OH)_2$, and $CaSO_4$. The presence of Ca^{+2} and Mg^{+2} ions in water can lead to galvanic corrosion (Hermann, 2007). Hard water interferes with cleaning task, laundering, dishwashing, bathing and personal grooming. Clothes laundered in hard water may look dingy and feel harsh and scratchy. Dishes and glasses may be spotted when dry. Bathing with soap in hard water leaves a sticky film of soap curd on the skin. The soap curd causes skin irritations and can leave the hair looking dull, lifeless and difficult to manage. McNally *et al.* (1998) in his study correlated domestic hard water usage with increased eczema in children.

Hard water requires extra detergent use, unnecessary rinse cycles, hot water use, fabrics lose their usefulness, and wearing out of washing machines wear out. When doing laundry in hard water, soap get lodge in the fabric and create a stiff and rough surface on the clothes. A sour odour may develop in clothes, and the continuous laundering can cause a shorter life span for the clothing. A Purdue University study in Indiana observed that, "fabrics washed in hard water tend to wear out as much as 15 % faster than fabrics washed in soft water (Hairston and LaPrade, 1995). Also hard water has negative effect on colours and laundry washed in hardwater resoiled with greater ease.

Cooking with hard water can also cause problems. Hard water can produce scale on pots. Some vegetables cooked in hard water lose colour and flavour. Home economists have reported that beans and peas may become tough and shriveled when cooked in excessively hard water (Hairston and LaPrade, 1995). Hard water may affect the performance of household appliances. When hard water is heated, a hard scale is formed that can plug pipes and coat heating elements. With increased deposits of scale on the heating unit, heat is not transmitted to the water fast enough and overheating of the metal causes failure. Build-up of deposits will also reduce the efficiency of the heating unit, increasing the cost of fuel (Hairston and LaPrade, 1995).

The concentration of total hardness in drinking water sources ranges between 75 - 1110 mg/l (Gupta *et al.*, 2009). A partial solution to this hardness problem is the addition of builders such as complex phosphates, silicates, or sal-soda, which can be added to counteract the hardness. Hard water also has a great effect on herbicides and their effectiveness, particularly, diquat, paraquat, and glyphosphate. According to WHO (2006) domestic water of total hardness above 500 mg/l is not recommended due to potential scale formation. At 500 mg/l level, soap consumption is very high and pipe and water heater scaling is severe. Treatment is not recommended unless hardness exceeds at least 51 mg/l (Hairston and LaPrade, 1995).

Nitrate

High concentration of nitrate above 50 mg/l in drinking water is deleterious especially to babies due to the formation of methmoglobinamea (WHO, 2006). Nitrate is the more stable oxidized form of combined nitrogen in most environmental media (USEPA, 2006). Nitrates occur naturally in mineral deposits, in soils, seawater, freshwater systems, the atmosphere, and in biota. Lakes and other static water bodies usually have less than 1.0 µg/l of nitrate. Groundwater levels of nitrates may range up to 20 µg/l or more, with higher levels occurring in shallow aquifers beneath areas of extensive development (USEPA, 2006).

The toxicity of nitrate in humans is due to the body's reduction of nitrate to nitrite (Pushard, 2005). This reaction takes place in saliva of humans at all ages and in the gastrointestinal tract of infants during the first three months of life. The toxicity of nitrite is demonstrated by cardiovascular effects at high dose levels and methemoglobinemia at lower dose levels. Methemoglobinemia, "Blue-Baby Disease" is an effect in which haemoglobin is oxidized to methemoglobin, resulting in asphyxia (Knepp and Arkin, 1973). Three months old infants are the most susceptible subpopulation with regard to nitrate. In adults and children, about 10 % of ingested nitrate is transformed to nitrite, while 100 % of ingested nitrate can be transformed to nitrite in infants (Knepp and Arkin, 1973).

Fluoride

The fluoride content of drinking water is a very important factor from the health point of view. There are many sources of fluoride in the diet. Dentists apply fluoride to teeth; some municipal water systems add fluoride to their water supplies; many tooth pastes have fluoride as an additive; and some foods also have elevated fluoride such as fish and tea. At higher concentration, there are health concerns. Waldbott (1998) indicates that excessive fluoride intake causes fluorosis, cancer, arthritis, and other diseases. Li *et al*. (1995) observed that fluorine in excess affects human intelligence, especially in children, who are most susceptible to early fluoride toxicity. The optimal concentration recommended by the Centre for Disease Control for New Hampshire is 1.1 mg/l. Below 0.5 mg/l there is little tooth decay protection whilst above 1.5 mg/l, prevents little tooth decay. In the range of 2.0 - 4.0 mg/l of fluoride, staining of tooth enamel is possible. Studies have shown that above 4.0 mg/l, skeletal fluorosis as well as the staining of teeth is possible (DES, 2007).

Iron

Metallic iron occurs in the free-state and is widely distributed and ranked in abundance among the entire element in the earth's crust, next to aluminium (Antovics *et al*., 1971). Chemically, iron is an active metal, and combines with the halogens (fluorine, chlorine, bromine, iodine and astatine) sulfur, phosphorus, carbon, and silicon. When exposed to moist air, iron forms a reddish-brown, flaky, hydrated ferric oxide commonly known as rust. There are two kinds of iron with respect to the mechanism of absorption in diet. These are heme-iron and non-heme iron (Halberg, 1982). Before iron can be absorbed, two conditions must exist, first, the iron is separated from its organic complex, and second, and the ferric iron is reduced to ferrous iron. Although the body can absorb both the ferrous (Fe^{+2}) and ferric (Fe^{+3}) iron, absorption is greater when iron is available in the ferrous form (Fifield and Haines, 1996).

The basic biochemical role of iron in humans is to permit the transfer of oxygen and carbon dioxide from one tissue to another. It accomplishes this primarily as part of both haemoglobin and myoglobin which are iron containing proteins in the blood and muscle (Cook *et al*., 1972). It is also important in blood formation. Iron also functions as a catalyst in the conversion of beta-carotene to vitamin A. Iron is also necessary for the growth of microorganisms, and it is an essential part of enzymes and immune substances needed to destroy invading infection organisms (Cook *et al*., 1972). Acute iron toxicity is nearly always due to accidental ingestion of iron containing medicines and most often occurs in children. Severe toxicity occurs after ingestion of more than 0.5 g of iron or 2.5 g of $FeSO_4$ (Fifield and Haines, 1996). Toxicity manifest with vomits being bloody owing to ulceration of the gastrointestinal tract; stools become black. These are followed by signs of shocks and metabolic acidiosis, liver damage and hepatic cirrhosis.

Fecal coliform

Coliform bacteria are common in the environment and are generally not harmful (Environmental Protection Agency-EPA, 2008). *Escherichia coli* indicate the presence of disease-producing organisms that normally live in the intestinal tracts of human or warm-blooded animals (EPA, 2008). The major pathogenic organisms that affect the safety of drinking water are bacteria, viruses, protozoa and worm infections. Typhoid, cholera and dysentery are caused by bacteria and protozoa (WHO, 2003).

Larger tanks generally record more zero readings than smaller ones in terms of *E. coli* levels, as die-off is allowed to continue for a longer period of time (Yaziz, 1989). High level of turbidity can protect micro-organisms from the effect of disinfection, stimulate the growth of bacteria and give rise to significant chlorine demand (Lundgren and Akerberg, 2006). The WHO recommends zero *Escherichia coli* or thermotolerant Coliform Forming Units (CFU's) per 100 ml for all drinking water supplies (WHO, 2004). Alternative standards for rainwater supply in tropical regions and developing countries was proposed by Krishna (2003). The classifications are:

Class I: 0 fecal coliform per 100 ml

Class II: 1 – 10 fecal coliform per 100 ml

Class III: > 10 fecal coliform per 100 ml

Class I is the highest quality, Class II is the marginal quality and Class III is unacceptable for drinking.

2.5.2 Factors affecting rainwater quality

Rainwater as it falls from the sky is among the cleanest of water sources. However, the quality of rainwater is influenced by the atmosphere and collecting devices. This section looks at the potential sources that affect the quality of rainwater.

Particulate matter

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

Roof catchment

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

Storage tanks

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

CHAPTER 3

MATERIALS AND METHODS

Chapter Three discusses the quantitative and qualitative approaches employed for data collection and analysis leading to the achievement of the specific objectives. First, the Chapter gives brief description of the study area. This is followed by the materials used for the study and a detailed account of how the fieldwork and laboratory analysis of water quality was conducted and data analysed.

3.1 Description of the study area

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

3.1.1 Location and size

The Central Gonja District lies within longitude 1^o 5' and 2^o 58' West and latitude 8^o 32' and 10^o 2' North. It shares boundaries in the north with Tamale Metropolis, Kintampo North District of Brong-Ahafo Region in the south, East Gonja District in the East and West Gonja District in the West. The district covers a total land area of 8,353 Km^2 (12 %) of the total landmass of the Northern Region (Dickson and Benneh, 2004). Buipe, Mpaha and Yapei townships were chosen for the study based on their high population and number of large houses with corrugated iron roofs which presents the potential for domestic rainwater harvesting. Figure 3.1 shows the location map of Central Gonja District.

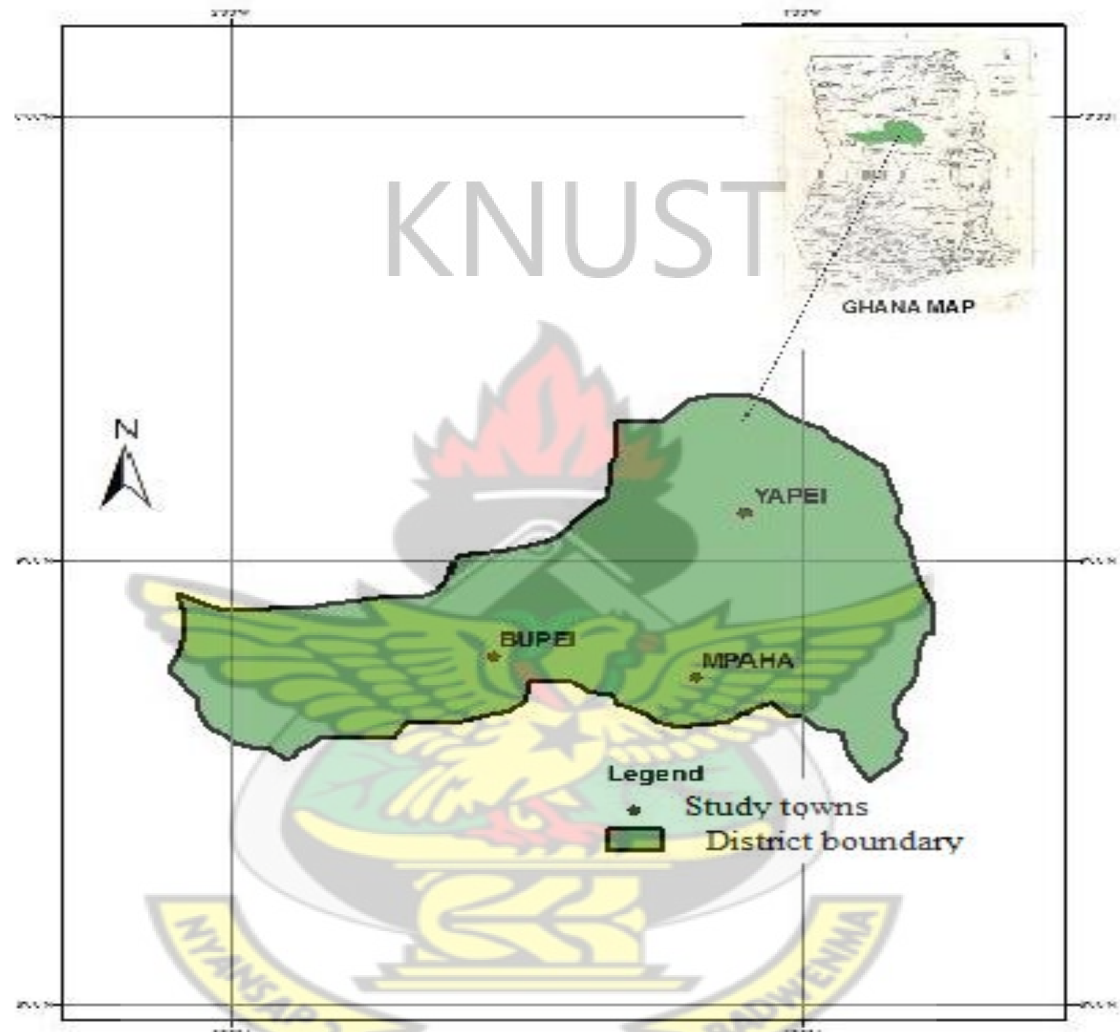

Plate 3.1: Location map of Central Gonja District and the sample areas

3.1.2 Demography and household characteristics

The district has about 86,345 people in 2010 projected based on 2000 population census. The population density of the district is 8.3 persons/km^2 and population growth rate of

3.1 %. Fertility rate is children per woman and the average household size is about 8 people (Dickson and Benneh, 2004). As a result of polygamy and accommodation problems, some households have separate cooking arrangements. About 60 % of the super structures of houses are constructed with mud bricks and over 20 % of these buildings are roofed with corrugated iron sheets, whilst the rest are roofed with thatch (Dickson and Benneh, 2004).

3.1.3 Climate and topography

The mean annual rainfall is between 1100 mm and 1200 mm. The rainy season start from March or April to October. The daily temperature is within 18 - 42 °C. The landform is low lying and gently undulating (Dickson and Benneh, 2004).

3.1.4 Soil and vegetation

Soil types in the Central Gonja District are alluvial, laterite and savanna ochrosols. Alluvial soils are fertile and mostly found along the Volta Rivers, their tributaries and the large plains. The most extensive soil type in the district is lateritic soil which covers 75 % of the area (Dickson and Benneh, 2004). The Savannah Ochrosols are well drained and porous but lack nutrients.

The vegetation is largely dissected by the permanent shifting cultivation. Slash and burn method of land preparation for farming has transformed the vegetative landscape into that of open savanna. The major trees are Sheanut (*Vitellaria paradoxa*), Dawadawa

(*Parkia biglobosa*), Baobab (*Adansonia digitata*), Acacia (*Acacia spp*.), Nim (*Azadirachta indica*) and Ebony (*Diospyros ebenum*).

3.1.5 Water resources

The White Volta flows in the North-South direction into the main Volta with a mean annual flow volume of approximately 303.3 m^3 s^{-1}; the Black Volta (mean annual flow volume approximately 219 m^3 s^{-1}) flows in the Southwest-Southeast direction and merges with the White Volta in the extreme south east to form the main Volta (Dickson and Benneh, 2004). The main sources of water are boreholes, rivers, dug-outs, dams and rainwater harvesting to buck-up their domestic water needs. At present, Buipe has seven boreholes and the Black Volta River, whilst Yapei area has the White Volta River and six boreholes. Mpaha has five boreholes and a dam.

3.2 Materials

Materials required for the study include, 10 metre measuring tape, ice chest, 1.0 l glass containers, digital camera, personal computer with Microsoft software Excel for data entry and storage.

3.3 Methods

The methods include field measurements of roof catchment areas of houses, household interviews using a pre-designed questionnaire and laboratory analysis of water samples for quality.

3.3.1 Survey of water sources

A study of water resources and storage practices was carried out at Buipe, Yapei and Mpaha townships through a survey. This was done to know the sources of water and to assess the existing rainwater harvesting and water storage practices information on quantity and quality of rainwater stored. A total of sixty (60) household representatives/heads were interviewed using the pre-tested questionnaire (See appendix 1). The households were asked to respond to questions on a variety of issues including socio-economic, water collection and storage practices, rainwater harvesting and health related issues. A digital camera was also used to capture images of water sources in the area.

3.3.2 Rainfall data

Ten years (1999-2009) rainfall data for Buipe in the Central Gonja District was collected from the Tamale Meteorological Department and analysed. The number of dry days (*dd*) was determined and the mean annual rainfall (R) was computed as follows:

$$R = \sum_{i}^{10} P \quad [3.1]$$

Where, P is the Total annual rainfall data for 10 years in mm/year.

3.3.3 Roof catchment area and rainwater supply

The area covered by the roof of houses was measured from eave to eave (length) and front to rear (width) with the measuring tape. The product of the length (L) and breath

(B) gave the roof catchment area (A), which was determined for 60 houses in the study area. The roof area of each house was determined and categorized into small roofs (<37 m^2), medium roofs (37-72 m^2) and large roofs (>72 m^2). The average roof area (A_v) was calculated by dividing the average roof catchment area by the number houses (N) in each of the roof area size category.

$$A_v = \frac{A}{N} \quad [3.2]$$

The annual rainwater supply (S) was determined for each roof area size category using the formula below;

$$S = R \times K \times A_v \quad [3.3]$$

Where; average annual rainfall (R), run-off coefficient (K) and average roof catchment area (A_v).

3.3.4 Per capita water consumption

Information was collected on the quantity of water consumed daily (Q) by households in terms of drinking, cooking, bathing, washing and other domestic purposes (performance of ablution, cleaning) in Buipe, Yapei and Mpaha areas separately for the wet and dry seasons. Women and children who are the main people who fetch water were interviewed. The quantity of water consumed by households was calculated based on their recall of water quantity consumed daily. The average quantity consumed (Q_v) by households in each community was computed and the per capita water consumption was also determined for each of the three communities as follows;

$$C = \frac{Q_v}{n}\text{, l/p/day} \quad [3.4]$$

Where; n = Average household size

The capacity of the storage tank was computed in relation to the roof catchment size of each category as shown below;

$$\text{Storage capacity} = dd \times n \times C \quad [3.5]$$

Where, dd is number of dry days.

3.4 Sampling

This section presents details of the water sampling procedure adopted for the study. It includes the sample areas and procedure for collecting water samples.

3.4.1 Preparation of sample containers

In order to obtain accurate results, proper sampling procedures were adopted to eliminate or minimise potential contamination of the samples. Sample containers were soaked in nitric acid (NHO_3) overnight and were washed with distilled water, rinsed with deionised water and dried in a drying cabinet. Some of the dry containers were selected, filled with distilled water and the *p*H tested, when it is 7.0 then it is ready for use, otherwise the container was washed and the *p*H tested again. This served as quality control (Anon, 1992).

Sample containers were clearly labeled to enhance record keeping. Rainwater samples collected from Buipe, Yapei and Mpaha were labeled; BRW, YRW and MRW respectively. Water resource samples from Buipe (B) were labeled as follows; BBH and BRV for borehole and river respectively. Those sampled from Yapei (Y) were coded YBH and YRV for boreholes and river respectively. Samples from Mpaha (M) were also coded MBH and MDM for boreholes and dam respectively. For the storage tanks, samples from Buipe were labeled BPT, BMT, and BCT for polyethene, metal and concrete tanks respectively. The samples from Yapei were coded YPT, YCT and YMT for polyethene, concrete and metal tanks respectively. Those from Mpaha were also labeled MPT, MCT and MMT for polyethene, concrete and metal tanks respectively. Rainwater *entry point samples* (water samples collected before the water has entered the storage tank) from Buipe were labeled BEN, those from Yapei and Mpaha were also labeled YEN and MEN respectively. All the samples were labeled with the site, date, time of sampling on the glass bottles.

3.4.2 Water sampling

Two sets of water samples were collected from each sampling site between the months of August 2010 and April 2011; August to November (wet season) and January to April (dry season). This was done to account for any seasonal variation in the quality of the water sources. In the wet season, rainwater samples were collected direct from the sky into plastic bottles in all the three sites. The plastic bottles were raised from the ground by placing them on top of 1 m block in order to avoid sand splash and other ground based pollution from contaminating the rainwater samples. The boreholes, rivers and the dam were sampled every month for the wet season. Boreholes were run for 5 minutes prior to sampling to ensure collection of a representative sample. In the dry season, water sampling from the boreholes, rivers and dam was repeated for the sample sites. One hundred and eight (108) water samples were collected for the wet and dry seasons (Table 3.1).

At the household level, rainwater samples were collected from the *entry points* of plastic, metal and concrete tanks in the wet season. This was done to know the quality of the rainwater before entering the storage tank and this served as control samples for the storage tanks. In the wet season, rainwater samples were collected every two weeks for 12 weeks (August to October, 2010) from plastic, concrete and metal tanks which represent the commonly used storage containers in the area. This done to because water stored for more than two weeks tends to deteriorates (Jusara *et al.*, 2003). A total of sixty-three (63) water samples were collected from the *entry points* of the tanks including water samples from plastic, metal and concrete tanks as shown in Table 3.1.

Table 3.1: Water sampling scheme for water sources and storage tanks

Town	**Water source**				**Total**	**Storage tanks**			*Entry point samples*	**Totals**
	Borehole	River	Dam	Rainwater		Plastic	Metal	Concrete		
Buipe	24	8	-	4	36	6	6	6	3	21
Yapei	24	8	-	4	36	6	6	6	3	21
Mpaha	24	-	8	4	36	6	6	6	3	21
					108					**63**

The labeled samples were stored in ice chest at a temperature below 4 ^{o}C and transported immediately to Water Research Institute (CSIR-WRI) Laboratory in Tamale within 24 hours for analysis.

3.5 Analysis of water samples

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

3.5.1 Water *p*H

The *p*H of water samples was determined immediately after sampling using Fisherbrand Hydrus 100 *p*H Meter. The CALCULATE key was pressed to calibrate and the automatic calibration procedure was followed. The *p*H of the samples was measured by reading the values that displayed on the screen after the READY signal has disappeared (Appendix 2A).

3.5.2 Total alkalinity

A 50 ml sample was measured into a conical flask. Two drops of methyl orange indicator was added and the resulting mixture titrated against the standard 0.1 M HCl solution to the first permanent pink colour at *p*H 4.5. A reagent blank was performed without the sample (Appendix 2B).

Calculation:

$$\text{Total alkalinity } (CaCO_3) = \frac{A \times N \times 50{,}000}{V_S} \qquad [3.5]$$

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

3.5.3 Electrical conductivity

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

3.5.4 Turbidity

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

3.5.5 Total hardness

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

Calculation:

$$\text{Total hardness} = \frac{(A - B) \times 1000}{C} \quad [3.6]$$

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

3.5.6 Nitrate

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

3.5.7 Fluoride

Fluoride was determined potentiometrically using a fluoride Ion-Selective Electrode (ISE) in conjunction with a standard single-junction reference electrode, and an ISE meter capable of being calibrated directly in terms of fluoride concentration. The standards and samples were mixed 1:1 with a Total Ionic Strength Adjustment Buffer (TISAB), which buffers *p*H to 5 - 5.5. Calibration was performed by analyses of a series of standards and calibrating the ion meter directly in terms of fluoride concentration (Appendix 2E).

3.5.8 Iron

A 250 ml of the samples was filtered through 0.45 µm cellulose membrane filter paper. The samples for iron determination were digested by adding 20 ml each of concentrated HN_3 to 200 ml samples and heated on a mantle till the volume decreased to 50 ml. The samples were filtered and analyzed for iron using the flame Atomic Absorption Spectrophotometer (AAS). Triplicate determinations were made for the iron concentration determined. A calibration curve was obtained with standard solutions of 1, 3 and 5 mg/l for iron (Milner and Peterside, 1984).

3.5.9 Faecal coliform

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

$$FC = \frac{C_C}{V_f} \times 100 \text{ CFU/100 ml} \qquad [3.7]$$

Where; FC= Fecal coliform, Coliform Faecal Unit (CFU) per 100 ml, C_C = Colonies counted and V_f = Volume of sample filtered (litres).

3.6 Data analysis

The data collected from the survey and laboratory analysis was checked for quality and entered into the computer. The mean values of parameters were computed using Microsoft Excel software. Statistical test (t-test at 5 %) was used to separate the mean values of the parameters measured. Descriptive statistics were also presented using charts and comparing the mean values with WHO (2006) drinking water guidelines.

CHAPTER 4

RESULTS AND DISCUSSIONS

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

4.1 Results and analysis of water sources

One-hundred and eight (108) water samples were collected from boreholes, rivers, dams and rainwater sources during the wet and dry seasons. This section discusses the results from the laboratory analysis in terms of physicochemical and biological parameters to ascertain their quality for domestic purposes.

4.1.1 Water *p*H

The mean *p*H of the borehole water from Buipe had mean *p*H of 8.65 and 7.65 for the wet and dry seasons respectively (Fig. 4.1). The results indicated significant difference (5.41, $P<0.05$) of *p*H between the seasons. At Yapei, the mean *p*H of borehole water in the wet season was 9.95 whilst the dry season had a value of 8.9. There was also significant difference (4.51, $P<0.05$) of *p*H between the seasons. The borehole water from Mpaha were more alkaline with mean *p*H of 9.74 for the wet season and 8.85 for the dry season. Significant difference (4.51, $P<0.05$) occurred between the seasons in terms of *p*H. The results indicated that the borehole water from Yapei and Mpaha towns were alkaline throughout the year. However, the high mean *p*H in the wet may be due to the presence of limestone in the aquifer formation that dissolved to release $CaCO_3$ into the water (Freeze and Cherry, 1979). The reason for low mean *p*H in the dry season may have been caused by high temperatures that increased the concentration of H^+ ions, hence decreasing the *p*H of the borehole water. There was no significant difference of *p*H between the borehole water from Buipe and Yapei (1.33): Buipe and Mpaha (1.4): Yapei and Mpaha (0.82) at 0.05 significant level in the wet season. In the dry season, no significant difference of *p*H was recorded between borehole water from Buipe and Yapei (1.24): Buipe and Mpaha (1.45): Yapei and Mpaha (0.82) at 0.05 significant level. This may be attributed to the almost homogeneous geological materials, mainly sedimentary rocks that underlie the study area (Dickson and Benneh, 2004). The sedimentary rocks are sources of Calcium ions which might have increased the *p*H of borehole water from the study towns.

River water from Buipe had mean *p*H of 8.9 and 7.70 in the wet and dry seasons respectively. There was significant difference (3.70, $P<0.05$) of *p*H between the seasons. At Yapei, the wet season mean *p*H was 9.25 and 7.85 for the dry season with significant difference (5.33, $P<0.05$) between the seasons. The high mean *p*H of the river water in the wet season could be due to the release from farmlands of alkaline fertilizers such as ammonia and phosphates carried by run-offs into the rivers. These substances might have altered the acid-base equilibrium and resulted in a lower acid-neutralizing capacity, hence raising the *p*H of the rivers (Wetzel, 2001). However, the mean *p*H of the river samples decreased in the dry season. During the dry season, CO_2 is released when phytoplankton and other organic materials in the river decay (Wetzel, 2001). The CO_2

can combine with the water to form HCO_3^- that may have lowered the *p*H of the rivers in Buipe and Yapei. Significant difference (1.82, P<0.05) of *p*H was recorded between river water from Buipe and Yapei in the wet season. The relatively low *p*H of Black Volta at Buipe may be due to high concentration of dissolved organic loads (Rickey *et al.*, 1990). The *p*H of Black Volta at Buipe might have been caused by high amount of dissolved sediments.

Mean *p*H of the Mpaha dam was 8.25 in the wet seson and 7.11 was recorded in the dry season. There was significant difference (5.29, P<0.05) of *p*H between the seasons. The high mean *p*H in the wet season can be attributed to run-offs from nearby cultivated field that carried amonia and phosphate fertilizers into the dam. These alkaline substances may have increased the the OH^- ions in the dam. The low mean *p*H in the dry season may be due to the build-up of dissolved gasses such as CO_2 and NO_2 from decaying aquatic plants and animals in the river body. These dissolved gaasses are acidic and might have reacted with the OH^- ions in the dam.

The mean *p*H of rainwater from Buipe, Yapei and Mpaha was 6.26, 6.37 and 6.82 respectively. Buipe and Yapei are situated along the Kumasi-Tamale trunk road, hence the lower mean *p*H values can be attributed to wet atmospheric deposition of CO_2, SO_2 and NO_2 produced by vehicular emissions including the slash and burn method of land preparation for farming in the study communities. Kohler *et al.* (1997) in their study of the contribution of aircraft emission to atmospheric nitrogen content indicates that rainwater acquires slight acidity as it dissolves CO_2 and NO_2 gases in the atmosphere.

There was no significant difference between rainwater from Buipe and Yapei (0.34, $P<0.05$). However, significant difference of *p*H was recorded between rainwater from Buipe and Mpaha (1.84): Yapei and Mpaha (1.92) at 0.05 significant level. Rainwater from Buipe and Yapei acquire slight acidity from vehicular emissions along the Kumasi-Tamale trunk road as confirmed by Kholer *et al.* (1997). Mpaha is located about 60 km away from the main road which might have accounted for relatively high *p*H values.

Generally, the mean *p*H of the boreholes, rivers, dam and rainwater sources in Buipe, Yapei and Mpaha areas were within the "safe range" of drinking water. Therefore, no skin diseases are expected in the study area. This may be the reason for no major reported cases of skin diseases in the study area as indicated by 2009/2010 annual report of Central Gonja District Health Directorate.

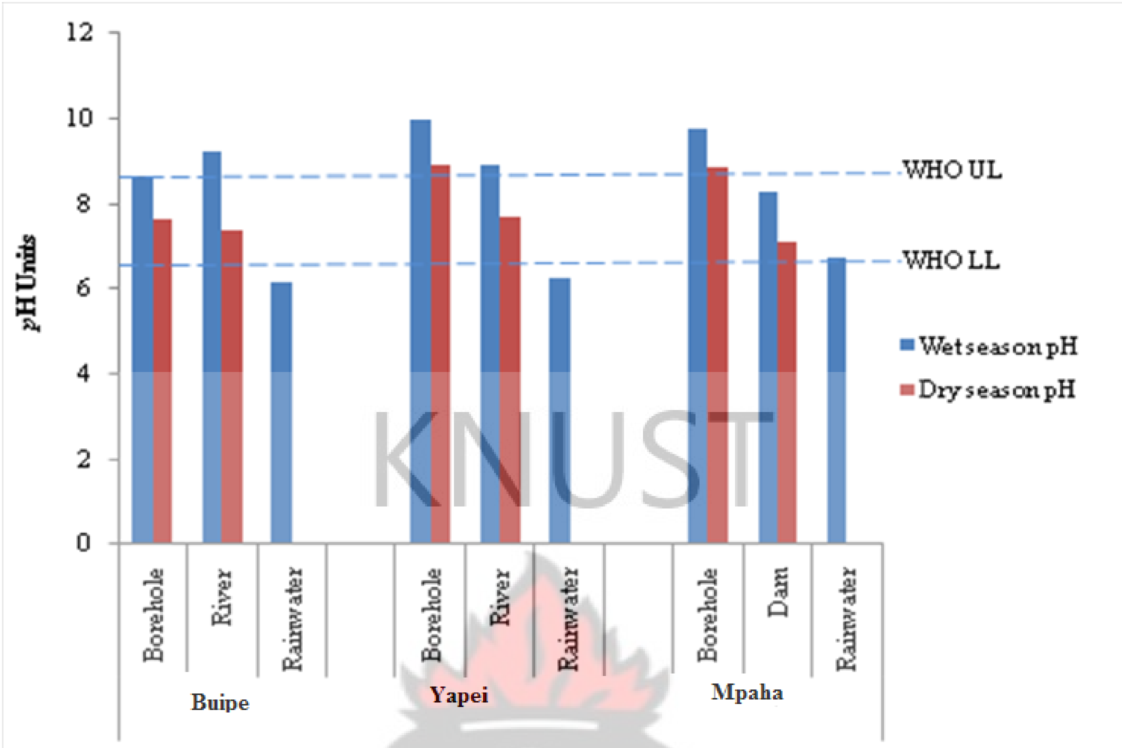

Figure 4.1: Comparison of water sources in terms seasonal variation of *p*H
*WHO LL - Lower Limit, WHO UL - Upper Limit

4.1.2 Total alkalinity

There was significant difference (5.57, $P<0.05$) boreholes water from Buipe which had mean total alkalinity of 338.7 mg/l and 226.5 mg/l for the wet and dry seasons respectively. At Yapei, the borehole water had mean total alkalinity of 342.6 mg/l in the wet season whilst the dry season had a value of 306.8 mg/l. The mean total alkalinity of borehole water from Mpaha was 343.8 mg/l in the wet season and 299.25 mg/l in the dry season. In the wet season, the leaching of $CaCO_3$ from limestone and alkaline fertilizers from cultivated fields by rainwater percolation into the soil may have increased the total alkalinity of the borehole water. The total alkalinity of the borehole water relatively low in dry season. The borehole water from Buipe, Yapei and Mpaha were relatively high and can increase the total alkalinity of borehole water in the study (Fig. 4.2). In terms geographical location, no significant difference of total alkalinity was recorded between borehole water from Buipe and Yapei (1.32): Buipe and Mpaha (1.21): Yapei and Mpaha (0.83) at 0.05 significant level in the wet season. There was also no significant difference of total alkalinity between borehole water from Buipe and Yapei (1.7): Buipe and Mpaha (1.61): and Yapei and Mpaha (0.82) at 0.05 significant level in the dry season. This may be attributed to the almost homogeneous geological materials, mainly sedimentary rocks that underlie the study area (Dickson and Benneh, 2004). The sedimentary rocks are sources of $CaCO_3$ which makes borehole water alkaline in the study towns.

At Buipe, there was significant difference (4.16, $P<0.05$) for the river water which had mean total alkalinity of 72.5 mg/l in the wet season and 56.0 mg/l in the dry season. There was also significant difference (2.93, $P<0.05$) of total alkalinity between the wet and dry seasons for the river water at Yapei. The high total alkalinity in the wet season may be due to runoff that carried ammonia and phosphate fertilizer from nearby farms into the rivers that raise the total alkalinity. The absence of rainfall coupled with high temperatures in the dry season may have increased the solubility of CO_2 that reacted with the OH^- ions and resulted in lower total alkalinity of the river. Significant difference (1.87, 1.79) of total alkalinity at 0.05 significant level was recorded between river water from Buipe and Yapei in the wet season and dry seasons respectively. The high total alkalinity of river water at Buipe may be due to high amount of dissolved sediments such as $CaCO_3$ in the water (Ricky *et al.*, 1990). Mean total alkalinity measured for the dam was 37.1 mg/l and 25.1 mg/l for the wet and dry seasons respectively. Significant difference (5.00, $p<0.05$) of total alkalinity occurred between the seasons. The high total alkalinity in the wet season may be the result of increased in photosynthetic activity (by the growth of phytoplankton) that reduced the CO_2 content of the dam including the release of carbonates and bicarbonate ions by sediments at the bottom of the dam. Wetzel (2001) confirms the above finding that the total alkalinity of a surface water bodies is a reflection of its carbonates and organic profiles. Also, high temperature in the dry season may have increased the solubility of CO_2 that resulted in lower total alkalinity of the dam water for the dry season.

Rainwater from Buipe, Yapei and Mpaha had mean total alkalinity of 2.20 mg/l, 2.32 mg/l and 3.02 mg/l in the wet season respectively (Fig. 4.2). The reaction products of SO_2, CO_2 and NO_2 in the atmosphere are acidic and may have reacted with the OH^- ions from the rainwater. There was no significant difference (0.68, $P<0.05$) of total alkalinity between rainwater from Buipe and Yapei. However, significant difference (1.84, 1.72) of total alkalinity at 0.05 significant level was recorded between rainwater from Buipe and Mpaha, Yapei and Mpaha respectively. Rainwater from Buipe and Yapei acquire slight acidity from vehicular emissions along the Kumasi-Tamale trunk road. Mpaha is located about 60 km away from the main road which might have resulted in relatively high total alkalinity values.

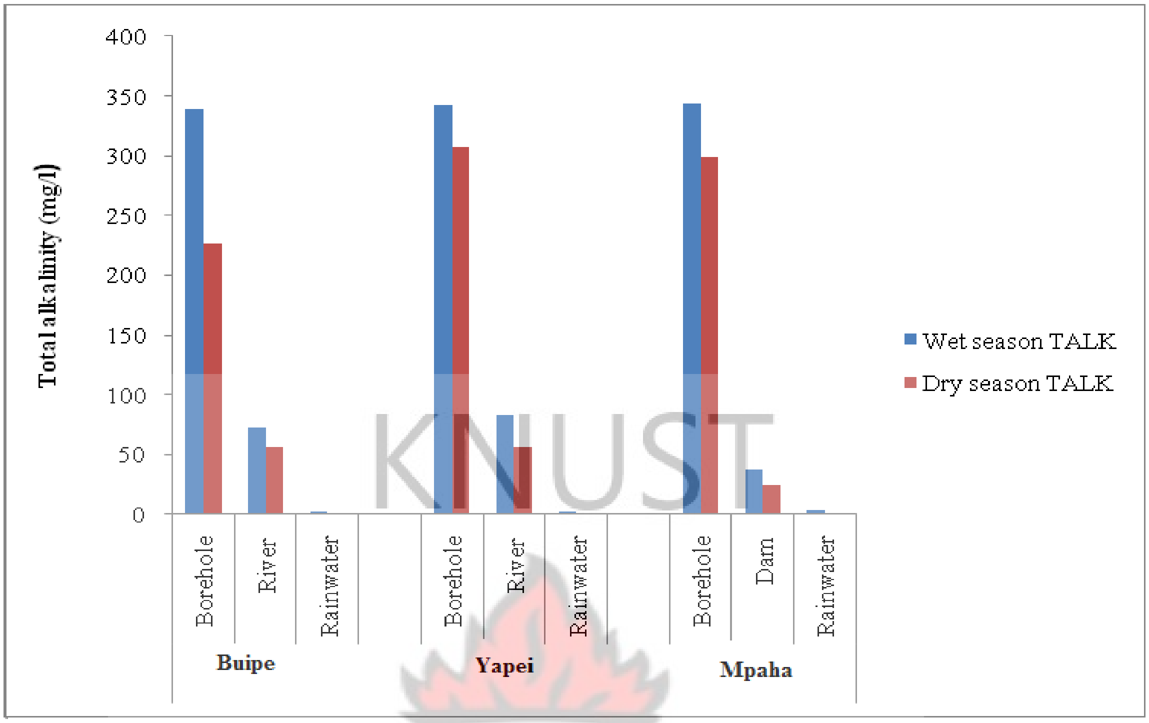

Figure 4.2: Comparison between water sources in terms of seasonal variation of Total Alkalinity (TALK)

4.1.3 Electrical conductivity

According to WHO (2006) electrical conductivity above 300 µS/cm can affect its suitability for domestic use.

Mean conductivity of the borehole water from Buipe was 677.7 µS/cm in the wet season whilst the dry season had a value of 801.2 µS/cm. Significant difference (4.83, $P<0.05$) of conductivity occurred between the seasons. In Yapei, the mean conductivity in the wet season was 715.4 µS/cm and 872.1 µS/cm in the dry season. The borehole water from Mpaha had mean conductivity of 715.4 µS/cm in the wet season 845.7 was recorded in the dry season. The relatively low conductivity in the wet season may be due to low temperatures that reduce the mobility of the inorganic particles such as carbonate and bicarbonate ions in the aquifer. The conductivity of the borehole water was higher in the dry season. High temperatures might have enhanced the mobility of the inorganic particles in the aquifer. However, the presence of carbonates, for instance $NaHCO_3$ in the aquifer may give salty taste to the borehole water leading to its rejection. The alkali carbonate resulted from meteoric water dissolving Na^+ from sodium-bearing silicates (eg. Albite) or reverse cation exchange where Ca^{2+} is taken up from the groundwater, in return for Na^+ helps to refresh the water quality and prevent it from having salty taste (Dickson and Benneh, 2004). There was no significant difference of conductivity between the borehole water from Buipe and Yapei (0.92): Buipe and Mpaha (0.61): Yapei and Mpaha (0.46) at 0.05 significant level in the wet season. In addition, no significant difference of conductivity was recorded between borehole water from Buipe and Yapei (0.73): Buipe and Mpaha (0.61): and Yapei and Mpaha (0.62) at 0.05 significant level in the dry season. This may be the effect of similar geological materials, mainly sedimentary rocks that underlie the study area (Dickson and Benneh, 2004).

The rivers from Buipe had significant difference (3.79, $P<0.05$) of mean conductivity of 137.5 μS/cm and 716.7 μS/cm in the wet and dry seasons respectively. The mean conductivity in the wet season for the river water in Yapei was 158.2 μS/cm in the wet season and 143.3 μS/cm in the dry season. There was significant difference (2.53, $P<0.05$) of conductivity between the wet and dry seasons for the river water from Yapei. The relatively high mean conductivity in the wet season can be adduced to run-offs that carried dissolved fertilizer, pesticides, herbicides and other particles from cultivated fields into the rivers. The relatively low mean conductivity may be due to the absence of run-offs in the dry season. Significant difference (2.10, $P<0.05$) and (1.72, $P<0.05$) of conductivity was recorded between river water from Buipe and Yapei in the wet and dry seasons respectively. The high conductivity of at Buipe may be due to high amount of dissolve ions in the river water (Alcour *et al.*, 2003).

The dam water at Mpaha had mean conductivity 82.4 μS/cm in the wet season was whilst 53.0 μS/cm was recorded in the dry season. Significant difference (3.75, $P<0.05$) of conductivity was observed between the seasons. The high conductivity in the wet season could be effect of run-offs from nearby farms as discussed earlier for the river. The recession in water level and the settlement of dissolved solids at the bottom of the dam might have resulted in the low conductivity in the dry season. Payne (1993) in his study farm waste and nitrate pollution established that low inflows and high temperature in the dry season decreases the conductivity of dam water.

Rainwater from Buipe, Yapei and Mpaha had mean conductivity of 8.5 μS/cm, 7.1 /cm and μS 8.3 /cm. The low conductivity of rainwater may be due to low levels of organic and inorganic ions in the atmosphere. Further, the low conductivity of fresh rainwater is validated by frequent rainfalls combined with low temperature during the sampling period (wet season). In conclusion, the conductivity for all the water sources fell within the WHO (2006) tolerable level for drinking water except for the boreholes (Fig. 4.3). There was no significant difference (0.62, <0.05) of conductivity between rainwater from Buipe and Yapei. However, significant difference of conductivity was recorded between rainwater from Buipe and Mpaha Yapei (0.74) and Mpaha (1.81) at 0.05 significant level. Rainwater from Buipe and Yapei acquire had relatively higher conductivity due to vehicular emissions along the Kumasi-Tamale trunk road. Mpaha is located about 60 km away from the main road which might have resulted in relatively lower conductivity values of rainwater.

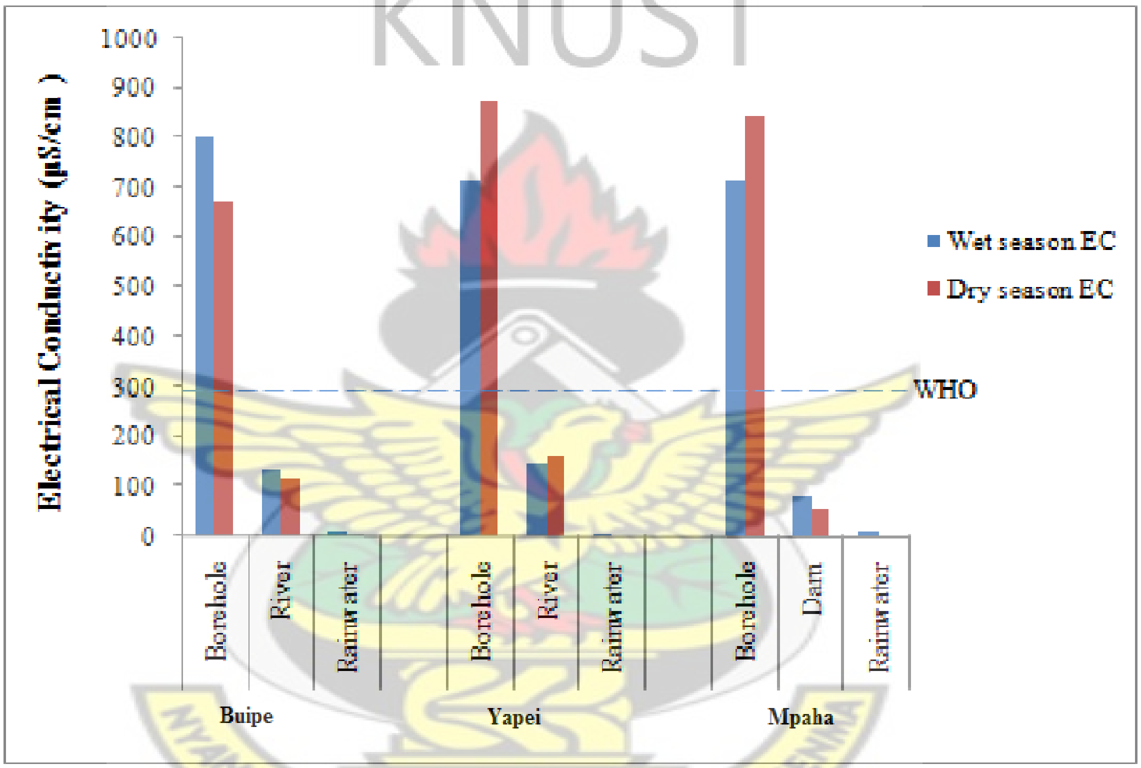

Figure 4.3: Conparison between water sources in terms of seasonal variation of Electrical Conductivity (EC)

4.1.4 Turbidity

There is no health guideline for turbidity, but the recommended value is below 5.0 NTU for effective disinfection (WHO, 2006).

Mean turbidity of the borehole water from Buipe was 2.8 NTU in the wet season and 1.2 NTU in the dry season. The borehole water from Buipe were not significantly affected (1.05, $P< 0.05$) by seasonal variation in terms of turbidity. The mean turbidity of the borehole water from Yapei had 2.51 NTU in the wet season and 1.6 NTU in the dry season. There was no significant difference (1.57, $P<0.05$) of turbidity between the seasons of the borehole water from Buipe. The mean turbidity of the borehole water from Mpaha was 2.78 NTU and 1.46 in the wet and dry seasons respectively. There was no significant difference (1.03, $P<0.05$) of turbidity occurring between the seasons for the borehole water from Mpaha. The mean turbidity of borehole water in the wet season was high. This could be the result of rainwater percolation in the soil that may have dissolved soil particles on its trip to recharge groundwater. The low recharge in the dry season may have resulted in lower turbidity of the borehole water. Generally, the low turbidity of the borehole water from the communities may be due to the fact that groundwater is naturally filtered by the soil and extracted by filter-aided mechanical pumps. In the wet season, there was no significant difference of turbidity between the borehole water from Buipe and Yapei (1.92): Buipe and Mpaha (1.81): Yapei and Mpaha (0.82) at 0.05 significant level. No significant difference of turbidity was recorded between borehole water from Buipe and Yapei (1.7): Buipe and Mpaha (1.61): Yapei and Mpaha (0.82) at 0.05 significant level in the dry season. This may be attributed to similar geology and soil conditions in the study towns.

The river water from Buipe had mean turbidity of 22.8 NTU in the wet season whilst the dry season had a value of 13.1 NTU. There was significant difference (5.09, $P< 0.05$) of turbidity between the seasons for the river water from Buipe. In the wet season, the river water from Yapei had mean turbidity of 24.9 NTU and 15.2 NTU for the dry season. Significant difference (4.98, $P<0.05$) of turbidity occurred between the seasons. The high turbidity of the river water from Buipe and Yapei may have been caused by higher flows rates during rainfalls that might have carried sediments and other materials into the rivers. The low mean turbidity of the river water may be due to the absence of run-offs and the recession in flow level in the dry season. Significant difference (1.85, 1.76) of turbidity at 0.05 significant level was recorded between river water from Buipe and Yapei in the wet and dry seasons. The high conductivity of White Volta at Buipe may be due to high amount of dissolved sediments in the river water. According to Alcour *et al.*, (2003) Black rivers have relatively high concentrations of dissolved sediments.

The wet and dry seasons had mean turbidity of 31.3 NTU and 23.12 NTU respectively for the dam water at Mpaha. However, there was significant difference (2.48, $P< 0.05$) of turbidity between the seasons. The high turbidity in the wet season may be due to runoff that carried sediments from the surroundings into the dam water. During rainfalls, it is possible runoffs erode soil particles and nutrients from farmlands into the dam water. The presence of the nutrients can enhance the growth of micro-organisms and aquatic plants in the dam. In the dry season, the recession in water level coupled with the decay of micro-organisms and aquatic plants may have contributed to the high turbidity of water in the dam. During water scarcity period, humans and cattle herd activities can also contribute significantly to high turbidity in the water.

Rainwater from Buipe, Yapei and Mpaha had mean turbidity of 4.55 NTU, 4.42 NTU and 4.30 NTU respectively. This is probably due to low levels of particulates such as smoke, dust, and soot suspended in the atmosphere which dissolved in the rain droplets as it falls from the sky. This may also be related to the presence of particles of clay, organic components and other microscopic substances (Ovrawah and Hymone, 2001). In addition, the low turbidity in the rainwater can be associated with frequent rainfalls during the sampling period. Appiah (2008) in the study of physicochemical analysis of roof run-off established that turbidity is affected by dry spell, and the longer the span of continuous rainfalls, the lower is the turbidity. There was no significant difference (0.63, <0.05) of turbidity between rainwater from Buipe and Yapei. However, significant difference of turbidity was recorded between rainwater from Buipe and Mpaha (1.71): Yapei and Mpaha (1.84) at 0.05 significant level. Rainwater from Buipe and Yapei were slightly turbid due to vehicular emissions along the Kumasi-Tamale trunk road. Mpaha is located about 60 km away from the main road which might have resulted in relatively low turbidity values of rainwater.

Generally, the borehole and rainwater had lower mean turbidity values below WHO (2006) guideline value of 5 NTU. However, water from river and dam had higher mean turbidity above the guideline value (Figure 4.4), meaning they were laden with pollutant load irrespective of the seasons. The high turbidity levels in the river and dam water can cause problems during purification, possibility of micro-biological contamination, low dissolved oxygen, high temperature and decrease in the rate of photosynthesis in the study area.

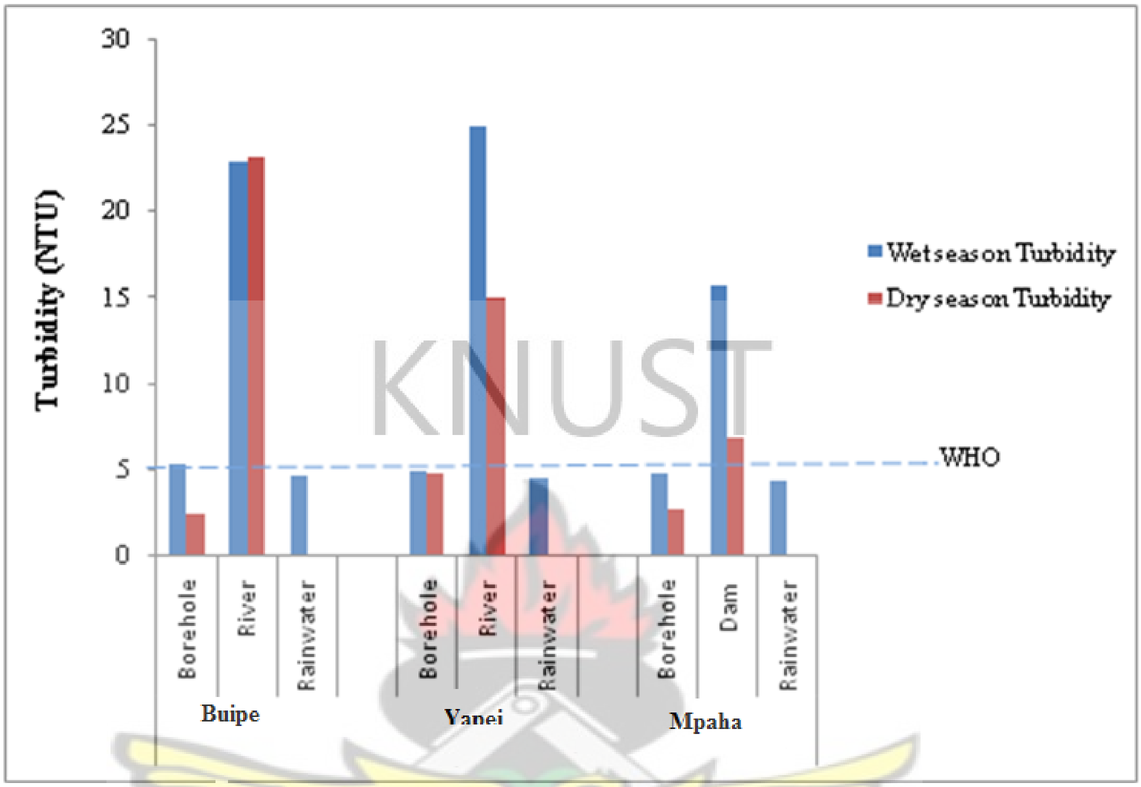

Figure 4.4: Comaparision between water sources interms of seasonal variation of Turbidity

4.1.5 Nitrate

High concentration of nitrate above 50 mg/l in drinking water is deleterious especially to babies due to the formation of methmoglobinamea (WHO, 2006).

The borehole water from Buipe had mean nitrate concentration of 4.5 mg/l and 3.30 mg/l in the wet and dry seasons respectively. There was significant difference (2.52, $P<0.05$) of nitrate concentration between the seasons borehole water from Buipe. In Yapei, the mean nitrate concentration was 4.33 in the wet season and 3.30 in the dry season. There was significant variation (2.41, $P<0.05$) of nitrate concentration between the season for borehole water from Yapei. The mean nitrate concentration of the borehole water from Mpaha in the wet season was 4.25 mg/l and 3.20 mg/l in the wet season. The presence of nitrates in the boreholes suggests the leaching of dissolved nitrogen from nearby farms facilitated by rainwater percolation into the groundwater. The low mean nitrate concentration in the borehole water may be due to the reduction of nitrate to nitrogen gas and ammonia by microbes (eg. nitrobacteria). A study on the modeling of groundwater flow and quality by Konikow and Glynn (2005) found that the presence of organic carbon (present in the soil) in the soil may cause the reduction of NO_3^- to NO_2 and sometimes to NH_4^+ ions in the phase of denitrifying microbes. There was significant difference (1.92, 1.73) at 0.05 significant difference of nitrate between borehole water from Buipe and Mpaha in the wet and dry seasons respectively. In boreholes are located within households and farms where fertilizer may dissolve and percolate to recharge groundwater. However, no significant difference of nitrate was recorded between borehole water from Buipe and Yapei (0.33): Yapei and Mpaha (0.82) at 0.05 significant level in the dry season. This may be due to the fact that the boreholes in Yapei are located far from households and farmlands.

In Buipe, the river water had mean nitrate concentration of 9.93 mg/l in the wet season whilst the dry season had a value of 5.2 mg/l with significant difference (5.09, $P<0.05$) between the seasons. The river water from Yapei had mean nitrate concentration of 9.59 mg/l and 4.75 mg/l for the wet and dry seasons respectively. The high mean nitrate concentration in the wet season can be attributed to run-offs from nearby farms which carried nitrogen fertilizers into the rivers. A study of trading on water by Greenhalgh and Faeth (2001) indicates that in the wet season, run-offs carry nutrients from farmlands and deposit it in the river body. In the presence of denitrifying bacteria, the nitrates may have been converted to NH_4^+ ions which lowered the nitrate concentration of the rivers as confirmed by Konikow and Glynn (2005). No significant difference (0.46, 0.66) of nitrate was recorded between river water from Buipe and Yapei in the wet season. At Buipe and Yapei, the households are located closer to the rivers and during the rainy season flood spread into the settlement and farmland, mixing household waste and fertilizer substances into the river water.

Mean concentration of nitrate for the dam in Mpaha was 24.10 mg/l and 20.87 mg/l in the wet and dry seasons respectively. There was significant difference (1.36, $P<0.05$) between the seasons in terms of nitrite concentration. The high nitrate concentration for the dam may be due to run-off that carried fertilizer particles from nearby cultivated land into the dam as indicated by Greenhalgh and Faeth (2001). The presence of nitrates may have facilitated the growth of water lily which was observed in the Mpaha dam. The presence of nitrate can enhance the growth of aquatic plants by a process known as eutrophication in the rivers (Greenhalgh and Faeth, 2001). However, the recession in flows due to the absence of rainfall including the conversion of nitrates into NH_4^+ ion by microbes may have lowered the nitrate concentration as established by Konikow and Glynn (2005).

Rainwater from Buipe, Yapei and Mpaha had mean nitrate concentration of 2.19 mg/l, 2.15 mg/l and 2.17 mg/l in the wet season. The presence of nitrates in the rainwater samples may be due to direct dissolution and oxidation of NO_2 to NO_3^- particles caused by the use of nitrogen fertilizers for crop cultivation in the study area. This observation is buttressed by Thomas and Grenne (1993) in his study of rainwater quality from different roof catchments that in agricultural areas, rainwater could have higher concentration of nitrate due to fertilizer residue in the atmosphere. There was no significant difference at 0.05 significant level of nitrate between rainwater from Buipe and Yapei (0.63): Buipe and Mpaha (0.71): Yapei and Mpaha (0.84). As observed during the survey, residence at the study towns are engage in farming which this might have introduced nitrate particles in the rainwater.

The mean nitrate concentration of the boreholes and rainwater was within the acceptable limit of 5 mg/l (Figure 4.5). The mean nitrate concentration of the rivers and the dam in the wet season was higher than the acceptable level. Though there has not been any reported case of methmoglobinamea disease in the study communities, however babies may be at risk upon consumption of the river or dam water in the dry season.

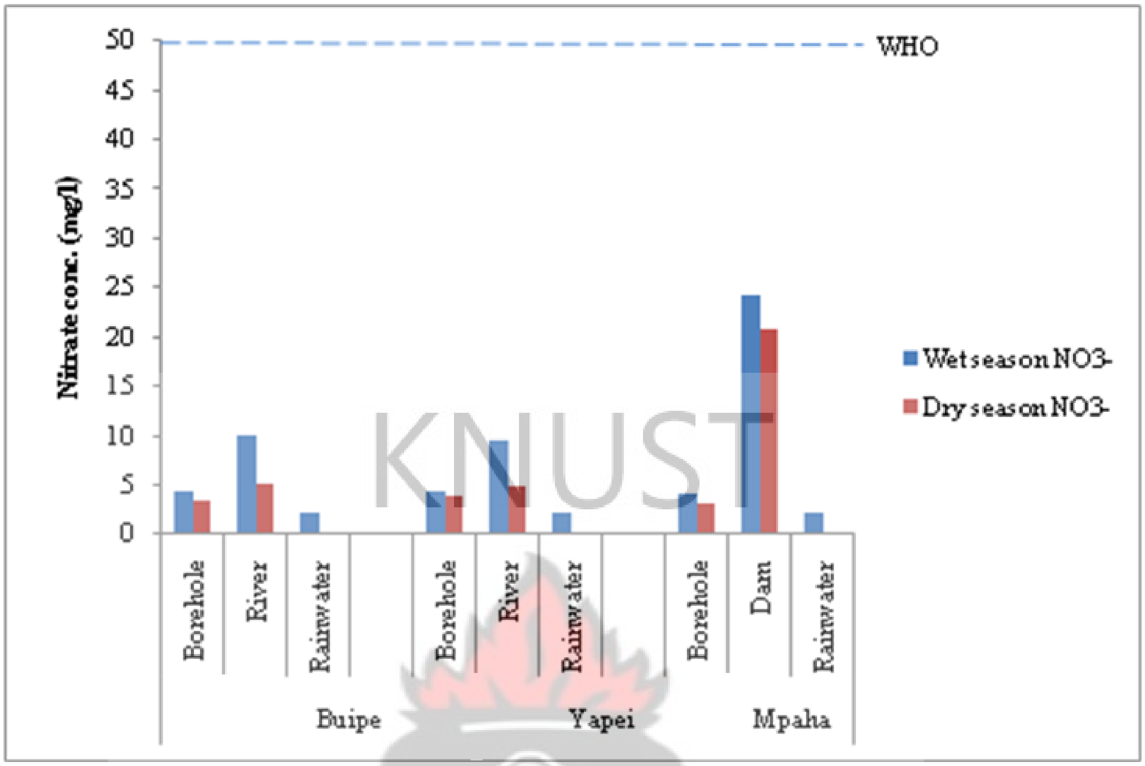

Figure 4.5: Comparison between water sources in terms of seasonal variation of Nitrate

4.1.6 Total hardness

According to WHO (2006) domestic water of total hardness above 500 mg/l is not recommended due to potential scale formation.

The borehole water from Buipe had mean total hardness of 226.67 mg/l in the wet season whilst the dry season had 170.83 mg/l with significant difference (3.83, $P<0.05$) between the season. The boreholes water from Yapei had mean total hardness of 163.50 mg/l and 135.41 mg/l for the wet and dry seasons. The borehole water from Yapei were also significantly affected (1.45, $P<0.05$) by seasonal variation. In Mpaha, the borehole water had mean total hardness of 125.41 mg/l and 90.83 mg/l for the wet and dry seasons respectively. There was significant variation (1.48, $P<0.05$) of total hardness between the season for the borehole water from Mpaha. The high mean total hardness of the borehole water in the wet season may be due to dissolution of metallic ions such as Mg^{+2}, Ca^{+2} ions from limestone and sedimentary rocks by rainwater percolation in the soil. The ions may have originated from run-offs that infiltrated into the soil, causing leaching and weathering of limestone and feldspars in the soil. The result is the precipitation of Ca^{+2} and Mg^{+2} ions and other mineral constituents in the soil that can also increase the total hardness of groundwater. A study by Olobaniyi (2007) of groundwater established that Ca^{+2} and Mg^{+2} ions are usually released into groundwater by the dissolution of limestone, feldspars and micas which increases its hardness. The low total hardness in the dry season may be the result of low aquifer recharge, hence less dissolution of the mineral composition of the aquifer. No significant difference of total hardness between borehole water from Buipe andYapei (0.93): Buipe and Mpaha (0.78): Yapei and Mpaha (0.73) at 0.05 significant level in the wet seasons. There was also significant difference of total hardness between borehole water from Buipe andYapei (0.72): Buipe and Mpaha (0.81): Yapei and Mpaha (0.88) at 0.05 significant level in the dry seasons. All the borehole water from Buipe, Yapei and Mpaha were alkaline. This may be the result of similar geological characteristics, mainly of sedimentary rocks which are sources of Ca^{2+} and Mg^{2+} ions from dissolution of limestone in the aquifer formation as confirmed by Dickson and Benneh (2004).

Mean total hardness measured for the river water from Buipe was 32.67 mg/l in the wet season and 20.35 mg/l for the dry season. The river water from Buipe were significantly affected (3.32, $P<0.05$) by seasonal variation in terms of total hardness. At Yapei, the borehole water had mean total hardness of 29.05 mg/l and 21.55 mg/l for the wet and dry seasons. Also, significant difference (1.70, $P<0.05$) of total hardness occurred between the seasons of the Yapei borehole water. The high total hardness of the river water in the wet season may the run-off that carried sediments containing Ca^{+2} and Mg^{+2} ions into the rivers. Significant difference (1.62, 1.74) of total hardness at 0.05 significant level was recorded between river water from Buipe and Yapei in the wet and dry seasons respectively. The soil formation of the river bed is mainly sedimentary rock which is a source Calcium and Magnesium ions in the river water.

Mean total hardness of the dam water from Mpaha was 37 mg/l and 34.8 mg/l for the wet and dry seasons respectively. The Mpaha dam was unaffected by seasonal variation (0.74, $P<0.05$) of total hardness. The high mean total hardness in the wet season may be due to the result of run-off that carried dissolved calcium and magnesium ions into the dam. High temperatures combined with the recession in water level of the dam may have concentrated the calcium and magnesium ions in the dam.

Rainwater from Buipe, Yapei and Mpaha areas recorded 0.00 mg/l mean total hardness. The above is confirmed by Krishna (2003) that the Zero hardness of rainwater helps prevent scale formation on appliances. However, there is some indication that very soft water may have adverse effect on mineral balance (Appiah, 2008). There was no significant difference (0.63, <0.05) of total hardness between rainwater from Buipe. However, significant difference (1.71, <0.05) and (1.84, <0.05) of total hardness was recorded between rainwater from Buipe and Mpaha and Yapei and Mpaha respectively. Buipe and Yapei are located along the Kumasi-Tamale trunk road, the possibility of particulate matter from vehicular emissions are higher than Mpaha which is 60 km away from the main road.

The results showed that borehole water was moderately hard, whilst the rivers and dam were moderately soft and within the recommended (Fig. 4.6). Most of the people I interacted with complained that the water from the borehole does no lather well when washing or bathing. The relatively high total hardness for the boreholes may the reason for this observation.

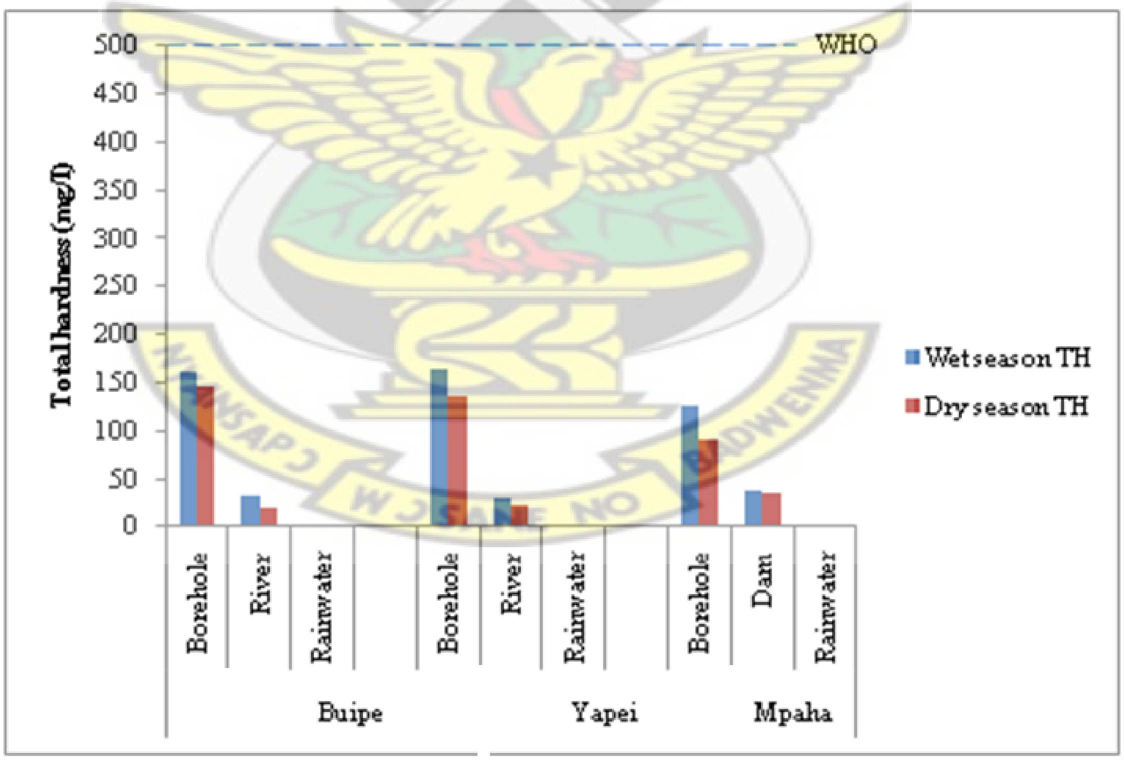

Figure 4.6: Comparison between water sources in terms of seasonal variation of Total Hardness (TH)

4.1.7 Iron

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

The borehole water from Buipe had mean iron concentration of 0.047 mg/l for the wet season and 0.014 mg/l in the dry season. Significant difference (2.55, $P<0.05$) occurred between the seasons in terms of iron concentration. In Yapei, the borehole water had mean iron concentration of 0.014 mg/l and 0.0115 mg/l in the wet and dry season respectively. Significant difference (1.82, $P<0.05$) of iron concentration occurred between the seasons. The mean iron concentration of the boreholes water from Mpaha was 0.015 mg/l in the wet season and 0.011 mg/l in the dry season with significant difference (2.81, $P<0.05$) between the seasons. The high iron concentration in the wet season may suggest dissolved iron by rainwater from lateritic soil into the groundwater. A study by Olobaniyi (2007) of the quality of groundwater and rainwater indicated that the occurrence of iron in the boreholes is due to the dissolution of iron from metallic wastes and scraps, and lateritic iron within the soil particles. The absence of rainwater percolation in the dry might have lowered the iron concentration of the boreholes. In the wet season, there was no significant difference of iron concentration between borehole water from; Buipe and Yapei (0.33): Buipe and Mpaha (0.23): Yapei and Mpaha (0.22) at 0.05 significance level. In the dry season, no significant difference was recorded between borehole water from Buipe and Yapei (0.18): Buipe and Mpaha (0.18): Yapei and Mpaha (0.26) at 0.05 significant level. In terms of iron concentration, all the borehole water from Buipe, Yapei and Mpaha were not significantly different from each other. This may due to the fact that about 75 % of the Central Gonja District is covered by lateritic soil (Dickson and Benneh, 2004).

In Buipe, the mean iron concentration for the river water was 0.60 mg/l and 0.56 mg/l for the wet and dry seasons respectively. No significant difference (0.34, $P<0.05$) occurred between the seasons in terms of iron concentration. The borehole water from Yapei had mean iron concentration of 0.60 mg/l in the wet season and 0.57 mg/l in the dry season. There was no significant difference (0.25, $P<0.05$) of iron concentration between the seasons. The relatively high iron concentration in the wet season may be the result of run-offs that carried metal scraps into the rivers. The high concentration of iron in the wet season is validated by the high turbidity and *p*H levels recorded for the rivers. The low concentration of iron in the dry season may be due to the precipitation of iron, as well as a natural cycling of iron between the dissolved and precipitated phases at the water sediment interface. No significant difference (0.23, 0.31) of iron concentration at 0.05 significant level was recorded between river water from Buipe and Yapei for the wet and dry seasons respectively. This may be attributed to the presence of lateritic soil which is found along the White and Black Volta rivers as confirmed by Dickson and Benneh (2004).

Mean concentration of iron for the Mpaha dam was in the wet season 3.97 mg/l and 2.56 mg/l in the wet and dry seasons respectively. Significant difference (2.49, $P<0.05$) occurred between the seasons in terms of iron concentration. The relatively high iron level was due to run-offs that carried sediments containing iron particles into the dam.

Corrosive materials contribute significantly to the levels of iron in surface water bodies Pelig-Ba (2001).

Rainwater from Buipe, Yapei and Mpaha were free from iron contamination, due to the absence of iron in the atmosphere. The rivers and the dam had mean iron concentration above the acceptable level (Figure 4.7). Hence, ulceration of the gastrointestinal tract; black stools of consumers can be anticipated in the study area.

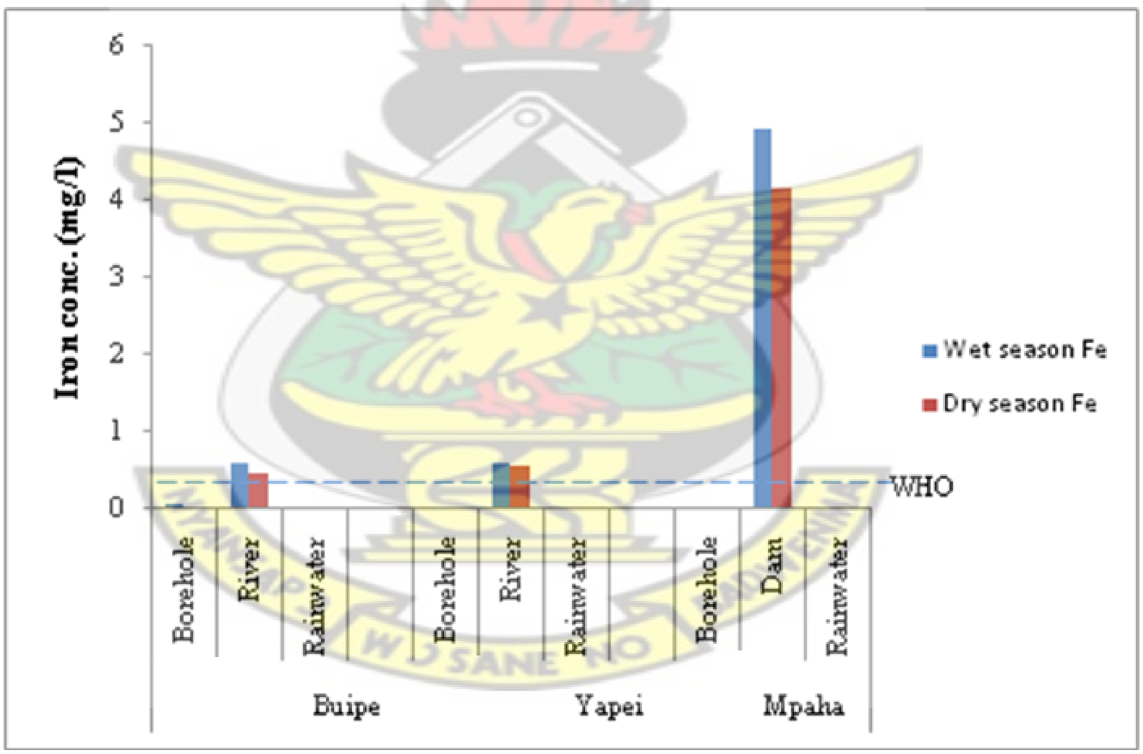

Figure 4.7: Comparision between water sources in terms of seasonal variation of Iron

4.1.8 Fluoride

WHO (2006) recommends that drinking water should ideally contain 0.5 - 1.5 mg/l fluoride to help prevent dental carriers.

In Buipe, the borehole water had mean fluoride concentration of 0.21 mg/l for the wet season and 0.39 mg/l in the dry season. Significant difference (5.55, $P<0.05$) occurred between the seasons in terms of fluoride concentration. In Yapei, the borehole water had mean iron concentration of 0.40 mg/l and 0.54 mg/l in the wet and dry season respectively. Significant difference (1.28, $P<0.05$) of fluoride concentration occurred between the seasons. The mean iron concentration of the boreholes water from Mpaha was 0.65 mg/l in the wet season and 0.01 mg/l in the dry season with significant difference (3.50, $P<0.05$) between the seasons. The presence of fluoride in the borehole may be indicative of granitic rock formation of the aquifer in the study area. The dissolution of granitic rock by rainwater percolation in the soil may have contaminated groundwater with fluoride. However, fluoride is highly reactive and might have reacted with other reactive metals in the rock formation leading to the lower values recorded in the dry season. No significant difference occurred between borehole water from Buipe and Yapei (0.52): Buipe and Mpaha (0.23): Yapei and Mpaha (0.18) at 0.05 significant level in the wet season. Also, there was no significant difference between Buipe and Yapei (0.31), Buipe and Mpaha (0.18), Yapei and Mpaha (0.12) at 0.05 significant level in the dry season. Most part of the Central Gonja district is made of sedimentary rock formation which might have account for the lower concentration in the study towns.

Mean fluoride concentration of the river sample from Buipe was 0.11 mg/l in the wet season and 0.9 mg/l in the dry season. There was significant difference (3.27, $P<0.05$) of fluoride concentration between the wet and dry seasons. In Yapei, the mean fluoride concentration was 0.10 mg/l and 0.09 mg/l for the wet and dry seasons. Significant difference (4.60, $P<0.05$) of fluoride concentration occurred between the seasons. The effect of run-off from the surround might have increased the fluoride concentration in the wet season. The low mean fluoride concentration in the dry season could be the result of pronounced electron affinity of the fluoride atom which might have reacted with most reactive species along the course of the river. There was no significant difference (0.27, 0.34) of iron concentration between river water from Buipe and Yapei in the wet and dry seasons respectively. The presence of fluoride in the river water may have been the result of flood spreading into the settlement and dissolving household waste into the water.

The mean fluoride concentration of the dam in Mpaha was 0.15 mg/l in the wet season whilst the dry season had 0.11 mg/l in the dry season. Significant difference (3.13, $P<0.05$) of fluoride concentration was found for the dam between the seasons. The wet season fluoride concentration was because run-off may have carried sediments containing fluoride into the dam. Fluoride is very reactive and high temperatures in the dry season may have favoured its reaction with other species in the dam during the dry season.

Rainwater was free from fluoride contamination. However, the boreholes, rivers and dam had fluoride concentration below 1.5 mg/l (Figure 4.8). This may account for no cases of dental fluorosis reported by the District Health Directorate in the study area.

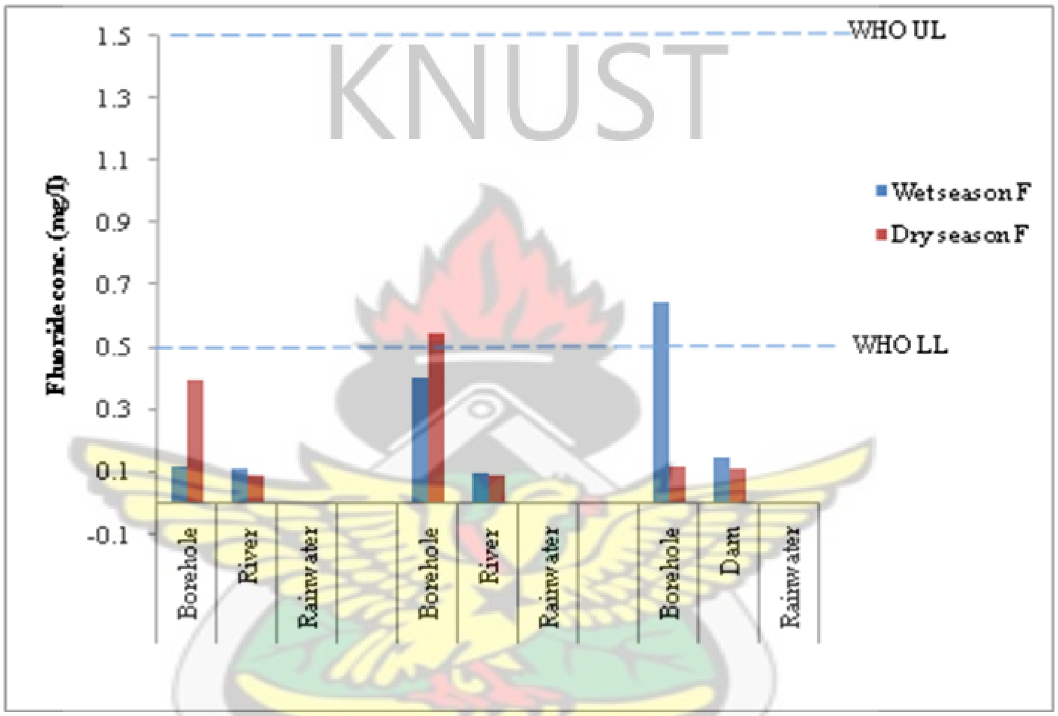

Figure 4.8: Comparison between water sources in terms of seasonal variation of Fluoride
*WHO LL - Lower Limit, WHO UL - Upper Limit

4.1.9 Faecal coliform

For water source to be considered as no risk to human health, the faecal coliform counts/100 ml should be Zero (WHO, 2006). Although the water sources in the study communities were not tested for specific pathogens, the presence of faecal coliform suggests that it may be potentially harmful for human consumption.

The mean faecal coliform of borehole water from Buipe was 25.16 CFU/100 ml in the wet season and 3.33 CFU/100 ml in the dry season. There was significant difference (3.422, $P<0.05$) of faecal coliform between the seasons for the borehole water from Buipe. In Yapei, the mean faecal coliform recorded for the borehole water was 43.91 CFU/100 ml and 2.41 CFU/100 ml for the wet and dry seasons respectively. Significant difference (5.37, $P<0.05$) of faecal coliform was found between the seasons for the borehole water from Yapei. The borehole water from Mpaha had mean faecal coliform of 16.84 CFU/100 ml in the wet season whilst the dry season had a value of 2.16 CFU/100 ml. The borehole water were also significantly affected (2.84, $P<0.05$) by seasonal variation in terms of faecal coliform. The high faecal coliform in the wet season can associated with the 2010 floods that hit the district where three toilet facilities were submerged in the study area. For instance, the practice of “free range” defecation by the inhabitants is reflected in the presence of faecal coliform in the borehole water from all the communities. In Buipe and Yapei, the boreholes are located within households and may have been the reason for the higher faecal loads in the borehole water. However, the boreholes from Mpaha are located 2 km away from the households, and the possibility of faecal contamination may be low. The ingress of coliform bacteria into the groundwater might have been facilitated by rainwater percolation into the borehole. In the wet season, there was significant difference of faecal coliform between borehole water from Buipe and Yapei (2.43): Buipe and Mpaha (2.28): Yapei and Mpaha (2.34) at 0.05 significance level. In the dry season no significant difference was recorded between borehole water from Buipe and Yapei (0.28): Buipe and Mpaha (0.21): Yapei and Mpaha (0.43) at 0.05 significant level. This may be the result of flood that which mixes faecal waste from the surroundings facilitated by rainwater percolation to recharge groundwater.

The river water from Buipe had mean faecal coliform of 1720.25 CFU/100 ml in the wet season and 627.5 CFU/100 ml in the dry season. There was significant difference (5.75, $P<0.05$) of faecal coliform between the seasons for the borehole water from Buipe. In Yapei, the mean faecal coliform for the river water was 1685 CFU/100 ml and 526.50 CFU/100 ml for the wet and dry seasons respectively. Significant difference (6.23, $P<0.05$) of faecal coliform occurred between the seasons for the river water from Yapei. The high faecal coliform in the wet season may have been caused by the massive floods that hit the Central Gonja District between August and December 2010. The floods affected 112 communities with 15 boreholes and 3 public toilets submerged in the district (CGDHD, 2010). Also, the high microbial load in the rivers might be due to contamination caused by human activities and livestock in the area. It is a common practice for people living along the river catchment to discharge domestic and agricultural wastes as well as human excreta into rivers. In addition, children use the river for bathing, washing of clothes and for recreational purposes such as swimming. They also serve as sources of drinking water for livestock which can contaminate the water through direct defecation and urination. There was significant difference (2.26, $P<0.05$) of faecal coliform between river water from Buipe and Yapei in the wet season. At Buipe, the household settlements are closer to the Black Volta river, and the possibility of contamination of the river water during flood is higher.

The mean faecal coliform for the dam in the wet season was 904.25 CFU/100 ml and 403.75 CFU/100 ml in the dry season. There was significant difference (6.23, $P<0.05$) of faecal coliform between the wet and dry seasons. However, livestock in search of water during the dry season can contaminate the dam. The relatively stagnant nature of the dam may habour micro-organisms resulting in higher faecal coliform loads.

Faecal coliform was not detected in the rainwater from Buipe, Yapei and Mpaha, suggesting that it is devoid of pathogens. The absence of coliforms can partly be explained by its mode of collection. Rainwater were collected directly into containers as it from the sky. However, contamination of rainwater may result from the environment, roof materials and containers which are used for rainwater storage (Polkowska *et al*., 2001). The laboratory results indicated faecal contamination of all the water sources except fresh rainwater (Figure 4.9). The unacceptable coliform counts in the boreholes, rivers and dam may be linked to the high rate of gastro-enteritis because many inhabitants rely on these water sources for domestic use. Currently, medical records from the District Health Directorate in the study area indicate that diarrheal diseases increased in Buipe, Yapei and Mpaha towns of the Central Gonja District.

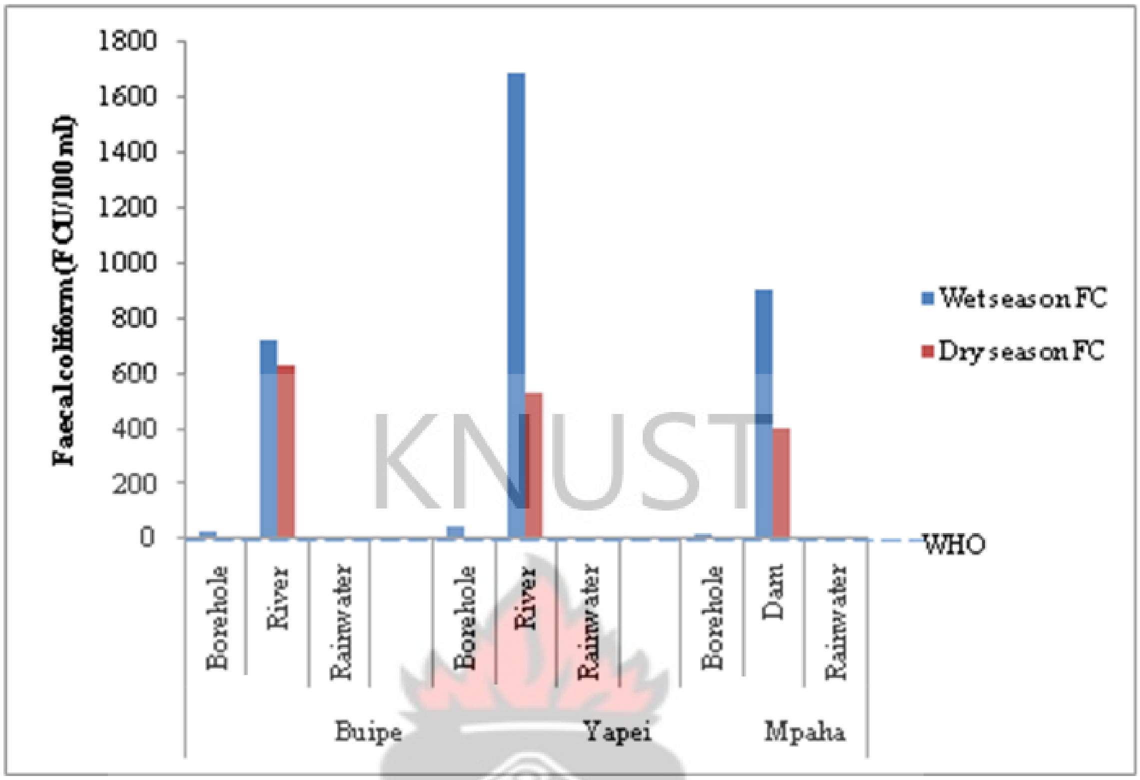

Figure 4.9: Comparison between water sources in terms of sasonal variation of Faecal Coliform (FC)

4.2 Impact of storage tank on quality of rainwater stored

Sixty-three (63) water samples were collected from the 'entry points' of the tanks, including samples from plastic, metal and concrete tank covering 12 weeks of storage. This section discusses the impact of the tanks on the quality of the water stored.

4.2.1 Water *p*H

The *entry point water* had mean *p*H of 6.4, indicating that the samples were slightly acidic. However, the mean *p*H of the *entry point water* was the same as the mean *p*H of rainwater in the plastic tanks. Compared to the metal and concrete tanks, the ‘entry point water had lower mean *p*H. The low mean *p*H value may be due to the slightly acidic nature of rainwater collected direct from the sky in the study area.

The mean *p*H (6.4) of plastic tank water remained unchanged after 12 weeks of storage (Figure 4.10). The mean *p*H of the plastic tank water was slightly acidic and within the WHO (2006) acceptable range. This may be due to the fact that plastic materials are chemically unreactive, and did not alter the *p*H of rainwater stored. However, the slightly acidic rainwater in the plastic tanks can react with the taps to give stain. Lower *p*H values of rainwater stored in plastic containers remains naturally acidic and can react with copper taps (TWDB, 2005).

Metal tank water had mean *p*H of 5.4 which is below the WHO (2006) lower limit value of 6.5 (Figure 4.11). Also, the *p*H of rainwater stored in metal tanks decreased significantly (0.362, $P<0.05$) after 12 weeks. The low *p*H in metal tanks may be the result of metabolic activities of micro-organisms such as bacterial, moulds and mosquitoes from the surroundings which were increasing in population, since the metal tanks were not properly covered. A study of the physico-chemical changes and bacteriological deterioration of potable water during long term storage by Popoola *et al.* (2007) established that the build-up of metabolites from micro-organisms in storage tanks can result in lower *p*H values. Also, the water from the metal tanks were slightly acidic and can facilitate the precipitation of metallic ions in the water stored due to chemical reaction with the metal material.

The mean *p*H (8.6) of concrete tank water increased significantly (2.02, $P<0.05$) after 12 weeks of storage but was narrowly higher than the upper limit *p*H set by the WHO (2006) as presented in Figure 4.10. The presence of $CaCO_3$ in the cement material may have resulted in high *p*H values of stored rainwater in the concrete tanks. Lundgren and Akerberg (2006) in their study of rainwater harvesting in peri-urban areas of Accra found that concrete tanks have the capacity to increase the *p*H of rainwater stored by the dissolving calcium carbonate from the walls of the tank.

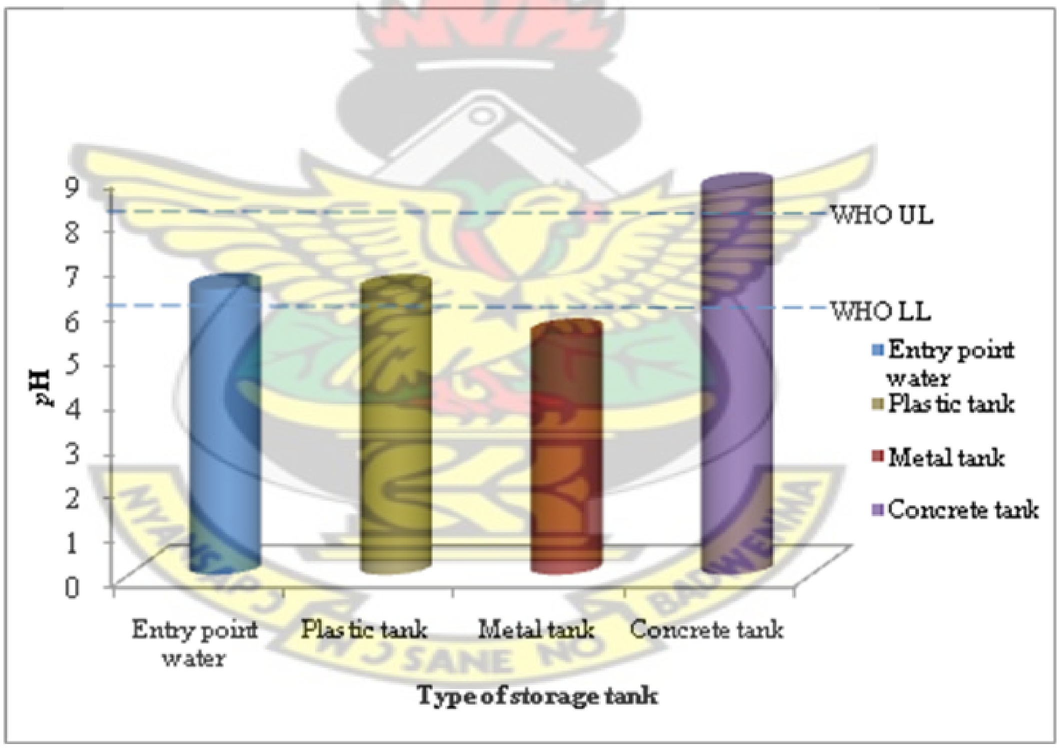

Figure 4.10: Comparison between storage tanks in terms of *p*H

4.2.2 Total alkalinity

The mean total alkalinity (6.5 mg/l) for the *entry point water* was considerably low (Figure 4.11). The *entry point water* came from rainwater and the acidic products of CO_2, SO_2 and NO_2 in the atmosphere may have reacted with the OH^- ions in the rainwater which might have lowered the total alkalinity.

The mean total alkalinity (6.5 mg/l) of the plastic tank water was not significantly different (0.477, $P<0.05$) from the *entry point water* after 12 weeks of storage. As indicated earlier, plastic tanks are chemically unreactive and did not affect the total alkalinity of the water stored.

The mean total alkalinity (3.3 mg/l) for the metal tank water decreased significantly (0.491, $P<0.05$) after 12 weeks of storage. This may be the result of metabolic activities of micro-organisms such as bacteria that produces CO_2 which might have reduced the concentration of H^+ ions, hence lower total alkalinity.

Concrete tank water had relatively higher mean total alkalinity of 20.5 mg/l, which was significantly different (3.723, $P<0.05$) from the *entry point water* after the 12 weeks. The relatively high values of total alkalinity in the concrete tank water may have been caused by the leaching of alkaline substances such as $CaCO_3$ in the cement material from the walls of the tank.

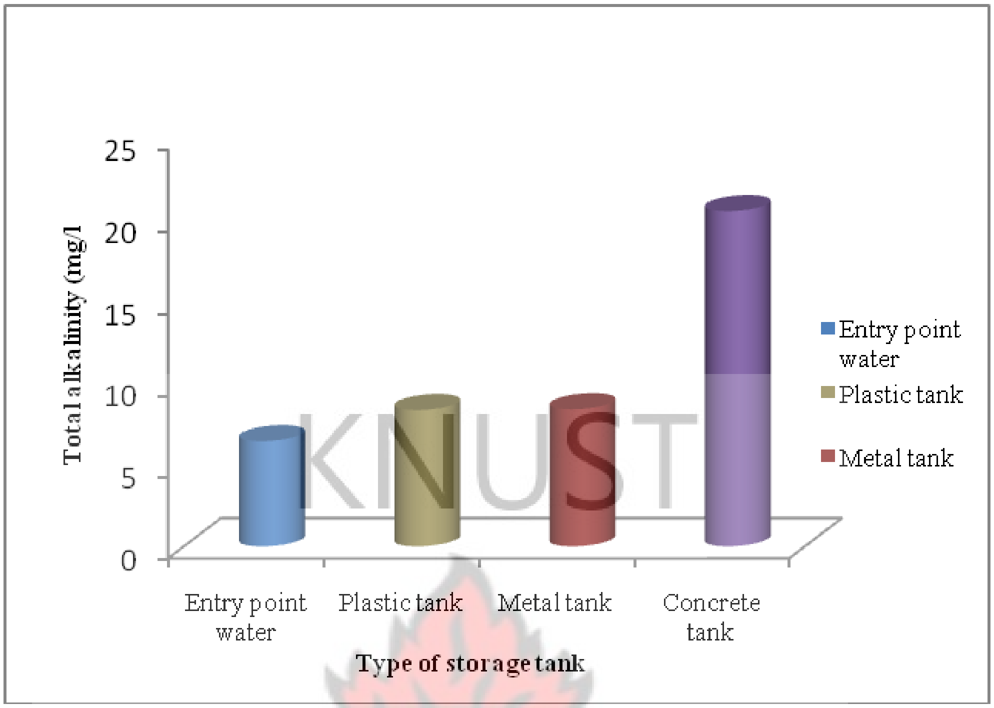

Figure 4.11: Comparison between tanks in terms of Total Alkalinity

4.2.3 Electrical conductivity

The *entry point water* had mean conductivity of 170 µS/l. This can be the result of the absorption of heat by the iron roofing material including the dry depositions of NO_3^-, SO_4^{-2}, PO_4^- from farming activities and the slash and burn method of land preparation in the area. Thomas and Grenne (1993) in their study of rainwater quality from different roof catchments found that high conductivity of rainwater can be the result of dry atmospheric deposition of ions on roof-tops with considerably high temperature during the dry spell.

Plastic tank water had mean conductivity of 168 µS/l, and within the WHO acceptable level as presented in Fig. 4.12. No significant difference (0.653, $P<0.05$) was observed between the plastic tank and the *entry point water* after 12 weeks of storage. This means that plastic tank material did not affect the conductivity of the water stored. The contribution to the high conductivity rather came from dry deposition of ions from the atmosphere on the roof catchment.

Metal tank water had mean conductivity of 184.33 μS/l, which is significantly different (2.533, $P<0.05$) from the *entry point water* after 12 weeks of storage. The reaction of the slightly acidic rainwater with the metal tank material can result in the release of metallic ions such as Fe^{+2} and Zn^{+2} ions into the water stored. Further, since the metal tanks were not properly covered, it is possible for particles from the environment to fall into the tank which can raise the conductivity level of the water stored.

The mean conductivity (153.13 μS/l) reported for the concrete tank water fell within the acceptable level (Figure 4.12). After 12 weeks of storage significant difference (5.80, $P<0.05$) was found between the concrete tank and the *entry point water*. The leaching of construction materials, for instance $CaCO_3$ clay, silt and other inorganic particles from the tank walls can raise the conductivity level of water stored.

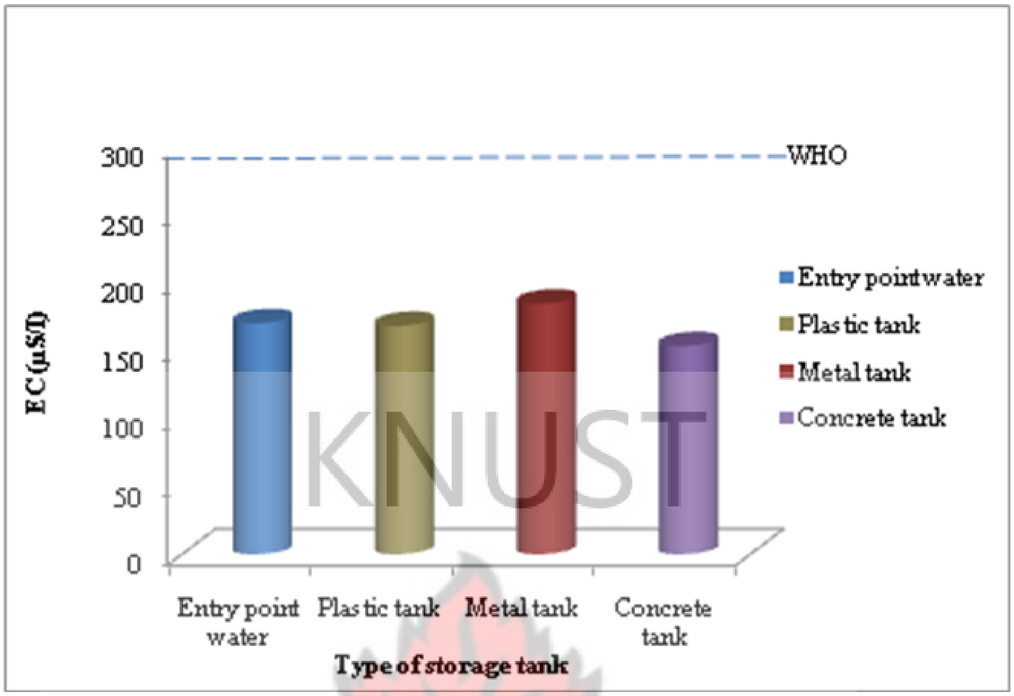

Figure 4.12: Comparison between tanks in terms of Conductivity

4.2.4 Turbidity

Turbidity analysis shows that the *entry point water* had mean turbidity of 9.41 NTU. The high turbidity can be attributed to dissolved atmospheric gases and particulate matter in the raindrops. Also, the presence of particulate matter on the roofs and can contribute to the high turbidity in the *entry point water*. According to Kohler *et al.* (1997) the presence of particulates in the atmosphere and on the roof are factors that can increase the turbidity of rainwater collected.

Mean turbidity of plastic tank water was 6.88 NTU and slightly higher than the WHO (2006) acceptable value of 5 NTU (Fig. 4.15). However, no significant difference

(0.962, $P<0.05$) was observed between plastic tank and the *entry point water* suggesting that the plastic material did not contribute to the turbidity level of the water stored.

After 12 weeks of storage, metal tanks water had mean turbidity 18.88 NTU, presented in Fig. 4.13. Significant difference (2.503, $P<0.05$) was found between the metal tank and *entry point water* which is above the WHO (2006) recommendation of 5 NTU. In corroded tanks, the release of metallic ion, like Fe^{+2} can change the colour of water stored into ferric brown. The resuspension of accumulated sediments such as silt and food particles at the bottom of the tank from the surroundings and roof-tops can also increase the turbidity of the water stored during fetching of the water with cups or bowls. The food particles may provide nutrients for the growth of bacterial and other micro-organisms in the tank (LeChavallier *et al.*, 1981). This may be the reason for higher faecal contamination in the metal tank water.

The mean turbidity (15.42 NTU) of concrete tanks varied significantly (2.602, $P<0.05$) from the *entry point water* after 12 weeks of storage. This means concrete tanks contributed to the high turbidity in concrete tanks which is above the recommended level of drinking water (Figure 4.13). The leaching of $CaCO_3$, clay, silt and other particles from the construction materials can raise the turbidity level of the water stored. According to LeChavallier *et al.* (1981) these sand and food particles can provide nutrients for bacteria, or they may even protect micro-organisms from chlorination. This may be the reason for high faecal contamination in the concrete tank water.

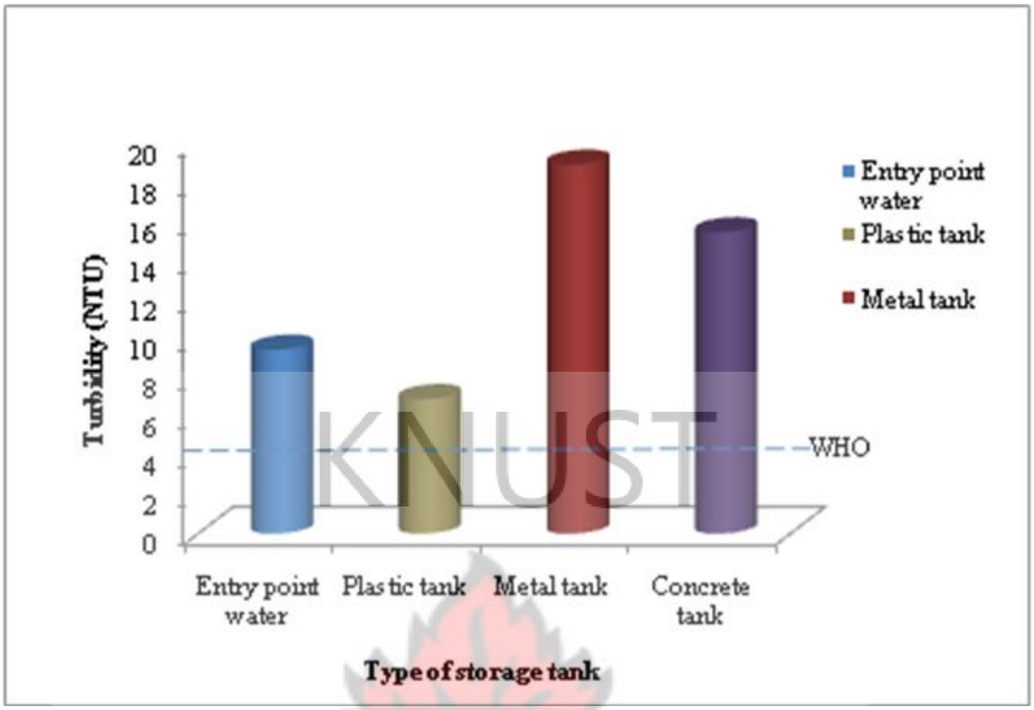

Figure 4.13: Comparison between tanks in terms of Turbidity

4.2.5 Nitrate

Mean nitrate concentration of the *entry point water* was 5.15 mg/l, which was higher than the rainwater collected. The presence of organic materials such as leaves and bird droppings on the roof catchment may have resulted in high nitrate concentration in the *entry point water*. Forster (1999) in his study of the variability of roof run-off quality established that nitrates present in roof run-offs may be due to bird feaces deposited on the roof.

Plastic tank water had mean nitrate concentration of 4.6 mg/l, which was no significantly different (0.25, $P<0.05$) from the *entry point water* after 12 weeks of storage. This could imply that the plastic tank did not contribute to the build-up of nitrates in the water stored.

Mean nitrate concentration (12.53 mg/l) of metal tank water was considerably higher (1.968, $P<0.05$) than the *entry point water* after 12 weeks. The high nitrate concentration in the metal tank water may be a reflection of the organic material loads that settled at the bottom of the tank. The absence of basic sanitation, as well as dropping of food particles by children, since the tanks were not properly covered can contribute significantly to the nitrate levels of the water stored. This informs us that water pollution is more to do with the way water is handled or managed and not the storage material per say. Jussara *et al.* (2005) in their study of the correlation between nitrite and nitrate levels in drinking water and methemoglobinemia cases established that lack of proper water handling and storage practices can result in high nitrate concentrations in tanks. However, the high nitrate level of the water metal tanks can provide nutrients that can facilitate the growth of biological organisms in the tank.

Mean concentration of nitrate (11.85 mg/l) the concrete tank water was significantly different (2.78, $P<0.05$) from the *entry point water* after 12 weeks of storage. Since most of the tanks were not cleaned for a long time, the contribution to the nitrate level of the water stored can be the result of lack basic sanitation and proper water handling practices as confirmed by Jussara *et al.* (2005). Generally, nitrate concentration of the water stored in the plastic, metal and concrete tanks was below the WHO (2006) acceptable limit (35mg/l) of drinking water guidelines (Figure 4.14.).

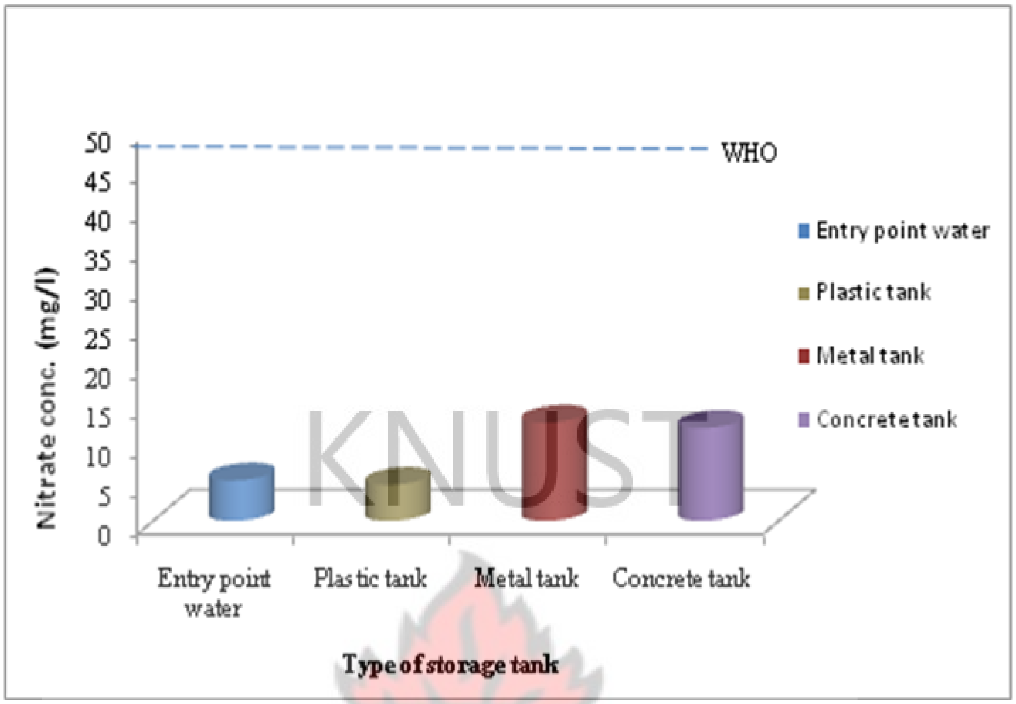

Figure 4.14: Comparison between tanks in terms of Nitrate

4.2.6 Total hardness

Mean total hardness of *entry point water* was 1.82 mg/l. Since the rainwater collected had Zero total hardness, it implies the contributory factor was as a result of dry atmospheric deposition of particulate matter on the roof catchment.

Mean total hardness of plastic tank water was 1.82 mg/l which remained the same as the *entry point water* after 12 weeks of storage. This means plastic tanks did not affect the total hardness of the rainwater stored.

After 12 weeks of storage, the metal tank water had mean total hardness of 6.53 mg/l which is higher than the *entry point water*. The result indicates that metal tanks contributed significantly (1.464, $P<0.05$) to the total hardness of the water stored. Since most of the tanks were not properly covered, it is possible for particles from the environment as well as the release of metal ions from the tank material into the water due to corrosion to occur.

The mean total hardness of concrete tanks was 10.52 mg/l which is significantly different (2.79, $P<0.05$) from the *entry point water* after 12 weeks of storage. This can be ascribed to the leaching of $CaCO_3$ and other particles from the construction materials into the water stored. The leaching of $CaCO_3$ from the walls of concrete tanks can increase the total hardness of the water stored (Lundgren and Akerberg, 2006). However, the dissolution of $CaCO_3$ in concrete tanks can impart desirable taste to the water stored.

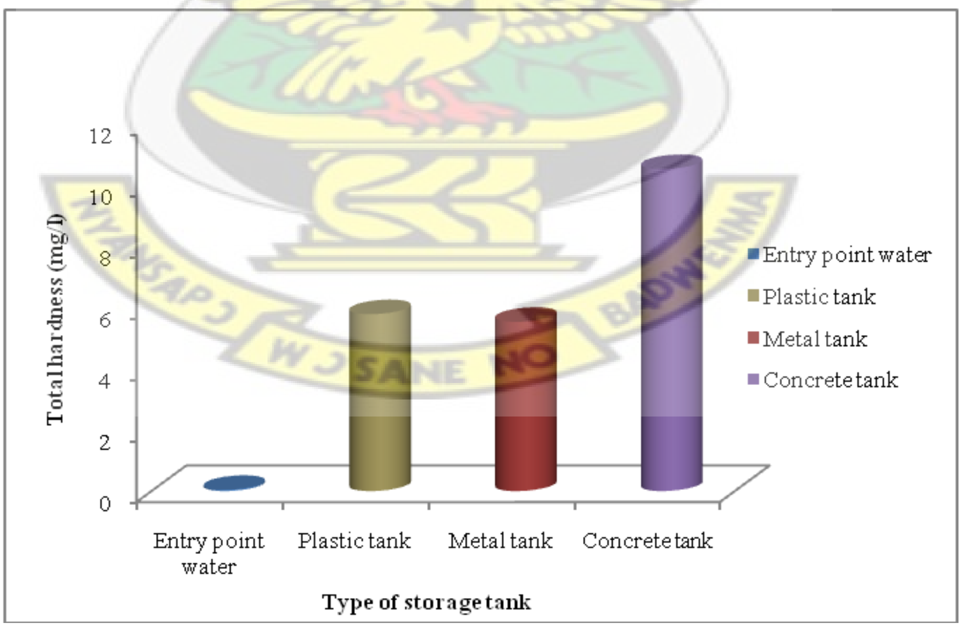

Figure 4.15: Comparison between tanks in terms of Total hardness

4.2.7 Iron

Mean iron concentration (0.72 mg/l) for the *entry point water* was significantly different (1.97, P<0.05) from the rainwater collected. The slightly acidic rainwater can enhance corrosion of the iron roofing materials which can incorporate iron particles into the rainwater harvested. A study by Ayenimo *et al.* (2006) of heavy metal fractionation in roof run-off found that iron roofs to a large extent contribute to iron concentrations in rainwater harvested.

Plastic tank water had mean iron concentration of 0.68 mg/l which was no significantly different (0.013, P<0.05) from the *entry point water*. This can mean that the contribution of iron particles in the water stored came from the reaction of slightly acidic rainwater with the iron roofing materials causing particles of iron to leach into the water stored.

Water collected from metal tanks after 12 weeks of storage had mean iron concentration of 3.4 mg/l which was significantly different (1.990, P<0.05) from the *entry point water* after 12 weeks of storage. The slightly acidic rainwater can react with the metal tank material and facilitate the precipitation of Fe^{+2}, hence increasing the concentration of iron concentration in the water stored. A study of the impact of storage tanks on drinking water quality by Ziadat (2005) found that high concentrations of iron in metal tanks could be significant if corrosion is evident, and when the tank has not been cleaned for a long time

Concrete tank water had mean iron concentration 1.23 mg/l which was no significantly different (0.135, P<0.05) from the *entry point water* after 12 weeks of storage. The leaching of the construction materials, for instance laterite sand from the tank wall can release iron particles into the water stored. This suggest that iron contamination of the water stored was to a large extent the result of dissolution of iron from the iron roofs as confirmed by Ayenimo *et al.* (2006). However, the water water in plastic, metal and concrete tanks were all above the guideline value of 0.3 set by the WHO (2006) as in Figure 4.16 below.

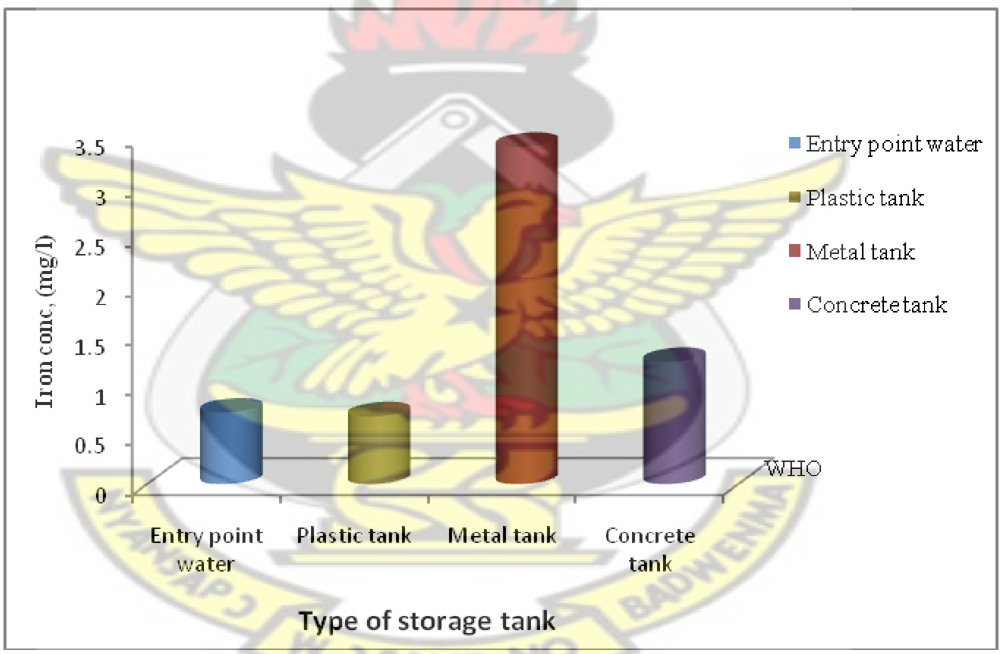

Figure 4.16: Comparison between tanks in terms of Iron

4.2.8 Faecal coliform

The presence of microbial indicators in rainwater makes it unsafe for drinking, without any treatment. In this study, *entry point water* had mean FC 6.1/100 ml. The faecal coliforms in the *entry point water* resulted from contact with the roof catchment and gutters. This fact is validated by the absence of microbiological contamination in the rainwater water collected direct from the sky. Rainwater harvested from roofs may contain animal and bird faeces, mosses and lichens which are sources of bacterial contamination (Kohler *et al.*, 1997).

The mean faecal coliform count in plastic tanks was 20.11/100 ml which is significantly different (3.733, P<0.05) from the *entry point water*. This means the contamination came from the way the water is handled during storage. The accumulation of sediments after several periods of rainwater collection and storage with cleaning can result in faecal contamination of the water stored. Tambekar (2004) in his study on intervention for control of water borne diseases observed that inadequate cleaning of storage vessels leads to the accumulation of sediments and pathogens. However, after 12 weeks, faecal coliform counts in the stored rainwater decreased significantly because of the die-off of bacteria.

The mean faecal coliform count (FCU 67.33/100ml) for metal tank water was significantly different (7.32, P<0.05) from the *entry point water* after 12 weeks of storage. However, after the period of storage faecal coliform counts in the stored rainwater was still higher. The means of water withdrawal from metal tanks was by dipping cups and bowls into the water which can result in faecal contamination of the rainwater stored. A study by Trevett, *et al.* (2004) confirms the finding that dipping water out of the storage container can introduce fecal matter into stored water. Also, the contamination of the stored rainwater may have resulted from the high household size including environmental effect, since most of the tanks were not properly covered. Small food particles during handling by children can lead to build-up of nutrient at the base of the tank which can encourage microbial growth. The larger the number of people in a household drinking water stored, the greater the levels of *E. coli* contamination in the water stored (Eshcol *et al.,* 2009).

The concrete tank water had mean faecal coliform counts of CFU 32.4/100ml, which was significantly different (24.55, $P<0.05$) from the *entry point water* after 12 weeks. The increase in faecal coliform counts may be due to the accumulation of sediments and pathogens at the bottom of tank, since users did not cleaned their tanks for a long time. Inadequate cleaning of storage tanks leads to the accumulation of sediments and pathogens (Tambekar and Banginwar, 2004). Generally, all plastic, metal and concrete tanks had faecal coliform count higher than WHO (2006) recommendation of Zero FCU/100 ml. This can be the reason for the prevalence of diarrhoeal cases reported by the Central Gonja District Health Directorate for the period 2009 to 2010.

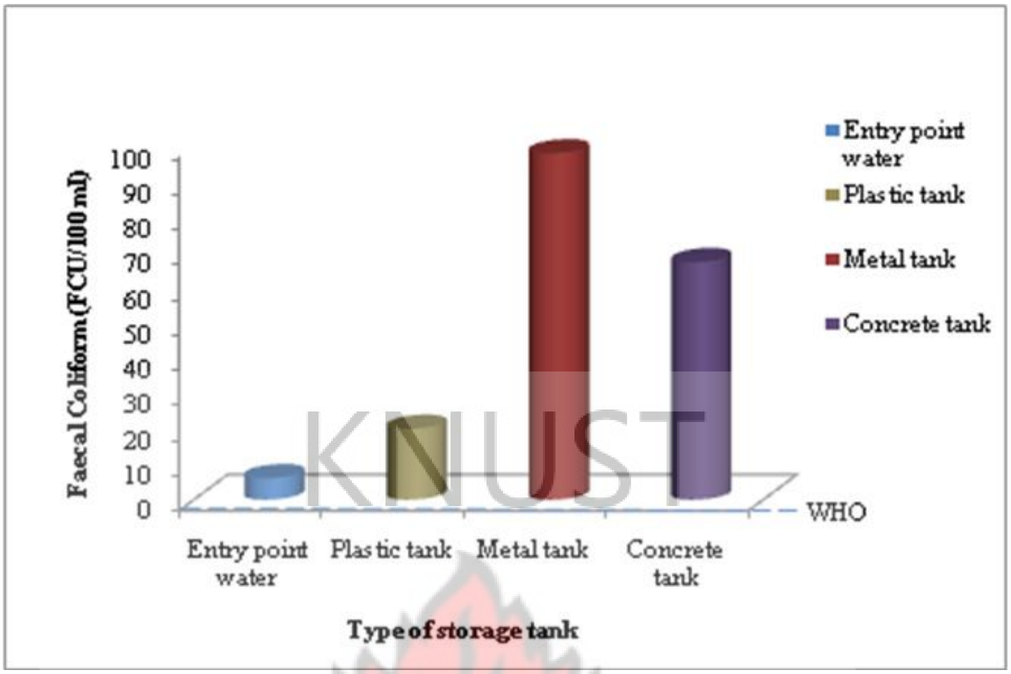

Figure 4.17: Comparison between tanks in terms of Faecal coliform

4.3 Response of survey Analysis

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

4.3.1 Household socio-economic characteristics

The size of household determines the quantity of water consumed in a household. The average household size was 9 persons per household in the study communities. This excluded members who reside outside the household for more than six months. The relatively high household size can be attributed to the polygamous marriage practiced by the people in these communities.

Eighty-four percent (84 %) of the respondents depended on agriculture as their main source of livelihood whilst 16 % relied on the non-agriculture sector. The average seasonal household income was US $ 401.27. According to the Presbyterian Church of Ghana (Northern Presbytery) Water Project in the district, the present cost of constructing and installing an 30 m^3 concrete tank ranges from US $ 1,100 to 1,250 depending on the availability of materials and labour. The average seasonal household income is sufficient to install smaller storage containers like earthen pots and old plastic or metal barrels. Hence the common storage facilities in the study area are barrels and earthen pots. These storage containers have smaller storage capacity and will not be enough to meet household water demand during the dry season.

*Currently, US $ 1.00 = GH¢ 1.57

4.3.2 Seasonal unreliability of the water sources

Dug-outs, wells, springs, boreholes and rainwater harvesting were identified as water sources in the study area. These water sources are highly affected by seasonal variation especially in the dry season. In Mpaha, the people rely on the rainwater, dam and borehole water for their water supply, but the long dry spell leaves them with water shortages. This is because the capacity of their rainwater harvesting tanks is not large enough to store water for the dry season. Demeke (2009) indicated that some boreholes and dug-outs dry up in dry season, forcing women and children to travel longer distances in search of water. The inhabitants of Buipe and Yapei also depend on the rivers, boreholes and dug-outs for their water needs. However, heavy rainfall in the rainy season leaves the surface water sources flooded, polluted and making it difficult to fetch water from such sources.

4.3.3 Distance and time spent on water collection

Majority of the respondents (86 %) walked 3 km returned trip on average to fetch water in the dry season. The average distance to the dam in Mpaha is 2 km. Such a distance is too long to walk while carrying ***'Garawa'*** 40 litre container head load of water. Respondents in Buipe and Yapei walk 1 km per trip to collect water. All the respondents collected water at an average distance < 0.5 km in the wet season, which may indicate that water from rainwater storage tanks is the main source for domestic needs during that period. The World Health Organisation recommends 0.20 km as a convenient distance fetching water (Sharma, 1996). Therefore, the distance covered by the people to fetch water is not convenient considering WHO recommendation.

Time allocated to water collection differ among households and communities. Generally, households allocate more time walking long distances during the dry season than in the rainy seasons. For a return trip an average distance of 3 km is covered in the dry season to collect water from rivers, which corresponds to an average return trip time of 2 hours. More time is spent collecting water in the dry season than in the wet season. Women in Oyo State, Nigeria spent about one (1) hour daily to collect water at an average distance of 0.50 km (Sangodoyin, 1993).

4.3.4 Household water consumption

The average daily household water consumption was 232, 192, 216 litres in the rainy season for Buipe, Yapei and Mpaha areas respectively. In the dry season, the average daily household water consumption drops to 194, 162, 180 l/day for Buipe, Yapei and Mpaha respectively. The quantities of water consumed per activity showed little variation in all the three communities (Figures 2 and 3). The quantity of water consumed by households in the dry season was lower because of water scarcity during this period, which makes households to adapt to lower water consumption strategies. Also, women and children can only carry small quantities for the long distance. The average per capita consumption of water in the dry season was 21, 18, 20 l/day/p is correct taking into account 9 persons per household for Buipe, Yapei and Mpaha respectively. Generally, the water quantities consumed daily exceeded the WHO minimum amount of 20 l/day/p of safe water needed for metabolic, hygienic and domestic purposes (WHO, 1996). However, Gleick *et al.* (1997) estimated 50 l/day/p as adequate: 25 l/day/p for drinking and sanitation and 25 l/day/p for bathing and cooking. According to the United Nations Development Programme (UNDP, 2006) report, the per capita water consumption in Ghana is 36 l/day/p. Considering Gleick's and UNDP estimates, the quantities of water used by households in the study area, regardless of seasonal variation are insufficient for healthy living. The reason for low consumptions levels may be due to inadequate water supply options, resulting in water consumption levels not matching-up with demand (London Economics, 1999). There was little variation in household water consumption between the three communities. The relatively high household water consumption in Buipe and Mpaha may suggest the availability of boreholes which are closer to households. However, the Boreholes are rather very far from the households in Yapei due to the difficult hydrogeological condition of the area. The convenience of location of water source is a significant determinant of water consumption level (Demeke, 2009). This means that households located nearer to the water source are likely to use water more than others located farther away.

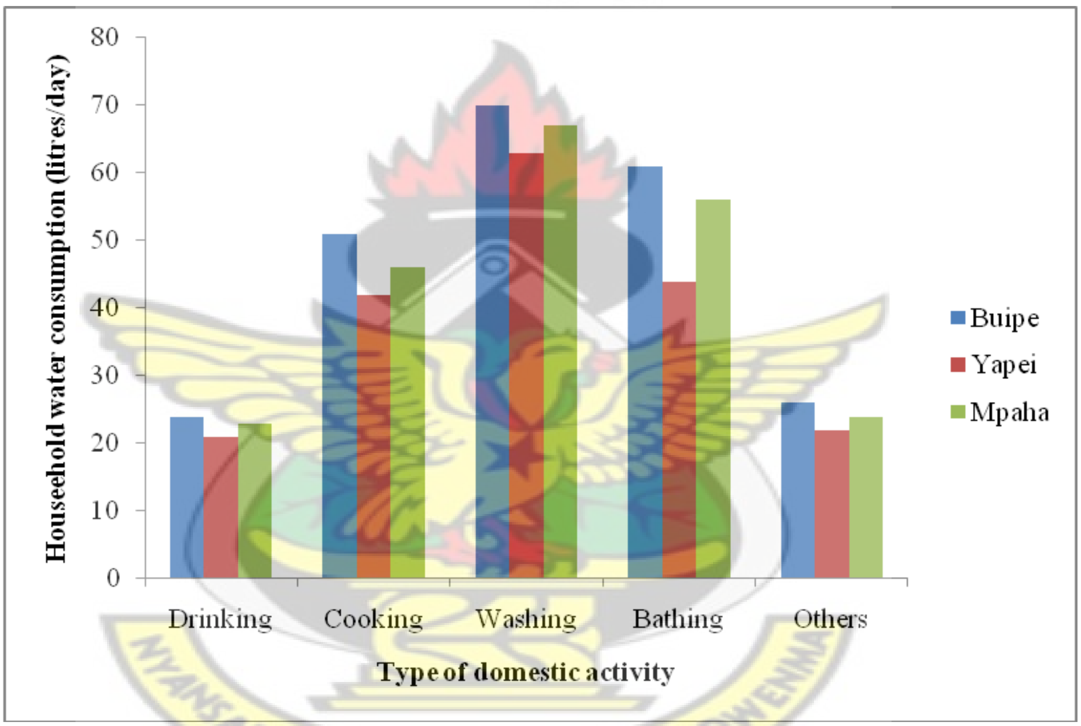

Fig. 19: Average daily household water consumption and type of domestic activity for the rainy season

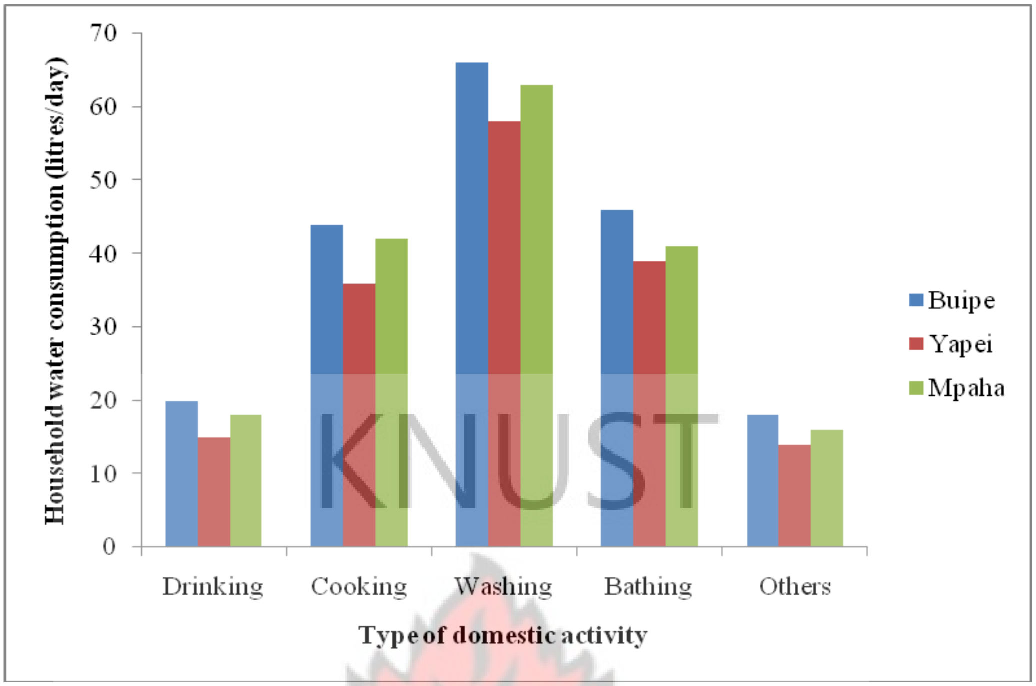

Fig. 20: Average daily household water consumption and type of domestic activity for the dry season

4.3.5 Rainwater storage capacity

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

Table 1: Annual rainwater supply

Roof area size	R (litres)	K	A (m^2)	S (l/year)
Small roof (36 m^2))	1200	0.9	36	38,880
Medium roof (72 m^2))	1200	0.9	72	77,760
Large roof (108 m^2))	1200	0.9	108	116,640

Where;
R: Rainfall
K: Run-off coefficient for roof material
A: Roof catchment area
S: Annual rainwater supply

Table 2: Household water demand for the dry season

Community	C (l/day/p)	n	Water demand = C × n × N_o	
			Monthly (l/month) (30 days)	Annual (l/year) (5 months)
Buipe	21	9	5,670	28,350
Yapei	18	9	4,860	24,300
Mpaha	20	9	5,400	27,000

Where;
N_o: Number of month
N: Average household size
C: Per capita water consumption

The roof area for the smaller houses in Buipe, Yapei and Mpaha areas does not provide the quantity for a sustainable system as can be observed in Table 3. The annual water demand in all the communities exceeds the annual rainwater supply. However, the annual rainwater supply from the roof catchment areas of the houses is greater than the annual water demand in all the three communities. Therefore, the roof catchment areas of the houses are sustainable.

Table 3: Annual water demand and annual water supply

Community	Annual Demand (l/year)	(litres) (36 m^2)	(litres) (72 m^2)	(litres) (108 m^2)
Buipe	28,350	38,880	77,760	116,640
Yapei	24,300	38,880	77,760	116,640
Mpaha	27,000	38,880	77,760	116,640

In the Central Gonja district, the longest period of the dry season is from November to March. In this case, adequate storage has to supply water for a period of five (5) months or 150 days. During this period, the minimum water consumption level is 21, 18 and 20 l/day/p. The annual water demand for Buipe Yapei and Mpaha are respectively 28,350, 24,300 and 27,000 litres. The storage capacity was sized with 20 % safety factor. From

Table 3, it obvious that a storage capacity of 30,000 litres (30 m^3) will be able to meet the annual household water demand in the dry season.

4.3.6 Water storage

Thirty-four (34) rainwater tanks were surveyed with storage capacities ranging from 500 - 10,000 litres, and constructed with different materials such as concrete, polyethylene, and metal. Twenty-four (24) of the tanks were subsidized by the Ghana Presbyterian Church and 8 were financed by households. Plastic and metal barrels (250 litres) were the most common water storage facility contributing 68 % of households whilst concrete and plastic tanks constituted 22 % and 10 % respectively. The period of water supply in households varied from 1 week to 3 months, but the rainwater stored is used rapidly within a week and is not able to bridge water shortages in the dry season.

4.3.7 Cost implication

The cost of constructing a rainwater tank varies considerably depending on location, type of materials and degree of labour used. A storage capacity of 30,000 litres (30 m^3) will be adequate for most households to harvest and store water for the critical period. In the Central Gonja District the cost of constructing a 30 m^3 concrete tank is between US $ 1,100 to 1,250. However, the presence of the Black and White Volta Rivers provide available sand for reducing the cost of constructing concrete tanks. The cost of constructing a 30 m^3 concrete tank in the NorthEast of Brazil is around US $ 1,000 depending on the materials used (Gould and Nissen-peterson, 2006). The average household income (US $ 401.27) in the Central Gonja District is relatively low for installing a rainwater tank, which is the main and expensive component of rainwater harvesting system. This calls for the Government and private Organisations in the water sector to financially support poor households to install rainwater tanks. The initial capital cost of constructing a rainwater tank is high compared to other improved water sources (dams, borehole). However, the high initial cost may be offset by its long life compared to a borehole facility. Even though it appears cheaper investing in boreholes, factors such as possibility of drilling dry holes, higher technical knowledge required for operation and maintenance and seasonal groundwater quality deterioration makes borehole-drilling operation less risk free.

4.3.8 Maintenance

Male family head had the responsibility for repairing the system which is usually once in a season. Majority (76 %) of the households said their DRWH systems had leakages in gutters and storage tank whilst 24 % affirmed that their system was working well.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This chapter draws from the analysis and discussions made in terms of the results in arriving at conclusions and recommendations for the study.

5.1 Conclusions

This study focused on the appropriateness of rainwater harvesting system for domestic water supply in the Central Gonja District. It was observed that the parameters of boreholes measured were seasonally affected except for conductivity which was high in the dry season. All the parameters for the river and dam water varied with season. In relation to faecal contamination, the borehole, river water and dam were seasonally affected, and unsuitable for drinking without treatment. Based on the WHO guidelines, rainwater can be regarded as potable owing to its higher quality over the other water sources in the study area.

The results also showed that except for conductivity, plastic tanks had lower values of *p*H, total alkalinity, turbidity, nitrite and total hardness which fell within the WHO acceptable limits of drinking water. The *p*H, total alkalinity, total hardness and iron was higher whilst EC, turbidity and nitrite levels fell below the guideline values in metal tanks. Iron level in metal tanks was high due to corrosion problem. Due to leaching of $CaCO_3$ from the walls, concrete tanks caused high *p*H, total alkalinity, and total hardness of stored rainwater. The results from the analysis also indicated that all the storage tank material did not contribute to faecal coliform in the stored water. Faecal contamination occurred during collection, storage and drawing of water. Therefore, the type of storage tank has direct impact on the physico-chemical quality of stored water.

Responses from household interview showed that rainwater harvesting has the potential of meeting water demand during the dry season in the study area for houses using iron roofing sheets material with roof areas between 36 m^2 or more, given the climatic and socio-economic characteristics of households in the Central Gonja district. The annual rainwater harvested from small to large houses exceeded the annual domestic water demand by households. Therefore a storage capacity of 30 m^3 is enough to meet household water demand during the critical period.

5.2 Recommendations

For this study to have positive impact on the safety of domestic water supply sources in Central Gonja District the following recommendations are made:

- Domestic rainwater harvesting should be implemented on large-scale to alleviate the risk of drinking from the unsafe water sources.
- Plastic and concrete tanks are best for storing rainwater.
- The use of first flush diverters and filters like the “guinea worm filters” should be promoted and incorporated in storage tanks. The filters could be used to treat the supplementary contaminated water supplies as well.

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APPENDICES

APPENDIX 1: QUESTIONNAIRE SURVEY FOR HOUSEHOLDS

Introduction: *The aim of this research is to determine an appropriate domestic rainwater harvesting system for this district. The purpose is to provide appropriate materials for rainwater storage. Your kind cooperation, response and time are highly appreciated.*

SECTION 1: LOCATION AND BACKGROUND

1. Name of community…………..…………………………

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

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

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

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

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

c) What is the average seasonal income of your household in all?
   - (i) < Gh¢ 200 [ ]
   - (ii) Gh¢ 200 – 300 [ ]
   - (iii) Gh¢ 300 – 400 [ ]
   - (iv) Gh¢ 400 – 500 [ ]
   - (v) >Gh¢ 500 [ ]

SECTION 2: COLLECTION AND USE OF WATER

6.

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

(i) River [ ]

(ii) Borehole [ ]

(iii) Dam [ ]

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

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

(i) River ……………………………..

(ii) Borehole ………………………

(iii) Dam………………………………

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

(i) Not reliable at all [ ]

(ii) Quite reliable [ ]

(iii) Very reliable [ ]

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

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

7.

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

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

(i) During wet season………………..

(ii) During dry season………………….

c) What do you like/dislike about water collection? ....

....

....

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

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

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

8.

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

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

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

SECTION 3: DOMESTIC RAINWATER HARVESTING

9.

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

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

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

(i) Metal tank [ ]
(ii) Plastic tank [ ]
(iii) Concrete tank [ ]
(iv) Others [ ] (specify)………………………

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

(i) Metal [ ]
(ii) Polyethylene [ ]
(iii) Cement and sand [ ]
(iv) Others [ ] (specify).......................................

e) How old is your tank?

(i) 0 – 3 years [ ]
(ii) 4 – 10 [ ]
(iii) > 10 years [ ]
(iv) Unknown [ ]

f) What is the capacity of your storage tank (measure and record in m^3)? ....

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

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

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

10.

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

(i) Corrugated iron sheet [ ]
(ii) Aluminium sheet [ ]
(iii) Thatched [ ]
(iv) Others[ ] (specify) ……………………………

b) Area of roof guttered (measure and record in m^2)..

c) Total roof area (measure and record in m^2)..

12. What type of material is the gutter made of?

(i) PVC pipe [ ]
(ii) Galvanised steel sheet [ ]
(iii) Bent zinc roofing sheet [ ]
(iv) Others [ ] specify.................................

11.

a) Is your rainwater harvesting system working in a satisfying way? (i) Yes [ ] (ii) No [ ]

b) If ***no***, why? ....

c) Who is responsible for maintenance of your rainwater harvesting system? ....

d) How many times does maintenance take place in a season? ....

e) Do you have any suggestions towards further improvement of your system? .... ………………………………………………………………………

12.

a**)** How did you finance your rainwater harvesting system?

(i) Household money [ ]

(ii) Household money/subsidies [ ] (specify)..........................

(iii) Subsidies only [ ] (specify)..................................

b) How much did your rainwater harvesting system cost you approximately? Gh¢......................

SECTION 4: KNOWLEDGE/PERCEPTION OF RAINWATER QUALITY

13.

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

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

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

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

d) How would you describe your frequency of illness?

(i) Once in two weeks [ ]

(ii) Once a month [ ]

(iii) Once in 3 months [ ]

(iv) Rarely [ ]

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

(i) Once in two weeks [ ]

(ii) Once a month [ ]

(iii) 0nce in 3 months [ ]

(iv) Rarely [ ]

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

Appendix 2A: *p*H- Preparation of buffer solution

Before the measurement of the *p*H a manual three buffer solutions of *p*H 4.01, 7.0, and 9.2 were used to calibrate the *p*H meter. One buffer tablet each was dissolved in a 100 ml volume of deionised water to prepare a 4.01 and 7.0 buffer solution. The 9.2 buffer solution was prepared by dissolving a sachet of buffer tablet in 500 ml deionised water. New buffer solutions were prepared for each set of water sample collected.

Appendix 2B: Alkalinity-Preparation of reagents

- 0.1 M of HCl reagent: A 2.1 ml solution of concentrated HCl was added to a 200 ml of distilled water in a 1000 ml volumetric flask. To this mixture was added more distilled water until it got to the 1000 ml mark.
- 0.05 M Na_2CO_3 reagent: one litre of $NaCO_3$ solution was prepared by dissolving 4.5 g of dried Na_2CO_3 in double distilled water and transferred into a 1 litre volumetric flask. The solution was made to the mark with distilled water.

Appendix 2C: Turbidity- Preparation of reagent water

- Deionised distilled water was passed through a 0.45 μ pore size membrane filter. One grams hydrazine sulfate, $(NH_2)_2.H_2SO_4$, (CASRN 10034-93-2) was dissolved in reagent water and dilute to 100 ml in a volumetric flask.
- Ten grams hexamethylenetetramine (CASRN 100-97-0) was dissolved in reagent water and diluted to 100 ml in a volumetric flask. In a 100 ml volumetric flask, 5 ml of each solution was mixed. Allow to stand 24 hours at 25 ± 3 °C, then dilute to the mark with reagent water.

- Primary calibration standards: Mix and dilute 10 ml of stock standard suspension to 100 ml with reagent water. The turbidity of this suspension is defined as 40 NTU. For other values, mix and dilute portions of this suspension as required. Primary calibration standards should be prepared daily by dilution of the stock standard suspension. Formazin in commercially prepared primary concentrated Stock Dilute turbidity standards should be prepared daily.
- AMCO-AEPA-1 Styrene Divinylbenzene polymer primary standards are available for specific instruments and require no dilution prior to use.
- Secondary standards may be acceptable as a daily calibration check, but must be monitored on a routine basis for deterioration and replaced as required.

Appendix 2D: Nitrite-Preparation of standards

- Preparation of Standard $NaNO_3$: A 1.232 g of $NaNO_3$ was weighed and dissolved with distilled water into a 100 ml volumetric flask and then diluted to the mark. 250 µg/L concentration of standard nitrite was prepared.
- M NaOH: Four grams of NaOH pellets was weighed and dissolved in a small volume of distilled water before transferring to a 100 mL volumetric flask where it was diluted to the mark.
- Colour developing reagent: A 300 ml distilled water, 50 ml concentrated Phosphoric acid, 7.5 g of sulphanilamide ($H_2N\text{-}C_6H_4SO_4NH_2$) and 0.375 g of naphthyl-1, 1-amide was mixed and diluted to the mark in a 500 ml volumetric flask.

- Calibration curve: Aliquots of 0.1, 0.2, 0.3 and 0.4 mL of the stock solution were measured into different 100 mL volumetric flasks. To these 2 mL of 0.1 M NaOH was added followed by the addition of 1, 2, 3, and 4 mL of colour developing reagent respectively. The mixtures were diluted to the 100 mL mark forming 0.25 µg/l, 0.50 µg/l, 0.75 µg/l and 1.00 µg/l of standard nitrite solution respectively (APHA, 1992). A straight line graph of absorbance at 543 nm versus concentration passing through the origin was obtained for the standard solutions.

Appendix 2E: Total hardness-Preparation of standards

- Preparation of standard solution: Buffer solution: Dissolve 17.5 g ammonium chloride (NH_4Cl) in 142 mL concentrated $NH_4(OH)$ and dilute to 250 ml with distilled water.
- Standard calcium solution: Place ~ 1.5 g anhydrous $CaCO_3$ (in oven) into a beaker, and place in a dessicator for 10 minutes. Weigh exactly 1.000g anhydrous $CaCO_3$ into a clean 600 mL Erlenmeyer flask and add 200 ml deionized water. Add a few drops of 6 M HCl until all CaCO3 has dissolved. Add 200 ml distilled water and boil for a few minutes to expel CO_2. Transfer quantitatively to a 1000 ml volumetric flask and dilute to the mark with distilled water. Dissolve 3.723 g disodium EDTA in distilled water and dilute to 1 litre.
- Standardization of the EDTA solution: A known concentration of EDTA was used for titrating water sample. Measure exactly 15.0 ml of the CaCO3 solution into a 250 ml flask. Add approximately 30 ml of deionized water to the flask.

Add 2.0 ml of the buffer solution. The remainder of the titration must be completed within 15 minutes of the time when the buffer is added. Add 4 drops of Eriochrome Black T indicator solution. Titrate using the EDTA titrant. At the end point the color should change from red to a pale blue. This procedure was repeated twice.

- Water samples: 25.0 ml of the hard water sample was measured into a 250 ml flask. 25 ml of deionized water was then added to the flask. The remainder of the titration must be completed within 15 minutes of the time when the buffer is added. 4 drops of Eriochrome Black T indicator solution was added. EDTA titrant was used for titrating, and. at the end point the color should changed from red to blue. This procedure was repeated twice. This data from parts A and B was used to calculate the hardness of the water samples in mg /l.

Appendix 2F: Fluoride-Sample preparation and calibration curve

- Sample preparation: A 200 mL water sample together with 100 mg of ashless cellulose powder (Whatman) was evaporated to dryness in a porcelain dish on a steam bath and then under an infra-red lamp. The residue was cooled at room temperature in a desiccator for 1 hour. The powdered sample was then weighed and sealed in a polythene bag and stored in a desiccator. A 50 mg sample was pressed into a 10 mm diameter pellet with 3 tons of pressure in a graduated hydraulic press. The pellet was mounted on a 35 mm slide frame with adhesive tape and preserved in a desiccator until irradiated. 200 ml deionised water mixed with 100 mg of cellulose was prepared as the blank and analyzed for any contamination in sample preparation.

- Concentration calibration: For concentration calibration, AnalaR grade NaF in the concentration range of 10-500 mg/kg in a $CaCO_3$ matrix was used. The nuclear reaction 19 F (p, p′ γ) F was used to construct the calibration curve. NaF standards were homogeneously dispersed in 100 mg of $CaCO_3$ with methanol, and the resulting matrices were dried under an infrared lamp.

Appendix 3A: Plates of sanitation scenes and engineering flaws

Plate 4: Animals drinking from the same source as humans

Plate 5: **Water fetching points from river/dam**

Plates 6: **Domestic waste in and around water sources**

Plate 7: Corroded iron roof with poor design of gutter system

Plate 8: **Gutter filled with debris from roof-top**