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Domestic Rainwater Harvesting in a Water-Stressed Community and Variation in Rainwater Quality from Source to Storage

G. Owusu-Boateng
Faculty of Renewable Natural Resources
Kwame Nkrumah University of Science and Technology (KNUST), Kumasi
godfredowusuboateng@yahoo.com

M. K. Gadogbe
Department of Material Engineering
KNUST, Kumasi

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 a great lack of standard maintenance and treatment systems in the community. In this study, we assessed the quality of rainwater in the Dzodze community and how it varies along the DRWH chain from free-fall to storage. Rain samples were collected at three points along the domestic rainwater harvesting (DRWH) chain. Specifically, the three points were free-fall, roof catchment, and storage tank, and the two systems were "poorly-maintained" and "well-maintained" systems. The physico-chemical and bacteriological patterns of rainwater samples were analyzed for physico-chemical and bacteriological parameters and results were compared with World Health Organization (and Ghana Standards Board guideline values. The harvested rainwater was found to be of good physico-chemical quality, but not bacteriological quality, calling for treatment before utilization. Also, irrespective of the type of DRWH system (poorly-maintained or well-maintained), there were substantial changes in rainwater quality upon interaction with roof catchment, with an increase noticed in all parameters.

Keywords: Rainwater harvesting, physico-chemical, 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; this is in part due to population growth, frequent droughts and the changing climate. The United Nations' Millennium Development Goal (MDG) Seven had a target to halve the proportion of global population without sustainable access to safe drinking water and sanitation by 2015. Although about 1.6 billion people have gained access to safe drinking water through various technologies since the implementation of MDG Seven (United Nations, 2008), 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 the collection of rainwater from the roofs of buildings via a guttering system and storage in a cistern (Doyle, 2008). At the 2006 Climate Change Convention in Nairobi, Rainwater Harvesting

(RWH) was recognized as a viable option for addressing current water needs and providing security against future droughts in many African countries. In Ghana, along with general water-scarcity, the situation is especially acute in many communities. In an attempt to circumvent the problem, RWH has been recognized as an appropriate technology to meet their water requirements. Despite this, RWH technology has not received adequate support from the governments of these water-scarce countries. For instance, the Ghana National Water Policy only focuses on the enactment of legislation for the provision of incentives for RWH systems and their incorporation and enforcement in all new building designs (National Water Policy, 2007). No consideration has been given to already existing settlements that are making the strategy inadequate. Lundgren and Akerberg (2006) made the observation 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 rise in many areas in Ghana. However, the absence of affordable systems, institutional support, and relevant research, especially in terms of the water quality, present significant constraints to DRWH's widespread adoption and usage.

One example of a successful use of RWH can be seen in Dzodze, a community in the Volta Region of Ghana, where water is scarce and the limited available sources perceived to be of undesirable quality. RWH serves as a highly dependable source of domestic water and has contributed immensely to its socio-economic development. Given the region's climatic and geographic characteristics and the storage capacity of the tanks used, RWH represents an appropriate way to improve water supply and has gradually received widespread adoption, serving households even in the extended dry seasons. One potential issue with RWH is the potential effects it may have on health, especially given the high number of infections in this community. Still, there is no evidence that RWH is linked to these infection rates, so RWH seems to provide a low-cost solution to the water crisis and contributes to the prevention of water-related health problems.

1.1 Rainwater Quality Variation Along the Supply Chain from Free-Fall to Storage

Rainwater harvesting systems are open to environmental hazards because of the nature of the catchment area. There are several points along the DRWH chain where contaminants can enter and compromise water quality. Contamination can occur during the free-fall of rain, after contact with roof catchment, and during storage (through complex interactions within the storage system). During free-fall, rainwater picks up atmospheric aerosols contributing to variations in the quality of rainwater as it reaches the place of collection. Roof catchment contamination may arise from contaminants deposited on roof and guttering systems, such as droppings from birds and small animals, leaf litter from overlying vegetation, and aerosols deposited by the wind. In storage, microbial contamination comes primarily from insect accumulation; *Salmonella* carriers, e.g., frogs (Spinks *et al*, 2003); and bacterial growth in stagnant storage tanks.

Microbial contamination, according to Nair and Ho (2009), is a primary health risk as it varies depending on location, season, environment, and maintenance practices, which leads to unpredictable water quality. In their study, the pH 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, they 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. Free-fall and roof-intercepted rainwater samples analyzed in Ile-Ife, Nigeria (Adeniyi and Olabanji, 2005), 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.

1.2 pH

Measured pH gives indication of the balance between hydrogen ions (H^+) and hydroxide ions (OH^-) in water (USEPA, 2006). According to Diwakar *et al* (2008), pH less than 7.0 may cause corrosion of metal pipes, thereby releasing toxic metals like Zn, Pb, Cd, Cu, and other substances that result in a higher pH, adversely affecting the disinfection process. As rainwater is often slightly acidic, high pH values are caused by contact with the catchment and the concrete tank (Amin and Han, 2011). Thomas (2009) noted that the pH of rainwater usually increases slightly after falling on the roof and during storage in tanks, and water sampled from cement tanks tends to be alkaline. Scott and Waller (1987) observed a rise in pH from 5.0 on roof surface to 9.4 in tank and 10.3 from tap, and that higher pH inhibits coliform growth.

1.3 Turbidity

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. An increased turbidity may increase the risk of waterborne diseases, such as gastro-intestinal infections (WHO, 2011). In drinking water, the maximum allowed turbidity is 5 NTU (GSB, 2009); however, the ideal is 1 NTU or lower (NHMRC, 2004). Studies on rainwater harvesting have often reported variability in turbidity levels; mostly within the range for filtered water, though some exceeded 5 NTU (Yaziz, *et al*, 1989). According to the WHO (2011), turbidity is important to track because it affects the acceptability of consumers and the selection and efficiency of treatment processes.

1.4 Electrical Conductivity

Conductivity is a measure of the ability of water to pass electric current (EPA, 2008). 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 values have been proposed (WHO, 2011; GSB, 2009). According to Suttar *et al* (1990), electrical conductivity of pure rainwater is usually < 15 µs/cm. Natural waters are found to vary between 50 and 1500 µs/cm.

1.5 Total Hardness

Water hardness, the capacity of water to react with soap, is reflected by the total concentration of Ca2+ and Mg2+ ions in the water. Water hardness is important to these communities, as 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 (Hairston and LaPrade, 1995). Gupta and Saharanb (2009) reported a range of 75 - 1110 mg/l for total hardness in drinking water while the GSB (2009) noted 500 mg/l. Tay (2004) 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 Thomas (2009) showed hardness of rainwater increasing upon storage.

1.6 Sulfate, Nitrate, Iron, Aluminum

Sulfates are discharged into water through industrial wastes and atmospheric deposition. Sulfates have 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 (Watkins *et al*, 2011). The GSB (2009) sets its recommend cap at 250 mg/l. It is recommended that at levels above 500mg/l, health authorities should be notified (WHO, 2011). Nitrate is the more stable, oxidized form of combined nitrogen in most environmental media (USEPA, 2006). There is usually no noticeable taste at iron concentrations below 0.3 mg/l, although turbidity and color may develop. Corrosion of iron is possible at high dissolved oxygen values (WHO, 2011). Background concentrations of aluminum (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 (Sorenson *et al*, 1974). Concentrations of Al are highly variable in drinking water, ranging from <0.001 to 1.029 mg/l (Schenk *et al*, 1989), though the limit by GSB (2009) is 0.2 mg/l. However, under good operating conditions, an Al concentration of less than 0.1 mg/l is achievable (WHO, 2011).

1.7 Coliform Bacteria

The microbial quality of water is determined by the presence of bacteria total coliforms, including fecal coliforms such as *Escherichia coli,* and indicates fecal contamination. According to Abbott *et al* (2006), *Escherichia coli* or fecal coliforms should be used as indicator bacteria for stored rainwater since *Escherichia coli* specifically indicates human or animal fecal pollution. In water, coliform bacteria have no taste, smell, or color, and can only be detected through a laboratory test. The WHO (2011) and GSB (2009) recommends zero *Escherichia coli* or thermotolerant Coliform Forming Unit (CFU) per 100 ml for all drinking water supplies. Krishna (2003) proposed the following alternative bacteriological water quality standards for potable roof-collected rainwater in tropical regions and developing countries:

Class I: 0 fecal coliform per 100 ml – highest and ideal quality
Class II: 1 - 10 fecal coliform per 100 ml – marginal quality
Class III: > 10 fecal coliform per 100 ml – unacceptable for drinking

2. Methodology

2.1 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-western corner of Volta Region, Ghana, and lies between latitudes 6° 03' N and 6° 20' N and longitudes 0° 49' E and 1° 05' E. The district capital, Dzodze, is located on the main trunk road linking the regional capital (Ho) to Aflao, 80 km away from Ho. The district has a total land area of 754 km^2 (MOFA, 2011). Dzodze was chosen for the study because of its long standing history of DRWH.

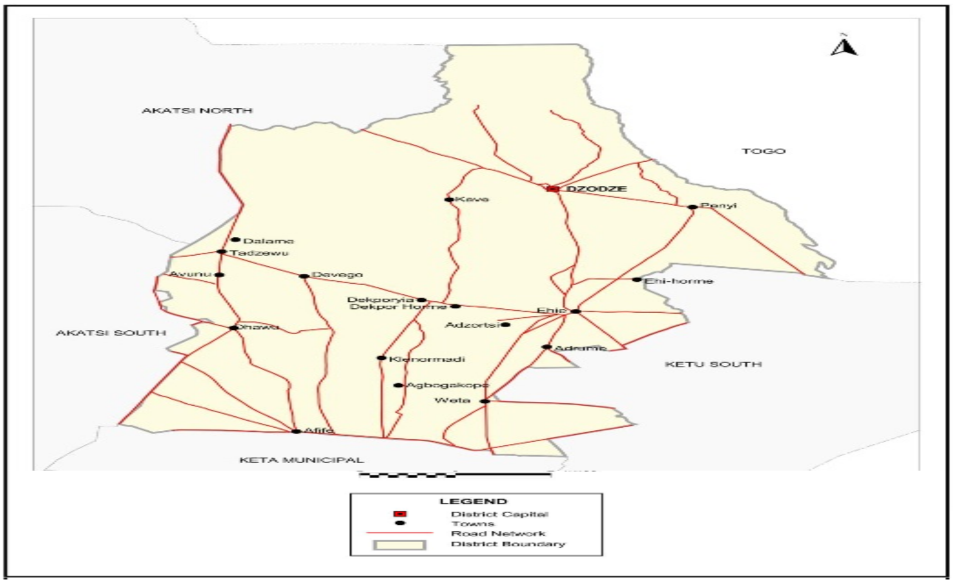

Figure 1: Ketu-North District map with the location of Dzodze (Source: Ketu-North District Planning Coordinating Unit (2010))

2.2 Rainwater Sample Collection

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

2.3 Laboratory Analysis of Water Samples

The investigated water-quality parameters were pH, turbidity, electrical conductivity, total hardness, sulfate, nitrate, iron, aluminum, total coliform, and fecal coliform. Total coliform and fecal coliform were determined through the use of the multiple tube fermentation technique (MPN method) using Lauryl tryptose broth for the presumptive phases of total and fecal coliforms, and Brilliant Green Lactose Bile Broth and EC Medium for the confirmation phases of total coliform and fecal coliform, respectively. Standard laboratory methods were followed for analysis, and great care was taken to ensure that 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 (APHA, 1998).

2.4 Data Analysis

Data obtained from laboratory analysis of rainwater samples was checked for quality and entered into the computer. Microsoft Excel was used to organize the data**.** Mean values of parameters were compared with WHO Guideline and the GSB standard values for Drinking-Water Quality.

3. Results

3.1 Variation in Rainwater Quality from Source (Free-Fall) to Storage

The results of the laboratory analyses of rainwater quality along the DRWH chain and for domestic use are presented in this section. The mean values of all measured water quality parameters (physico-chemical and bacteriological) computed are presented in Table 1.

3.2 Physico-Chemical Parameters

pH

At each sampling destination, the range of values of pH recorded in the well-maintained system (S2) was lower than in the poorly-maintained system (S1) (Table 1). In both systems, acidity decreased from free-fall to storage tank and only samples within storage tank were within the WHO and GSB recommended values of 6.5 – 8.5.

Turbidity

The well-maintained system recorded the lowest and narrowest range of turbidity values 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 the same for both systems) to roof catchment destination followed by a decrease in the storage tank. Values fell below the WHO and GSB guideline value of 5 NTU, except for samples collected from roof catchment.

Conductivity

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

Table 1: Water quality parameters measured in the poorly-maintained system (S1) and the well-maintained system (S2)

Parameters	Range of values						5% LSD	
	Free-fall		**Roof catchment**		**Storage tank**			
	S1	**S2**	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**
pH	.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)	.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 $CaCO_3$)	.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
Sulfate (mg/l)	.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)	.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
Aluminum (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
Fecal 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 parentheses are means

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 vs. 3.37 mg/l). The poorly-maintained system exhibited a wider range of total hardness than the well-maintained system, except in the storage tank (Table 1). However, values recorded in this study were below both the WHO and GSB guideline value (500 mg/l).

Sulfate

Higher concentrations of sulfate were recorded in the poorly-maintained system. 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.

Nitrate

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

Iron

The trend of concentrations observed for sulfate and nitrate was also observed in iron concentrations 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. Values were below the WHO and GSB guideline value (0.3 mg/l).

Aluminum

In every aspect of comparison with iron, the trends observed in the concentrations of aluminum in this study were similar.

Bacteriological Parameters

The well-maintained system exhibited better bacteriological quality than the poorly-maintained system. Total and fecal 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.

4. Discussion

4.1 Variation in Rainwater Quality from Source (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 conditions. These conditions are also vital for determining the safety of the water in public health terms (NHMRC, 2004).

4.2 Variation in Physico-Chemical Parameters

Physico-chemical parameters such as iron, nitrate, sulfate, ammonia, and turbidity can have adverse public health impacts when present in water at high levels or at varying concentrations. Thomas (2009) reported significant variations in the physico-chemical quality of rainwater from free-fall as it interacts with various components of the harvesting system. Also, Adeniyi and Olabanji (2005) reported higher values for roof-intercepted samples than free-fall samples.

4.3 pH

The results of this study, subjected to ANOVA, indicate significant variation in pH of water in both the poorly-maintained system (5.53) and the 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 Thomas (2009) and may be attributed to the dissolution of acid-forming gases such as carbon dioxide (CO_2) and sulfur dioxide (SO_2) from the atmosphere, which causes the build-up of these acid-forming compounds in free-fall. The acidity of rainwater decreased from free-fall through roof catchment to storage tanks. This supports the assertion by Amin and Han (2011) that rainwater is often slightly acidic and that increases in pH are caused by contact with catchments and concrete tanks. The slightly higher pH values observed for the storage tank may be due to the presence of calcium carbonate ($CaCO_3$) in cement material, of which the concrete tanks are made. $CaCO_3$ might have leached into the water on interaction with the slightly acidic water entering the tank to cause the decreased acidity. According to Lundgren and Akerberg (2006), concrete tanks have the capacity to increase the pH of stored rainwater by dissolving $CaCO_3$ from the walls of the tank. Scott and Waller (1987) 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 events for collection cannot be discounted as well.

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 (Diwakar *et al.*, 2008). Higher pH values facilitate the solubilization of ammonia, heavy metals, salts, and also the precipitation of carbonated salts. Also, low pH increases CO_2 and carbonate concentration. The 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 a potential corroding effect on roof material and the possible release of aluminum/iron into the water. According to Chang *et al* (2004), older roofs tend to release more metals in this process, 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.

4.4 Turbidity

Turbidity increased upon contact with the roofs of rainwater harvesting systems through the 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 (NHMRC, 2004). The mean turbidity of rainwater in this study varied from 0.83

NTU to 7.77 NTU (both systems) and does not indicate pollution (Yaziz, *et al.*, 1989; NHMRC, 2004). Values decreased in storage tanks, however. This may be due to the 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 the 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 (RISC, 1998).

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

4.5 Electrical Conductivity

According to the WHO (2011), 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 the poorly- and well-maintained systems were 17.50 µs/cm and 55.60 µs/cm, respectively. Electrical conductivity values obtained were high (Suttar *et al.*, 1990). This may imply that the rainwater was impacted by local air pollution and the accumulation of debris in rainwater catchment and conveyance components. Conductivity increased generally along the DRWH chain for both systems. This agreed with findings by Thomas (2009), who reported the conductivity of rainwater in the range of 14.82 µs/cm at free-fall, 36.61 µs/cm on roof catchment, and 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 and not due to chance.

4.6 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 these ions in the water, Al^{3+} and Fe^{2+} ions in water samples from roof catchment and $CaCO_3$ in the cement material of the concrete tanks may account for the increases noticed in total hardness after free-fall. Similarly, a study by Thomas (2009) observed that hardness of rainwater increases upon storage, reporting that total hardness increased from 3.68 mg/l (free-fall) to 7.24 mg/l (roof-harvested) and 13.00 mg/l (storage tanks). In this study, rainwater may generally be considered as "soft": hardness between 0 and 60 mg/l (Thomas, 1953; Gupta and Saharanb, 2009 and GSB, 2009). Soft water is appropriate for domestic use since hardness exerts great negative impact on household resources e.g. extra detergent, a rinsing cycle, and fabric destruction.

For both systems, variation in total hardness along the DRWH chain was significant based on ANOVA results and LSD calculations. According to WHO (2011), although consumers can tolerate water hardness in excess of 500 mg/l, domestic water of hardness above 500 mg/l is not recommended due to potential scale formation and high soap consumption. One benefit of hard water is its tendency to reduce the toxicity of some metals including copper, lead, and zinc.

However, the detriments of the formation of scaling from the presence of Ca^{2+} ion and overall contamination outweigh potential benefits.

4.7 Sulfate

Mean sulfate concentrations recorded in this study did not indicate threatening situations (GSB, 2009; Watkins *et al*, 2011; WHO, 2011). ANOVA revealed significant variation (8.63) at $P < 0.05$ in sulfate concentration along the DRWH chain in the poorly-maintained system but no significant variation (1.41) at $P < 0.05$ in the well-maintained system. Pairwise mean differences comparison with corresponding LSD value of 1.96 (poorly-maintained system) showed that sulfate concentration at free-fall (1.77 mg/l) varied significantly from sulfate concentration at roof catchment (4.93 mg/l), which also varied significantly from storage tank sulfate concentration (2.50 mg/l). However, 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 sulfate concentration upon contact with roof catchment. This could be attributed either to the natural occurrence of sulfate compounds in surrounding soils that could have been blown onto the roof or sulfate compounds from automobiles. Refuse dumping and burning in the open could also be a contributing factor. The presence of sulfate in drinking water is believed to cause noticeable differences in taste, and very high levels (1000-1200 mg/l) might have a laxative effect in unaccustomed consumers (WHO, 2011).

4.8 Nitrate

Results in this study showed that nitrate concentrations were 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, like for sulfate, could be attributed to the natural occurrence of nitrate salts in surrounding soils and plant debris that were blown onto the roof catchment or from vehicular exhaust fume emissions. It may also result from fecal matter deposited on the roof by birds and rodents. According to the WHO (2011), water naturally contains less than 1 mg nitrate-nitrogen per liter and is not a major source of exposure.

4.9 Iron

No iron was detected in free-fall samples due to its absence in the atmosphere. Varying levels were detected in roof catchment and in storage tank samples but were below the WHO and GSB guideline value (0.3 mg/l). The slightly acidic nature of the rainwater may have accounted for the traces of iron, as pH below 6.5 is believed to have a corroding effect (Diwakar *et* al, 2008). ANOVA indicated 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 for both systems. Iron imparts objectionable taste to water, stains laundry (at levels above 0.3 mg/l), and promotes turbidity (WHO, 2011).

4.10 Aluminum

The presence of aluminum at concentrations in excess of 0.1 - 0.2 mg/l leads to consumer complaints (WHO, 2011). This exerts important health effect on consumers. Traces of aluminum 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/aluminum roofs aged more than 10 years. Chang *et al* (2004) noted that older roofs tend to exude more metals. The maximum mean concentration of Al did not signal a contamination threat (GSB, 2009). ANOVA results indicate significant variation in aluminum concentration along the DRWH chain of both the poorly-maintained system (6.53) and the well-maintained system (36.21) at $P < 0.05$. LSD calculations revealed significant variation in aluminum concentration at all sample destinations except between the poorly-maintained system's roof catchment and storage tank. Variability in concentration of Al have been (Sorenson *et al*, 1974; Schenk *et al.*, 1989) previously observed.

4.11 Variation in Bacteriological Parameters

Microbial contamination is of main concern for health risk and varies with location, the surrounding environment, and maintenance practices (Nair and Ho, 2009). The microbiological quality of the rainwater was assessed using total coliform and fecal coliform as the main indicators of bacteriological quality.

4.12 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/100 ml (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 the water supply may be vulnerable to contamination by more harmful microorganisms (EPA, 2008). The presence of total coliform in samples may thus suggest 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 agrees with the assertion by Lye (1996) 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 Shelton (2000), 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 the level of system maintenance employed was not generally effective in totally eliminating bacteriological contaminants, the well-maintained system still exhibited better bacteriological quality than the poorly-maintained system.

4.13 Fecal Coliform

ANOVA revealed significant variation in fecal coliform along the DRWH chain of both the poorly-maintained system (8.86, $P < 0.05$) and the well-maintained system (11.32, $P < 0.05$). In this study, only free-fall samples met set standards (GSB, 2009; WHO, 2011). No fecal coliform was detected at free-fall destination. Levels were increased upon contact with roof catchment and then reduced in storage tank. This finding was consistent with a study by Vasudevan *et al*, (2001) which reported that fecal coliforms, total coliforms, and fecal streptococci decline rapidly in rainwater storage tanks. The observed reductions in the storage tank may be attributed to the change in pH from slightly acidic to about neutral or to the change in environmental conditions. This is because biochemical reactions and processes are mostly sensitive to and affected by variations in pH and environmental conditions.

Again, the well-maintained system had better bacteriological quality in terms of fecal coliform levels. This observed impact of system maintenance on rainwater quality confirms findings of Hammad *et al* (2008) that well covered household tanks showed less microbial contamination compared to uncovered or poorly covered ones. According to Spinks *et al* (2005), 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 the detention of rainwater in storage tanks (Amin and Han, 2011).

5. Conclusion

This study showed variation in all physio-chemical parameters along the DRWH chain from free-fall to storage and, irrespective of system type, there was a substantial change in rainwater quality upon interaction with roof catchment, with an increase in concentration of all unwanted parameters. Although the harvested rainwater for domestic purpose in the Dzodze community was of good physico-chemical quality, its bacteriological quality is below the WHO guideline values and GSB standard for its designated usage. Boiling and other treatments of the harvested water could be employed before consumption to ward off possible health-related hazards.

Bibliography

Abbott, S. E., Douwes, J. and Caughley, B. P. "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).

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, 21.3(2005.): 149-166.

Amin, T and Han, M. Y. "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, 5.9(2011): 1804-1813pp.

APHA (American Public Health Association). "Standard Methods for the Examination of Water and Wastewater." 20th edn. Washington, D.C. (1998).

Chang M., McBroom M. W., and Beasley S. R.. "Roofing as a source of nonpoint water pollution." Journal of Environmental Management 73.4(2004): 307-315pp.

Diwakar, J., Yami, K. D. and Prasai, T. "Assessment of drinking water of Bhaktapur municipality area in pre-monsoon season." Scientific World, 6.6(2008.): 95pp.

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).

DWAF (Department of Water Affairs and Forestry). "Quality of Domestic Water Supplies. Assessment Guide.", 2nd edn. DWAF, Department of Health and Water Research Commission, Pretoria, South Africa. (1998).

EPA (Environmental Protection Agency). "Results of the Interlaboratory Testing Study for the Comparison of Methods for Detection and Enumeration of Enterococci and *Escherichia coli* in Combined Sewer Overflows" (CSOs).(2008). [http://www.epa.gov/waterscience/methods/method/biological/csoreport200809.pdf]. (Accessed: 25th June, 2012).

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

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

Lundgren, A. and Akerberg, H. “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.

Gupta, D. P. and Saharanb, J. P. “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):1-4pp.

Hairston, J. E. and LaPrade, J. C. “Hard water can be a nuisance”. Environmental Education Series. (1995).

Hammad, Z. H., Ali, O. A. and Ahmed, H. H. “The quality of drinking water in storage tanks in Khartoum State.” National Health Laboratory, Khartoum. (2008). 1-3pp.

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):335-343pp.

Lundgren, A. and Akerberg, H. 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.

Lye, D. J. “Water Quality of American Cistern Systems. American Rainwater Catchment Systems Association (ARCSA).” Austin, TX. (1996).

Nair, J. and Ho, G.E. “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 December, 2012).

National Water Policy. “Government of Ghana. Ministry of Water Resources, Works and Housing” (2007). [http:// www.water-mwrwh.com/WaterPolicy.pdf]. (Accessed: 23rd May, 2012).

NHMRC (National Health and Medical Research Council). “Australian Drinking Water.” (2004).

RISC (Resources Information Standards Committee). 1998. Guidelines for interpreting water quality data. Province of British Columbia. [http://www.ilmb.gov.bc.ca/risc/pubs/aquatic/interp/interp-01.htm]. (Accessed: 27th July, 2013).

Schenk, R. U, Bjorksten, J., and Yeager, L. “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).

Scott, R. and Waller, D. "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).

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

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

Spinks, A. T., Coombes, P., Dunstan, R. H. and Kuczera, G. " Water quality treatment processes in domestic rainwater harvesting systems." In: Proceedings of the 28th International Hydrology and Water Resources Symposium, Wollongong, Australia, 10–14 November 2003.

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

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

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

Thomas, J. F. "Industrial water resources of Canada". Water Survey Rep. No.1. Scope, Procedure, and Interpretation of Survey Studies. Quen's Printer, Ottawa (1953).

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).

Thomas, T. H. and Martinson, D. B. "Roofwater Harvesting: A Handbook for Practitioners. Delft." The Netherlands, IRC International Water and Sanitation Centre. Technical Paper Series; No. 49. (2007):160pp.

UN (United Nations). "The Millennium Development Goals Report 2008. [http://mdgs.un.org/unsd/mdg/Resources/Static/Products/Progress2008/MDG_Repo rt_2008_En.pdf%5D. (2008). (Accessed: 2nd May, 2012).

USEPA (United States Environmental Protection Agency Report).(2006): 3-11pp.

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

Watkins, C., Raftery, J. and Schaden, C. "Parameters for rainwater quality testing at Isla Urbana and the Ajusco Lab." [http://www.appropedia.org/Parameters_for_rainwater_quality_testing_at_Isla_Urbana_and_the_Ajusco_Lab%5D. (Accessed: 29th May, 2012h).

WHO (World Health Organization) "Guidelines for Drinking-Water Quality." 4th Ed. Geneva, Switzerland (2011): 1-564pp. ISBN 978 92 4 154815 1.

Yaziz, M. I., Gunting, H., Sapri, N. and Ghazali, A. W. "Variations in rainwater quality from roof catchments." Water Research 23.6 (1989): 761-765pp.