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Variation in the Quality of Harvested Rainwater from Source to Storage in a Water-Stressed Community in Ghana

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Abstract: The quality of rainwater which is the main source of domestic water in Dzodze, a community in the Volta Region of Ghana was unknown. Therefore the possible utilization of contaminated domestic water and occurrence of health hazards could not be underestimated due to prevailing poor hygiene and great lack of standard maintenance and treatment systems in community. In this study, we assessed the quality of rainwater in the Dzodze Community and how it varies along the domestic rainwater harvesting (DRWH) chain from free-fall to storage. Rain samples were collected at three points along the DRWH chain of two DRWH systems: from free-fall, roof-catchment and storage tank and two systems described as poorly-maintained and well-maintained systems. Samples were analyzed for physico-chemical and bacteriological parameters and results compared with WHO and Ghana Standards Board (GSB) guideline values. The harvested rainwater was found to be of good physico-chemical quality but not bacteriological, calling for treatment before utilization. Also, irrespective of the type of DRWH system (poorly-maintained or well-maintained), there was substantial change in rainwater quality upon interaction with roof-catchment with an increase noticed in all parameters.

Keywords: Rainwater Harvesting, Physico-Chemical Variables, Systems, Standards

1. Introduction

Safe drinking water is essential for human survival yet water scarcity remains a serious problem for both urban and rural communities throughout the world partly due to population growth, frequent droughts and the changing climate. The United Nations' Millennium Development Goal (MDG) 7 has as its target to halve by 2015 the proportion of people without sustainable access to safe drinking water and sanitation. Although about 1.6 billion people have gained access to safe drinking water through various technologies since its implementation [1], many people worldwide, especially in developing countries are still in dire need of safe and sustainable drinking water.

Rooftop rainwater harvesting, a technology used to supply water for domestic purposes in developing countries, involves collection of rainwater from the top of building roof via a guttering system and storage in a cistern [2]. At the 2006 Climate Change Convention in Nairobi, Rainwater Harvesting (RWH) was recognized as a viable option to addressing current water needs and providing security against future droughts in many African countries. In Ghana, in spite of the general water-scarcity, the situation is very acute in many communities and in an attempt to go round the problem RWH has been recognized as an appropriate technology for exploitation of water to meet their water requirements. This, notwithstanding, the option of RWH technology has not received adequate support from government of these water-scarce countries. For instance the Ghana National Water Policy only focuses on enactment of legislation for provision of incentives for RWH systems and their incorporation and enforcement in all new building designs [3]. In this no consideration has been given to already existing settlements making the strategy inadequate. This observation support that made by [4] that public interest in permanent Domestic Rainwater Harvesting (DRWH) and its sustainability as a useful and appropriate source of clean drinking water is on the increase in many areas in Ghana. The absence however of affordable systems, institutional support and relevant research especially on quality issues present significant constraints to its widespread adoption and exploitation.

In Dzodze, a community in the Volta Region of Ghana where water is scarce and the limited available sources are of undesirable quality, rainwater harvesting serves as a highly dependable source of domestic water and has contributed immensely to its socio-economic development. Given the community's climatic and geographic characteristics and the storage capacity of tanks used, RWH represents one of the most appropriate solutions to improve water supply and has over the years received widespread adoption, serving households even fairly into extended dry seasons. Although no evidence exists that links contamination of rainwater to number of human infections that prevail in the community, RWH provides a low-cost intervention for water crisis and hence contribute to prevention of possible water-related problems.

2. Rainwater Quality Variation from Free-Fall to Storage

Rainwater harvesting systems are open to environmental hazards because of the nature of the catchment area. There are several ways and several points along the DRWH chain that contaminants can enter the rainwater system and compromise the water quality. Contamination can occur during free-fall of rain, after contact with roof catchment and during storage (through complex interactions within storage system). During free-fall, rainwater scavenges atmospheric aerosols contributing to variations in the quality of rainwater as it reaches the place of collection. Roof catchment contaminations may arise from contaminants deposited on roof and guttering systems such as droppings from birds and small animals, leaf litter from overlying vegetation, and wind deposition of aerosols. In storage, microbial contamination comes primarily from insect accumulation, *Salmonella* carriers, e.g., frogs [5], and bacterial growth in stagnant storage tanks.

Microbial contamination, according to [6] is of main concern for health risk as it varies depending on location, season, environment, and maintenance practices; and therefore unpredictable. From the study, the pH for instance, of the free-fall was 5.94, 7.11 after contact with roof catchment and 6.8 at the point of exit from the harvesting storage tank (after a month of storage). Conductivity varied from 14.82 µs/cm at free-fall and 36.61 µs/cm on roof catchment, to 104.65 µs/cm after a month of storage. Similarly, he observed that total hardness increased from 3.68 mg/l (free-fall) to 7.24 mg/l (roof-harvested) and 13.00 mg/l in storage after a month. Also, free-fall and roof-intercepted rainwater samples analyzed in Ile-Ife, Nigeria. [7] revealed that values of different quality parameters for roof-intercepted samples were higher than those of free-fall samples with an enrichment factor within the range of 1 and 5.

Measured pH gives indication of the balance between hydrogen ions (H^+) and hydroxide ions (OH^-) in water [8]. According to [9], pH less than 7.0 may cause corrosion of metal pipes thereby releasing toxic metals like Zn, Pb, Cd and Cu etc, and higher than 8.0 adversely affect disinfection process. As rainwater is often slightly acidic, increase in pH is caused by contact with the catchment and then in the concrete tank [10]. [11] noted that pH of rainwater usually increases slightly after falling on the roof and during storage in tanks and that water sampled from cement tanks is likely to be alkaline. [12] observed a rise in pH from 5.0 on the roof surface, to 9.4 in the tank and 10.3 from the tap, and that higher pH inhibits coliform growth.

Turbidity is a water quality parameter that reflects the amount of small solid particles such as silt, finely divided organic matter and biological material suspended in water and may increase the occurrence of waterborne diseases. In drinking water the maximum allowed turbidity is 5 NTU [13]; however the ideal is 1 NTU or lower [14]. Studies on rainwater harvesting have often reported variability in turbidity levels with most within the range for filtered water while some exceeded 5 NTU [15]. According to [16], it is important because it affects the acceptability of consumers and selection and efficiency of treatment processes. Increasing risk of gastro-intestinal infections has been linked to high turbidity [16].

Conductivity is a measure of the ability of water to pass electric current [17]. It is an indirect measure of the presence of dissolved solids and can be used as an indicator of water pollution; however, no health-based value has been proposed [13; 16]. According to [18], electrical conductivity of pure rainwater is usually < 15 µs/cm. Natural waters are found to vary between 50 and 1500 µs/cm.

Water hardness, the capacity of water to react with soap, is reflected by the total concentration of Ca^{2+} and Mg^{2+} ions in the water. It has been reported that, fabrics washed in hard water tend to wear out as much as 15% faster than fabrics washed in soft water [19]. [20] reported a range of 75 - 1110 mg/l for total hardness in drinking water while the [11] noted 500 mg/l. [21] reported a mean hardness value of 496.7 mg/l for boreholes in Dzodze and a generally high concentration of dissolved calcium, magnesium and chlorides in groundwater throughout the District. A study by [11] showed hardness of rainwater increasing upon storage.

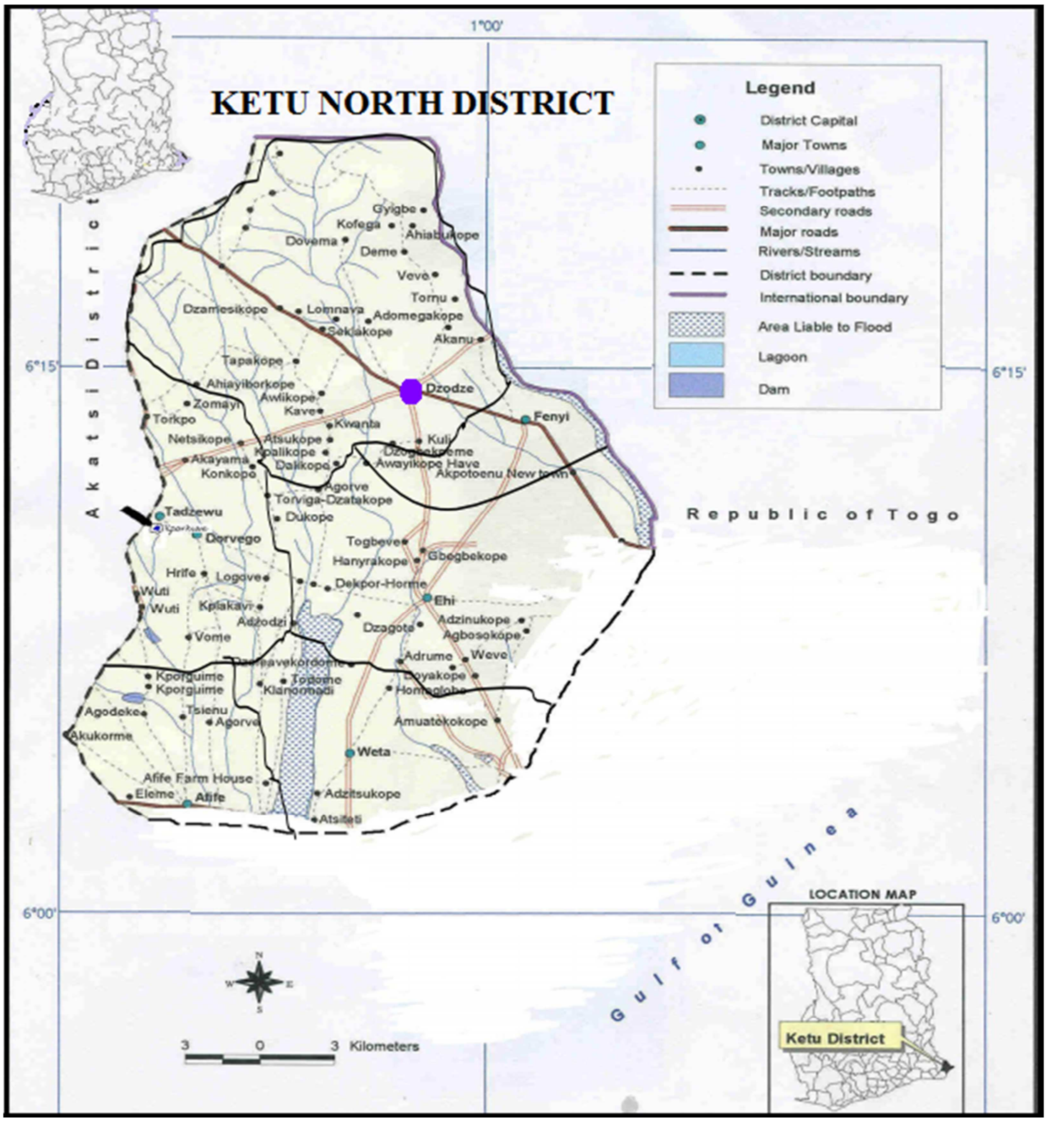
Sulphates are discharged into water in industrial wastes and through atmospheric deposition. I has been found in rainwater at concentrations between 1.0-3.8 mg/l in Canada and at a mean value of 6mg/l in Europe [22]. The [13] sets its value at 250 mg/l. It is recommended that at levels above 500mg/l, health authorities should be notified [15]. Nitrate is the more stable oxidized form of combined nitrogen in most environmental media [8]. There is usually no noticeable taste at iron concentrations below 0.3 mg/l, although turbidity and colour may develop. Corrosion of iron is possible at high dissolved oxygen values [16]. Background concentrations of Al in rural air range from 0.005 to 0.18µg/m^3, whereas concentrations in urban and industrial areas can be considerably higher, ranging from 0.4 to 8.0μg/m^3 [23]. Concentrations of Al are highly variable in drinking water, ranging from <0.001 to 1.029 mg/l [24] but the limit by [13] is 0.2 mg/l. However, under good operating conditions, Al concentration of less than 0.1 mg/l is achievable [16].

The microbial quality of water is determined by the presence of bacteria total coliforms and faecal coliforms such as *Escherichia coli* and indicates faecal contamination. According to [25], *Escherichia coli* or faecal coliforms should be used as indicator bacteria for stored rainwater since *Escherichia coli* specifically indicates human or animal faecal pollution. In water, coliform bacteria have no taste, smell, or colour and can only be detected through a laboratory test. [16] and [13] recommends zero *Escherichia coli* or thermotolerant Coliform Forming Unit (CFU) per 100 ml for all drinking water supplies. [26] proposed the following alternative bacteriological water quality standards for potable roof-collected rainwater in tropical regions and developing countries; Class I: 0 faecal coliform per 100 ml - highest and ideal quality; Class II: 1 – 10 faecal coliform per 100 ml - marginal quality; Class III: > 10 faecal coliform per 100 ml - unacceptable for drinking.

3. Methodology

3.1. Description of the Study Area

The Ketu-North District (Figure 1), created in 2008 out of the former Ketu District is located at the South Eastern corner of Volta Region, Ghana and lies between latitudes 6º 03'N and 6º 20'N and longitudes 0º 49'E and 1º 05'E. The district capital, Dzodze is located on the main trunk road linking the regional capital (Ho) to Aflao 80km away from Ho. The district has a total land area of 754km^2 [27]. Dzodze was chosen for the study because of its long standing history of DRWH.



Source: Ketu-North District Planning Coordinating Unit [27]

Figure 1. *Ketu-North District map showing the location of Dzodze (*in blue colour).

3.2. Rainwater Sample Collection

Samples were collected during rain events at three points along the DRWH chain: from free-fall, after contact with roof catchment and from storage tank. The free-fall samples were collected with containers mounted about 1.5 metres above the ground to avoid influx of rain splash. All samples were collected in triplicate. All samples were placed in individual sterile 500ml bottles and transported to the Ghana Water Company laboratory in a chilled ice chest.

3.3. Laboratory Analysis of Water Samples

The investigated water-quality parameters were pH, turbidity, electrical conductivity, total hardness, sulphate, nitrate, iron, aluminium, total coliform, and faecal coliform. Total coliform and faecal coliform were determined by means of the multiple tube fermentation technique (MPN method) using Lauryl tryptose broth for the Presumptive Phase of total and fecal coliforms and Brilliant green lactose bile broth and EC Medium for the Confirmation Phases of total coliform and faecal coliform respectively. Standard laboratory methods were followed for all the analysis and great care was taken to ensure the integrity of the samples was not compromised. The water-quality analysis was carried out in accordance with procedures and protocols outlined in the Standard Methods for the Examination of Water and Wastewater [28].

3.4. Data Analysis

Data obtained from questionnaire and laboratory analysis of rainwater samples was checked for quality and organized with Microsoft Excel. Mean values of parameters were compared with WHO Guidelines for Drinking-Water Quality.

4. Results

4.1. Rainwater Quality Variation from Free-Fall to Storage

Results of the laboratory analyses of the quality of rainwater along the DRWH chain from source (free-fall) to storage and for domestic use are presented in this section. Mean values of all measured water quality parameters (physico-chemical and bacteriological) were computed and presented in a table (Table 1).

Table 1. *Characteristics of DRWH systems from which samples were collected.*

Poorly-maintained system	Well-maintained system
Galvanized iron/aluminium sheet roof and rain gutter (Age ≥ 21 years)	Galvanized iron/aluminium sheet roof and rain gutter (Age ≥ 10 years)
Concrete tank; storage capacity of 50,000L	Concrete tank; storage capacity of 50,000L
Age of tank: 21 years	Age of tank: 10 years
No filter component (no wire mesh over downpipes)	Filter component (wire mesh over downpipes)
Rusted tank cover with large perforations that allow direct sunlight through	Tank cover not rusted and without perforations
Tank not well sealed, rodents easily enter	Tank well sealed
When last cleaned: > 4 years ago	When last cleaned: < a year ago

Table 2. *Water quality parameters measured in poorly-maintained system (S_1) and well-maintained system (S_2).*

Parameters	Range of values						5% LSD	
	Free-fall		Roof-catchment		Storage tank			
	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
pH	6.0–6.4	6.0–6.1	6.0–7.0	6.0–6.4	6.9–7.3	7.1–7.4	-	-
Turbidity (NTU)	0.9–1.1 (1.00)	0.8–1.2 (1.00)	5.4-11.3 (7.77)	4.9–8.3 (6.33)	2.8–6.2 (4.00)	2.5–4.7 (3.30)	4.22	2.48
Conductivity (µs/cm)	11.5–23.6 (17.50)	11.0–24.2 (17.50)	22.5–59.2 (43.63)	20.2–38.8 (27.03)	41.7–54.1 (46.67)	54.8–56.2 (55.60)	24.21	14.09
Total hardness (mg/l as $CaCO_3$)	2.1–3.2 (2.77)	2.3–3.0 (2.77)	4.2–6.0 (4.87)	2.8–3.9 (3.37)	6.5–8.0 (7.17)	6.0–9.0 (7.37)	1.59	1.92
Sulphate (mg/l)	0.9–3.3 (1.77)	0.8–3.0 (1.77)	4.3–6.1 (4.93)	2.3–4.7 (3.57)	2.2–2.7 (2.50)	1.9–5.3 (3.27)	1.96	2.81
Nitrate (mg/l)	0.6–1.0 (0.80)	0.7–0.9 (0.80)	1.0–2.1 (1.53)	0.8–1.5 (1.20)	0.9–1.3 (1.10)	0.6–1.1 (0.90)	0.72	0.53
Iron (mg/l)	0 (0.00)	0 (0.00)	0.16–0.19 (0.11)	0.03–0.11 (0.06)	0.01–0.06 (0.04)	0–0.05 (0.02)	0.09	0.058
Aluminium (mg/l)	0 (0.00)	0 (0.00)	0.02–0.06 (0.04)	0.07-0.1 (0.09)	0.02–0.05 (0.03)	0.03–0.06 (0.04)	0.029	0.025
Total coliform (MPN/100ml)	0–3.0 (1.00)	0–3.0 (1.00)	9.0-16.0 (11.00)	5.0-16.0 (9.00)	3.0-10.0 (5.00)	0–3.0 (2.00)	6.9	7.86
Faecal coliform (MPN/100ml)	0 (0.00)	0 (0.00)	9.0-16.0 (11.00)	5.0–9.0 (6.00)	3.0-10.0 (5.00)	0–3.0 (2.00)	6.6	3.33

* Values in brackets are means

4.2. Physico-Chemical Parameters

4.2.1. pH

At each sampling destination, the range of values of pH recorded in the well-maintained system (S_2) was lower than in the poorly maintained system (S_1) (Table 1). In both systems, acidity decreased from free-fall to storage tank and only samples in storage tank were within the WHO and GSB recommended values of 6.5–8.5.

4.2.2. Turbidity

Well-maintained system recorded the lowest and narrowest range of turbidity values than poorly-maintained system (S_1) except at free-fall (Table 1). The highest mean turbidity values were recorded in samples collected from roof catchment in both systems. They were 6.33 NTU and 7.77 NTU for the well- and poorly- maintained systems respectively. There was also a general increase in turbidity from free-fall (where values were same for both systems) to roof-catchment destination followed by a decrease in storage tank. Values fell below the WHO and GSB guideline value of 5 NTU, except for samples collected from roof-catchment.

4.2.3. Conductivity

Conductivity increased generally along the chain for both systems. There was no difference in mean conductivity at free-fall for both systems. Higher values were however recorded in storage tank destination in the well-maintained system (55.60 µs/cm) than poorly-maintained system (46.67 µs/cm) but not at roof-catchment destination.

4.2.4. Total Hardness

With the exception of the free-fall destination where the mean value of total hardness recorded for both systems was the same (2.77 mg/l), different values were recorded at the other sampling destinations with higher values recorded at roof-catchment for the poorly-maintained system (4.87 mg/l) than the well-maintained system (3.37 mg/l). The poorly maintained system exhibited a wider range of total hardness than the well-maintained system, except in storage tank (Table 1). However, values recorded in this study were below both WHO and GSB guideline value (500 mg/l).

4.2.5. Sulphate

Higher concentration of sulphate was recorded in poorly maintained system than well-maintained system at roof-catchment destination than in storage tank. In both systems however, there was a general increase in concentration from free-fall to roof-catchment destination but a decrease from the latter to the storage tank. Values were below the WHO guideline value of 500 mg/l and the GSB value of 250 mg/l.

4.2.6. Nitrate

Results of nitrate concentration followed a trend similar to that of sulphate although higher values were recorded for sulphate than nitrate. Nitrate concentrations at roof-catchment and storage tank destinations were higher in poorly-maintained system than well-maintained system. Values recorded were well below the WHO and GSB guideline value of 50mg/l.

4.2.7. Iron

The trend of concentration observed for sulphate and nitrate was also observed in iron concentration in both poorly and well-maintained systems. Although no iron was detected in free-fall samples, it occurred at the other sampling locations with those of the poorly maintained system recording the highest. Values were below the WHO and GSB guideline value (0.3 mg/l).

4.2.8. Aluminium

In every aspect of comparison with iron, the trend observed in the concentration of aluminium in this study was similar.

4.3. Bacteriological Parameters

The well-maintained system exhibited better bacteriological quality than the poorly maintained system. Total and faecal coliforms were present in the roof-catchment and storage tank destinations of both systems but at the free-fall destination, only total coliform was present.

5. Discussions

5.1. Rainwater Quality Variation from Free-Fall to Storage

The quality of rainwater is essential because it serves as the source of water in all domestic rainwater harvesting (DRWH) systems. Variations in rainwater quality are reflected in its physical, chemical and biological condition. These conditions are also vital in determining the safety of the water in public health terms [13].

5.2. Variation in Physico-Chemical Parameters

Physico-chemical parameters including iron, nitrate, sulphate, ammonia and turbidity can have adverse public health impacts when present in water at high levels or varying concentrations. [10] reported significant variations in the physico-chemical quality of rainwater from free-fall as it interacts with various components of the harvesting system. Also, [6] reported higher values for roof-intercepted samples than free-fall samples.

5.3. pH

Results of this study, subjected to ANOVA indicates significant variation in pH of water in both the poorly maintained system (5.53) at and well-maintained system (60.45) $P < 0.05$. For both systems, acidity decreased from free-fall to storage tank (Table 1). This agreed with findings by [11] and may be attributed to dissolution of acid-forming gases such as CO_2 and SO_2 from the atmosphere which causes build-up of these acid-forming compounds in free-fall. Acidity of rainwater decreased from free-fall through roof-catchment to storage tanks. This supports the assertion by

[10] that rainwater is often slightly acidic and increase in pH is caused by contact with catchments and then in concrete tanks. The slightly higher pH values observed for the storage tank may be due to the presence of $CaCO_3$ in cement material of which the concrete tanks are made. Calcium carbonate might have leached into the water on interaction with the slightly acidic water entering the tank to cause decreased acidity. According to [4], concrete tanks have the capacity to increase pH of stored rainwater by dissolving $CaCO_3$ from the walls of the tank. [12] posited that pH is usually higher in tanks but gradually decreases with addition of rain during rain events. The contribution of the time lapse, after rain event, for collection cannot also be discounted.

Most biochemical reactions are sensitive to variations in pH. Water with pH below 6.5 can cause corrosion of metal pipes and pH higher than 8.0 affects disinfection [8]. Higher pH values facilitate solubilization of ammonia, heavy metals and salts and also precipitation of carbonated salts. Also low pH increases CO_2 and carbonate concentration. pH values of rainwater destinations recorded in this study were below the WHO and GSB recommended guideline values (6.5 to 8.5) at free-fall and roof-catchment. This may signal potential corroding effect on roof material and the possible release of aluminium or iron (from roof) into the water. According to [29], older roofs tend to leach more metals, suggesting that the age of the roof can negatively impact the quality of harvested rainwater. This may explain the relatively high acidity of water in the poorly-maintained systems, which involved relatively older sheets.

5.4. Turbidity

Turbidity increased upon contact with roof of rainwater harvesting systems through entry of particles such as clay, silt, organic matter and biological materials that may be present on the roofs. The values exceeded the WHO and GSB guideline value of 5 NTU with an ideal level of 1 NTU or lower [14]. The mean turbidity of rainwater in this study varied from 0.83 NTU to 7.77 NTU (both systems) and does not indicate pollution [14]; [15]. It however decreased in storage tanks. This may be due to settlement of particles. The observed higher turbidity in poorly-maintained systems may suggest that the roofs of the poorly- maintained systems were laden to a greater degree with contaminants or may be due to factors such as exposure of storage system. High turbidity increases the total surface area of particles in suspension upon which bacteria can grow. High turbidity may therefore promote water-borne diseases [30].

There was significant variation in turbidity along the chain in both poorly maintained system (7.74) and well-maintained system (13.93) at $P < 0.05$). At 5% LSD turbidity at free-fall and roof-catchment (both systems); and at roof-catchment and storage tank (well-maintained system) varied significantly.

5.5. Electrical Conductivity

According to the [15], conductivity is an indirect measure of the presence of dissolved solids and can be used as an indicator of water pollution. The mean conductivity for both poorly- and well-maintained systems ranged from17.50 µs/cm to 55.60 µs/cm respectively. Electrical conductivity values obtained were high [18]. This may imply that the rainwater was possibly impacted by local air pollution and accumulation of debris in rainwater catchment and conveyance components. Conductivity increased generally along the DRWH chain for both systems. This agreed with findings by [11] who reported conductivity of rainwater in the range of 14.82 µs/cm at free-fall and 36.61 µs/cm on roof-catchment, to 104.65 µs/cm after storage over a month. The differences in conductivity at the various stages along the DRWH chain as well as between the two systems appear to be real but not due to chance.

5.6. Total Hardness

Total hardness varied from 2.77 mg/l to 7.37 mg/l (S_1 and S_2) with hardness increasing generally along the DRWH chain. This could be attributed to increased levels of dissolved salt ions such as Ca^{2+}, Fe^{2+}, and Al^{3+} after rainwater made contact with roof catchment. Also, because hardness depends on the presence of ions such as these in water, the presence of Al^{3+} and Fe^{2+} ions in water samples from roof-catchment and $CaCO_3$ in cement material of the concrete tanks which might have leached by the acidic water entering the tank may account for the increases noticed in total hardness after free-fall. Similarly, a study by [11] observed that hardness of rainwater increases upon storage and reported total hardness increasing from 3.68 mg/l (free-fall) to 7.24 mg/l (roof-harvested) and 13.00 mg/l in storage tanks. In this study, rainwater may generally be considered as soft since water with hardness of 0 to <60 mg/l is a soft water [11]; [20] and [13]. Soft water is appropriate for domestic use since hardness exert great negative impact on household resources e. g. extra detergent, rinsing cycle and destruction of fabric.

For both systems, variation in total hardness along the DRWH chain was significant based on ANOVA results and LSD calculations. According to [16], although consumers can tolerate water hardness in excess of 500mg/l, domestic water of hardness above 500 mg/l is not recommended due to potential scale formation and high soap consumption. Hard water has the tendency to reduce the toxicity of some metals including Cu, Pb and Zn. This coupled with the absence of scaling of pipes and wastage of detergents and increased rinsing-cycles is expected to promote the benefits derived by the community for the occurrence of water of such degree of hardness. However, the formation of scale due to the presence of Ca^{2+} ion and consumption of contaminated harvested rainwater in the communities may preclude these benefits.

5.7. Sulphate

Mean sulphate concentrations recorded in this study did not indicate threatening situation [12]; [16]; [29]. ANOVA revealed significant variation (8.63) at $P < 0.05$ in sulphate concentration along the DRWH chain in the poorly-maintained system but no significant variation (1.41) at $P < 0.05$ in well-maintained system. Pair wise mean differences comparison with corresponding LSD value of 1.96 (poorly maintained system) showed that sulphate concentration at free-fall (1.77 mg/l) varied significantly from roof-catchment (4.93 mg/l), which also varied significantly from storage tank (2.50 mg/l); but concentration at free-fall (1.77 mg/l) did not vary significantly from that in storage tank (2.50 mg/l).

A general increase was observed in sulphate concentration upon contact with roof-catchment. This could be attributed either to natural occurrence of sulphate compounds in surrounding soils which could have been wind-blown onto the roof or sulphate compounds from automobiles (mainly motorcycles commonly called 'okada' which are the major means of commuting within the study area. Refuse dumping and burning in the open as in the study area could also be a contributing factor. The presence of sulphate in drinking-water is believed to cause noticeable taste, and very high levels (1000-1200 mg/l) might cause a laxative effect in unaccustomed consumers [16].

5.8. Nitrate

Results in this study showed that nitrate concentration was well below the WHO and GSB guideline value of 50 mg/l. When subjected to ANOVA, nitrate concentration did not vary. However, post hoc comparisons using the Fisher LSD test (Table 1) revealed that for the poorly maintained system, nitrate concentration at free-fall (0.80 mg/l) and roof-catchment (1.53 mg/l) varied significantly. In this study, nitrate concentration was lowest at free-fall and highest on roof-catchment. This could be attributed to natural occurrence of nitrate salts in surrounding soils and plant debris which could have been wind-blown onto the roof catchment or from vehicular exhaust fume emissions. It may also result from fecal matter deposited on roof by birds and rodents. According to [16], water naturally contains less than 1mg nitrate-nitrogen per litre and is not a major source of exposure.

5.9. Iron

No iron was detected in free-fall samples due to absence in the atmosphere. Varying levels were detected in roof-catchment and in storage tank samples but they were below the WHO and GSB guideline value (0.3 mg/l). The slightly acidic nature of the rainwater may have accounted for the detected traces of iron as pH below 6.5 is believed to have a corroding effect [9]. ANOVA indicate that for both systems, iron concentration did not vary significantly at all sampling destinations. However the Fisher LSD test (Table 1) revealed significant variation in iron concentration at free-fall and roof-catchment (both systems). Iron imparts objectionable taste to water, stains laundry (above 0.3 mg/l) and promotes turbidity [17].

5.10. Aluminium

The presence of aluminium at concentrations in excess of 0.1-0.2 mg/l leads to consumer complaints [16]. This exerts important health effect on consumers. Traces of aluminium were observed in roof-catchment and storage tank samples but not in free-fall samples. This may be attributed to the slightly acidic nature of the rainwater or the age of the roofs since both systems had galvanized iron/aluminium roofs aged more than 10 years. [29] noted that older roofs tend to leach more metals. The maximum mean concentration of Al does not signal contamination threat [13]. ANOVA results indicate significant variation in aluminium concentration along the DRWH chain of both the poorly maintained system (6.53) and well-maintained system (36.21) at $P < 0.05$. LSD calculations revealed significant variation in aluminium concentration at all sample destinations except between the poorly maintained system's roof-catchment and storage tank. Variability in concentration of Al have been [23; 24] observed.

5.11. Bacteriological Parameters

Microbial contamination is of main concern for health risk and varies with location, surrounding environment, and maintenance practices [6]. Microbiological, particularly bacteriological quality of the rainwater was assessed using total coliform and faecal coliform as the main indicators of bacteriological quality.

5.12. Total Coliform

Total coliform was recorded in at all destinations and in all systems and at levels above the WHO and GSB guideline value of 0 MPN/100ml (Table 1). There was significant variation (6.79) at $P < 0.05$ in total coliform in the poorly maintained system but not for the well-maintained system (3.37) at $P < 0.05$. Even though total coliform bacteria are mostly unlikely to cause illness, their presence indicates water supply may be vulnerable to contamination by more harmful microorganisms [17]. The presence of total coliform in samples may thus present some level of health risk to consumers.

The results also revealed highest total coliform counts in roof-catchment samples implying that the rainwater was impacted by roof-catchment and run-off contamination perhaps through fecal depositions by birds and rodents or accumulated organic debris. This finding agreed with the assertion by [31] that microbial contamination and other water quality problems associated with rainwater harvesting systems are most often derived from the catchment area and storage components. In this study, rainwater was most turbid on roof-catchment. It is thus not surprising that total coliform counts were greatest on roof-catchment. According to [32], there is a positive correlation between the level of total coliform bacteria and the grade of turbidity in roof-collected rainwater.

Again, the results demonstrated that even though level of system maintenance employed was not generally effective in totally eliminating bacteriological contaminants, the well-maintained system exhibited better bacteriological quality than the poorly maintained system.

5.13. Faecal Coliform

ANOVA revealed significant variation in faecal coliform along the DRWH chain of both the poorly maintained system (8.86, $P < 0.05$) and well-maintained system (11.32, $P < 0.05$). However, in this study, only free-fall samples met set standards [13; 16]. No faecal coliform was detected at free-fall destination. Levels however increased upon contact with roof catchment and then reduced in storage tank. This finding was consistent with a study by [33] who reported that faecal coliforms, total coliforms and faecal streptococci decline rapidly in rainwater storage tanks. The observed reductions in storage tank may be attributed to change in pH from slightly acidic (at free-fall and on roof-catchment) to about neutral (in storage tank) or the change in environmental conditions (from an open environment to a closed one). This is because biochemical reactions and processes are mostly sensitive to and are affected by variations in pH and environmental conditions.

Again, well-maintained system had better bacteriological quality in terms of faecal coliform levels. This observed impact of system maintenance on rainwater quality confirms findings of [34] that household tanks that were well covered showed less degree of microbial contamination compared with uncovered or poorly covered ones. According to [35], improvement in water quality upon storage can be attributed to a number of processes including sedimentation through which contaminant load becomes higher in sediment than the water column itself. Moreover, it can also be attributed to low temperatures in the tanks and also to the detention of rainwater in storage tank [10].

6. Conclusion

The study showed that measured physico-chemical and bacteriological quality varied along domestic rainwater harvesting chain from free-fall to storage. Regardless of the system type, there was increasing deterioration in quality of rainwater upon interaction with roof catchment and progressing toward storage point. This notwithstanding, the harvested rainwater for domestic purpose in the Dzodze Community was of good physico-chemical and bacteriological quality exhibiting levels below the GSB and WHO guideline values for this designated use. Treatment of harvested rainwater such as boiling could be adopted to further ward off any possible health risk related its consumption.

References

[1] UN (United Nations), "The Millennium Development Goals Report" 2008. [http://www.un.org/millenniumgoals/2008highlevel/pdf/newsroom/mdg%20reports/MDG_Report_2008_ENGLISH.pdf], (Accessed: 20th May, 2016).

[2] Doyle, K. C., "Sizing the first flush and its effect on the storage-reliability-yield behavior of rainwater harvesting in Rwanda". Massachusetts Institute of Technology, 2008.

[3] National Water Policy. "Government of Ghana. Ministry of Water Resources, Works and Housing" (2007). [http://www.water-mwrwh.com/WaterPolicy.pdf], (Accessed: 23rd May, 2016).

[4] Lundgren, A. and H. Akerberg, " Rainwater harvesting in peri-urban areas of Accra: status and prospects'. MSc thesis submitted to the Royal Institute of Technology, Stockholm, Sweden, (2006), 27-35pp.

[5] Spinks, A. T., Coombes, P., Dunstan, R. H. and G. Kuczera, "Water Quality Treatment Processes in Domestic Rainwater Harvesting Systems", In 28th International Hydrology and Water Resources Symposium, Wollongong, Australia, 2003.

[6] Nair, J. and G. E. Ho, "Monitoring bacterial water quality in rainwater tanks using the H_2S method." (2009), [http://www.docstoc.com/docs/17798836/Monitoring-bacterial-water-quality-in-rainwater-tanks-using-the-H2S-method]. (Accessed: 13th February, 2016).

[7] Adeniyi, I. F. and Olabanji, I. O, "The physico-chemical and bacteriological quality of rainwater collected over different roofing materials in Ile-Ife, southwestern Nigeria". Chemistry and Ecology, Vol. 21, (3), 2005, 149-166.

[8] USEPA (United States Environmental Protection Agency Report), (2006), 3-11pp.

[9] Diwakar, J., Yami, K. D. and T. Prasai, "Assessment of drinking water of Bhaktapur municipality area in pre-monsoon season". Scientific World, Vol. 6, (6), 2008, 95pp.

[10] Amin, T and M. Y. Han, "Microbial quality variation within a rainwater storage tank and the effects of first flush in Rainwater Harvesting (RWH) System". Australian Journal of Basic and Applied Sciences, 2011, Vol. 5, (9), 2011, 1804-1813pp.

[11] Thomas, R. M. "Studies on the quality of rainwater at various land use locations and variations by interaction with domestic rainwater harvesting systems". Doctor of Philosophy Thesis submitted to Cochin University of Science and Technology (2009).

[12] Scott, R. and D. Waller, "Water quality analysis of a rainwater cistern system in Nova Scotia, Canada." In: Proceedings of the 3rd International Rainwater Collection System Association Conference. Khon Kaen, Thailand (1987).

[13] GSB (Ghana Standards Board) "Water Quality- Specification for Drinking Water". GS 175-1, 2009, 3rd Edition.

[14] NHMRC (National Health and Medical Research Council). "Australian Drinking Water" (2004).

[15] Yaziz, M. I., Gunting, H., Sapri, N. and A. W. Ghazali, "Variations in rainwater quality from roof catchments." Water Research Vol. 23 (6), (1989): 761-765pp.

[16] WHO (World Health Organization) "Guidelines for Drinking-Water Quality." 4th Ed. Geneva, Switzerland (2011): 1-564pp.

[17] EPA "Results of the Inter- laboratory Testing Study for the Comparison of Methods for Detection and Enumeration of Enterococci and *Escherichia coli* in Combined Sewer Overflows" (CSOs) 2008. [www.epa.gov/waterscience/methods/method/biological/csoreport200809.pdf]. (Accessed: 25th June, 2015).

[18] Suttar, S., Switzer, C. and J. Codling, "Ribbons of Blue Handbook". Scitech Discovery Centre, 1990.

[19] Hairston, J. E. and J. C. LaPrade, "Hard water can be a nuisance". Environmental Education Series, 1995.

[20] Gupta, D. P. and J. P. Saharanb, "Physiochemical Analysis of Ground Water of Selected Area of Kaithal City (Haryana)". Haryana College of Technology and Management-Kaithal (Hr), India. Vol. 1(2): 2009, 1-4.

[21] Tay, C. "Chemical Characteristics of Groundwater in the Akatsi and Ketu Districts of the Volta Region, Ghana." CSIR – WRI. Accra, Ghana (2004).

[22] Watkins, C., Raftery, J. and Schaden, C. "Parameters for rainwater quality testing at Isla Urbana and the Ajusco Lab."

[23] Sorenson, J. Campbell, R. J., Tepper, L. B. and R. D. Lingg, "Aluminium in the environment and human health" Environ. Health Persp., Vol. 8, 1974, 3-95pp.

[24] Schenk, R. U, Bjorksten, J., and L. Yeager,. "Composition and consequences of Al in water, beverages and other ingestibles." In: Environmental chemistry and toxicology of Al (Lewis T. E., ed.). Chelsea, M. I: Lewis Publishers Inc. (1989).

[25] Abbott, S. E., Douwes, J. and B. P. Caughley, A survey of the microbiological quality of roof-collected rainwater of private dwellings in New Zealand. In Proceedings: Water 2006 International Conference Hyatt Regency Hotel Auckland 2006.

[26] Krishna, H. "An overview of rainwater harvesting systems and guidelines in the United States". Proceedings of the First American Rainwater Harvesting Conference; August 21-23, 2003; Austin (TX), 2003, 335-343 pp.

[27] Ketu-North District Planning Co-ordinating Unit, "Strategic Environmental Assessment (SEA) of the Ketu-North District Assembly Medium Term Development Plan (2010-2013)"., 2010, pp 5-6 pp.

[28] APHA, "Standard Methods for the Examination of Water and Wastewater" 20th edn. Washington, D. C., 1998.

[29] Chang M., McBroom M. W., and S. R. Beasley, "Roofing as a source of nonpoint water pollution. Journal of Environmental Management" Vol. 73 (4): 2004, 307-315pp.

[30] RISC (Resources Information Standards Committee), "Guidelines for interpreting water quality data. Province of British Columbia". [http://www.ilmb.gov.bc.ca/risc/pubs/aquatic/ interp/interp-01.htm] 1998, (Accessed: 27th July, 2015).

[31] Lye, D. J. "Water Quality of American Cistern Systems. American Rainwater Catchment Systems Association (ARCSA)" Austin, TX. (1996).

[32] Shelton, T. B. "Interpreting drinking water quality analysis- What do the numbers mean." Rutgers Cooperative extension (2000).

[33] Vasudevan, P., Tandon, M., Krishnan, C. and T. Thomas, "Bacterial quality of water in DRWH." Proceedings of 10th International Rainwater Catchment Systems Conference, Weikersheim, Germany. International Rainwater Catchment Systems Association, 2001, 153-155pp.

[34] Hammad, Z. H., Ali, O. A. and H. H. Ahmed, "The quality of drinking water in storage tanks in Khartoum State." National Health Laboratory, Khartoum, 2008, 1-3pp.

[35] Spinks, A., Berghout, B., Dunstan R., Coombes, P. and G. Kuczera, "Tank sludge as a sink for bacterial and heavy metal contaminants and its capacity for settlement, re-suspension and flocculation enha ncement." In: Proceedings of the 12th International Rainwater Catchment Systems Association Conference, New Delhi, India, 2005.