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Impact of Household Storage Tanks and Practices on Quality of Rainwater Stored in Central Gonja District, Ghana

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ABSTRACT

The containers for storing rainwater and storage practices can be a source of contamination to the water stored and this has become a major concern. This study focused on the impact of household storage tank and practices on the quality of rainwater stored in Central Gonja District of northern Ghana. A baseline study was conducted in households to know the types of storage tanks and sanitation practices in the study area. Sixty-three (63) rainwater samples were collected from plastic, metal and concrete tanks within three (3) months of storage including water from entry points of the tanks. The samples were analysed in the laboratory for pH, total alkalinity, electrical conductivity, turbidity, total hardness, nitrate, iron, and faecal coliform. The results showed that plastic and concrete tanks were generally within WHO recommendations for drinking water for most of the parameters measured except for faecal coliform. The results also showed that faecal contamination of rainwater stored was the result poor storage and sanitation practices on the part of households. The results also showed that the type of storage material has direct impact more on the physico-chemical quality of rainwater stored and care must be taken in the use of metal tanks for rainwater storage.

Keywords: *Rainwater, plastic, metal, concrete, storage*

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I. Introduction

Water is life and a valuable natural resource that sustains the environment and supports livelihood. According to Water Research Institute (WRI, 2000) more than 1 billion people in developing countries do not have access to clean water whilst 2 billion lack adequate sanitation.

In Ghana, 22 % of the population and over 30 % of the rural population lack access to safe drinking water (Allison, 2007). In rural Ghana, people depend on rivers, streams, hand dug-wells and rainwater for their water needs. 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. 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). Many households store rainwater harvested in pots, drums, plastic, metal and concrete tanks for future use and aid self-sufficiency of water. However, 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). In addition, storage tank materials can impact on the quality of water stored. For instance, high concentrations of heavy metal ions in storage tanks could be significant if corrosion is evident, and when the tank has not been cleaned for a long time (Ziadat, 2005). High levels of heavy metals such as Fe^{2+} can be toxic to humans if it exceeds certain concentrations. Concrete tank consist of a cement binder in which an inert aggregate is embedded. However, cement contains a variety of metal ions which can leach into the water stored. Pier and Bang (1980) indicated that high concentrations of trace metals in drinking water can cause cancer, sudden infant death and cardiovascular syndrome.

The growing interest in rainwater harvesting has necessitated research to investigate the impact of household storage tank and practices on the quality of rainwater stored in the Central Gonja district.

II. Methodology

2.1 Study area

Central Gonja district lies between longitude 1^o 5' and 2^o 58' West and latitude 8^o 32' and 10^o 2' North. The landmass is 8,353 km^2 with major towns as Buipe, Mpaha and Yapei (Dickson and Benneh, 2004). These towns were chosen for the study because they constitute the largest population in the district. According to the provisional results of the 2010 Ghana Population and Housing Census (PHC) the population of the district stood at 95,493 with annual growth rate of 3.1 % Ghana Statistical Service (GSS, 2011). The mean annual rainfall is 1200 mm and daily temperature between 18 - 42 °C (Dickson and Benneh, 2004). The mean annual rainfall is 1200 mm and daily temperature between 18 - 42 °C (Dickson and Benneh, 2004). The main sources of water are boreholes, rivers, dams, hand dug-wells and harvested rainwater. Agriculture is the main occupation of the inhabitants of the district.

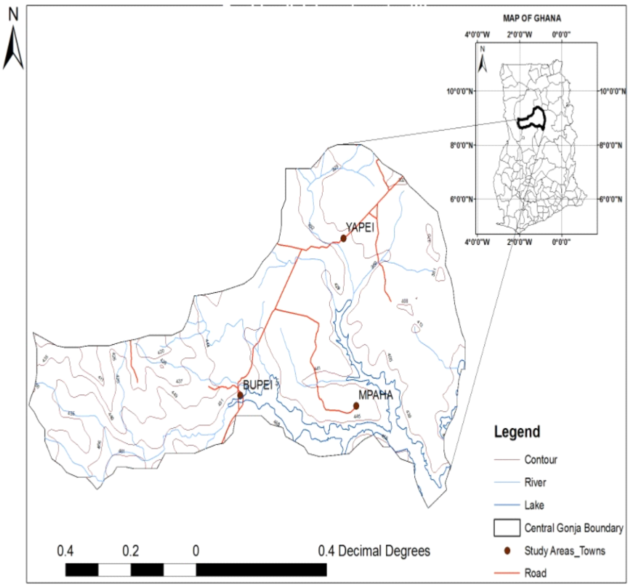

Fig. 2.1: Map of study area showing sample towns (Source: Adapted from Ghana map)

2.2 Sampling

The water sampling was carried out in Buipe, Mpaha and Yapei, which are small towns in the Central Gonja district. In order to eliminate or minimise potential contamination of the samples, the 1.5 litre plastic bottles were soaked in 0.1 M nitric acid (HNO_3) overnight, washed with distilled water, rinsed with deionised water and dried in a drying cabinet. Some of the dry bottles were selected, filled with distilled water of pH 6.3 and the pH tested immediately, when it is 7.0 then it was ready for use otherwise, the bottle was washed and the pH tested again. This served as quality control (Anon, 1992). The Sample containers were clearly labeled with the site, date and time of sampling on the bottles. At the household level, rainwater samples were collected from the entry points (rainwater samples collected before it has entered the storage tank) of plastic, metal and concrete tanks in the wet season. Nine water samples were collected from the entry points of the tanks whilst 18 water samples were collected from plastic, metal and concrete tanks were collected every 2 weeks for 12 weeks (August to October, 2012). The basis for adopting this regime of water sampling is that water stored for more than two weeks tends to deteriorates in quality (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.

2.3 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).

2.3.1 Water pH

The pH of water samples was determined immediately after sampling using Fisherbrand Hydrus 100 pH Meter. Before the measurement were taken, a manual three buffer solutions of pH 4.01, 7.0, and 9.2 were used to calibrate the pH meter. The CALCULATE key was pressed to calibrate and the automatic calibration procedure was followed. The pH of the samples was measured by reading the values that displayed on the screen after the READY signal has disappeared.

2.3.2 Total alkalinity

50 ml sample was measured into a conical flask. Two drops of methyl orange indicator was added and the resulting mixture titrated against 0.1 M HCl standard solution to the first permanent pink colour at pH 4.5.
Calculation:

$$\text{TA}\ (\text{CaCO}_3) = \frac{A \times N}{V_s} \times 5000 \qquad [1.1]$$

Where;
TA: Total Alkalinity (mg/l)
V_s: Volume of sample (l)
A: Volume of acid (l)
N: Normality of acid (l)

2.3.3 Electrical conductivity

The Hi 9032 Microprocessor Bench Conductivity Meter was calibrated by pressing the TDS key to display '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 a data sheet. The plastic and concrete tanks were covered fitted with taps whilst metal tanks were mostly uncovered. Generally, most of the containers for fetching water from the storage tank were not protected from children, hence were seen lying on the floor.

2.3.4 Turbidity

The Turbidity meter was first calibrated using Formazin polymer. The water samples were allowed to come to room temperature and thoroughly mixed to disperse the solids. After the air bubbles have disappeared, the samples were poured into the turbidimeter tube and the turbidity value was read directly from the scale in Nephelometric Turbidity Units (NTU).

2.3.5 Total hardness

25 ml of the well-mixed water sample was measured into a conical flask. 2.0 ml of buffer solution and a pinch of Eriochrome black were added. If the sample turned into wine red in colour, 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.
Calculation:

$$\text{TH} = \frac{(A-B)}{C} \times 1000 \qquad [1.2]$$

Where;
TH: Total Hardness (mg/l)
A: Volume of EDTA for sample (ml),
B: Volume of EDTA for blank (ml)
C: Volume of water sample (ml).

2.3.6 Nitrate

An aliquot of 2 ml of 0.1 M NaOH solution and 1.0 ml of naphthyl-1, 1-amide (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.

2.3.7 Iron

250 ml of the samples was filtered through 0.45 µm cellulose membrane filter paper and digested by adding 20 ml each of concentrated HN_3 to 200 ml samples and heated till the volume decreased to 50 ml. The samples were filtered and analyzed for iron using the flame Atomic Absorption Spectrophotometer (AAS).

2.3.8 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. 250 ml of the sample was measured into 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:

$$FC = \frac{C_C}{V_f} \times 100 \qquad [2.3]$$

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

2.4 Data analysis

The mean values of parameters were computed using Microsoft Excel software. Two replicates were made and 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 drinking water guidelines.

III. Results

3.1 Water pH

Figure 3.1 show that, water from entry point had mean pH value of 6.4. The mean pH (6.4) of water from plastic tank remained unchanged from the entry point water after 12 weeks. Water from metal tank had mean pH of 5.4 which decreased significantly (0.362, P<0.05) from the entry point water after 12 weeks. The mean pH (8.6) of water from concrete tank increased significantly (2.02, P<0.05) from the entry point water after 12 weeks.

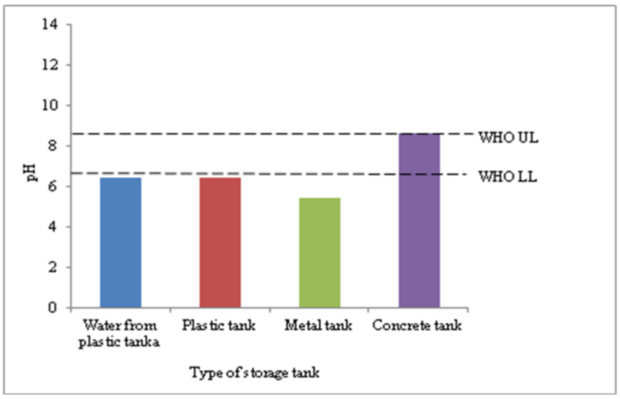

Fig. 3.1: Comparison of storage tanks in terms of water pH
***WHOLL: WHO Lower Limit**
WHOUP: WHO Upper Limit

3.2 Total alkalinity

As illustrated in fig.3.2, the mean total alkalinity for the entry point water was 6.5 mg/l. Water from plastic tank had mean total alkalinity of 6.5 mg/l which was not significantly different (0.477, P<0.05) from the entry point water after 12 weeks. The mean total alkalinity (3.3 mg/l) of water from metal tank decreased significantly (0.491, P<0.05) from the entry point water after 12 weeks. Water from concrete tank had mean total alkalinity of 20.5 mg/l which was significantly different (3.723, P<0.05) from the entry point water after 12 weeks.

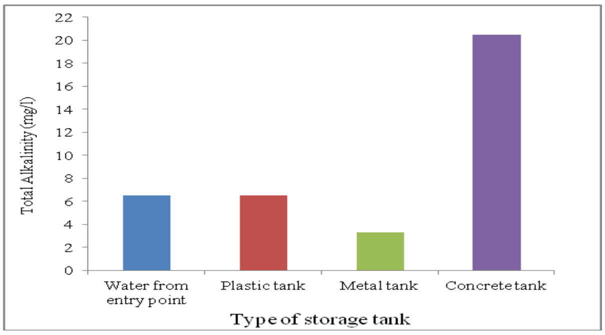

Fig. 3.2: Comparison of storage tanks in terms of water total alkalinity

3.3 Electrical Conductivity

In fig 3.3, the entry point water had mean conductivity of 170 µS/cm. Water from plastic tank had mean conductivity of 168 µS/cm which was not significantly different (0.653, P<0.05) from the entry point water after 12 weeks. Metal tank had mean conductivity of 184.33 µS/cm which was significantly different (2.533, P<0.05) from the entry point water after 12 weeks. Water from concrete tank had mean conductivity of 153.13 µS/cm. Significant difference (5.801, P<0.05) was found between water from concrete tank and the entry point water after 12 weeks of storage.

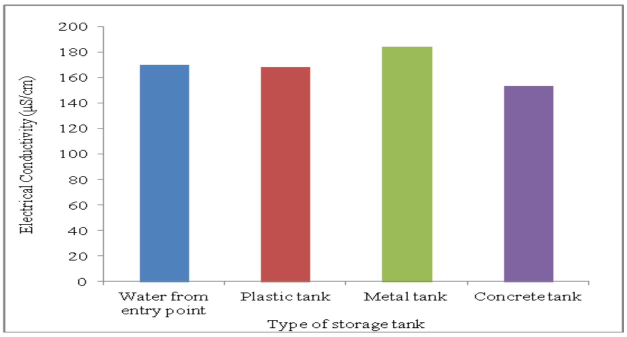

Fig. 3.3: Comparison of storage tanks in terms of water electrical conductivity

3.4 Turbidity

As shown in fig. 3.4, the entry point water had mean turbidity of 9.41 NTU. Mean turbidity of water from plastic tank was 6.88 NTU which was not significantly different (0.962, P<0.05) compared to the entry point water after 12 weeks. After 12 weeks of storage, water from metal tank had mean turbidity of 18.88 NTU which was significantly different (2.503, P<0.05) from the entry point 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.

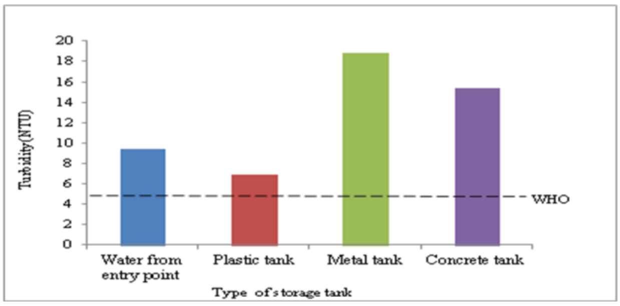

Fig. 3.4: Comparison of storage tanks in terms of water turbidity

3.5 Nitrate

In terms of nitrate concentration, as in fig.3.5, mean value at the entry point water was 5.15 mg/l. Water from plastic tank had mean nitrate concentration of 4.6 mg/l which was not significantly different (0.25, P<0.05) from the entry point water after 12 weeks. Mean nitrate concentration (12.53 mg/l) of water from metal tank was considerably significant (1.968, P<0.05) compared to the entry point water after 12 weeks of storage. weeks. However, mean concentration of nitrate (11.85 mg/l) of the water from concrete tank was significantly different (2.78, P<0.05) from the entry point water after 12 weeks.

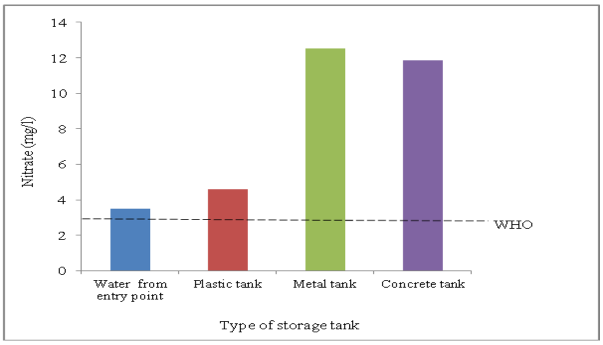

Fig. 3.5: Comparison of storage tanks in terms of water nitrate

3.6 Total Hardness

The results of total hardness as shown in fig.3.6 revealed that, the mean values of entry point water and water from plastic tank were the same, i.e.1.82 mg/l. Nonetheless, water from metal tank had mean total hardness of 6.53 mg/l which was significantly different (1.464, $P<0.05$) from the entry point water after 12 weeks. The mean total hardness of water from concrete tank was 10.52 mg/l which was also significantly different (2.79, $P<0.05$) from the entry point water after 12 weeks of storage.

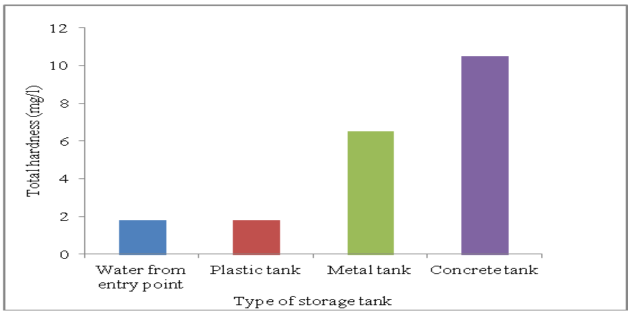

Fig. 3.6: Comparison of storage tanks in terms of water total hardness

3.7 Iron

As indicated in fig. 3.6, mean iron concentration of entry point water was 0.72 mg/l. Water from plastic tank had mean iron concentration of 0.68 mg/l which was not significantly different (0.013, $P<0.05$) from the entry point water. Water from metal tank after 12 weeks had mean iron concentration of 3.4 mg/l which was significantly different (1.990, $P<0.05$) from the entry point water. Water from concrete tank had mean iron concentration of 1.23 mg/l which was not significantly different (0.135, $P<0.05$) from the entry point water after 12 weeks.

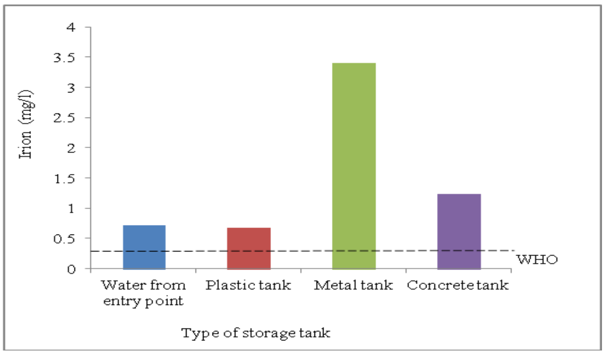

Fig. 3.7: Comparison of storage tanks in terms of water iron

3.8 Faecal coliform

As in figure 3.8, the entry point water had mean count of 6.1 cfu/100. The mean faecal coliform count for plastic tank was 20.11 cfu/100 ml which was significantly different (3.733, $P<0.05$) from the entry point water. The mean faecal coliform count (67.33 cfu/100ml) for water from metal tank was significantly different (7.32, $P<0.05$) from the entry point water after 12 weeks. Water from concrete tank had mean faecal coliform counts of 32.4 cfu/100ml, which was significantly different (24.55, $P<0.05$) from the entry point water after 12 weeks of storage.

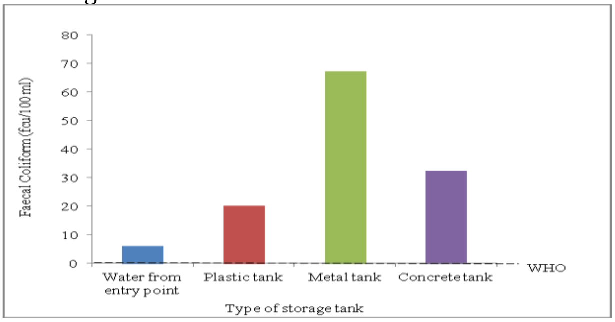

Fig. 3.8: Comparison of storage tanks in terms of water iron

IV. Discussion

4.1 Entry point water

The pH of entry point water was slightly acidic, and remained the same as pH of water from plastic tank as in figure 3.1.

The total alkalinity for the water from entry point was low. The water from entry point 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 (Apiah, 2008).

The conductivity of entry point water was relatively high. This may be the result of absorption of heat by the Aluminium roofing sheets material including the dry depositions of NO_3^-, SO_4^{-2}, PO_4^- ions from farming (Apiah, 2008).

Turbidity of the entry point water can be attributed to particulate matter in the atmosphere that dissolves in rainwater as it falls. The presence of particulates in the atmosphere and on the roofs are factors that can increase the turbidity of rainwater collected (Kohler *et al.*, 1997).

The nitrate concentration of entry point water may have resulted from the presence of organic materials such as leaves and bird droppings on the roof catchment. Forster (1999) established that the presence of nitrates in roof run-offs may be due to bird faeces deposited on the roof.

Total hardness of entry point water was the result of dry atmospheric deposition of particulate matter on the roof catchment. Total hardness of water from plastic tank remained the same as the entry point water after 12 weeks.

The slightly acidic rainwater can enhance corrosion of the aluminium roofs which might have incorporated iron particles into the entry point water. Ayenimo *et al.* (2006) found that aluminium roofs to a large extent contribute to iron concentrations in rainwater harvested.

The presence of faecal coliform in entry point water may be the result of contact of rainwater with the roof catchment and gutters. Rainwater harvested from roofs may contain animal and bird faeces, mosses and lichens which are sources of bacterial contamination (Kohler *et al.*, 1997).

4.2 Plastic tank

The pH of water from plastic tank was slightly acidic and within WHO acceptable range after 12 weeks of storage (figure 3.1). Plastic materials are chemically unreactive, and did not alter the pH and total alkalinity of rainwater stored. However, the slightly acidic water from plastic tank can react with the copper taps installed in the tank to give a blue stain. The blue stain ($CuSO_4$) is the reaction product between the slightly acidic rainwater and the copper tap. Rainwater with a lower pH value stored in plastic containers remains naturally acidic and can react with copper taps (TWDB, 2005).

Plastic tank material did not affect the conductivity and turbidity of the water stored. However, the conductivity and turbidity of rainwater stored in plastic tank may be the result of dry deposition of ions from the atmosphere on the aluminium roofs.

Plastic tank did not contribute to the build-up of nitrates and total hardness in the rainwater stored. The absence of basic sanitation, as well as dropping of food particles by children, since the tanks were not properly covered may have contributed significantly to the nitrate levels of the rainwater stored. Jussara *et al.* (2005) observed that lack of proper water handling and storage practices can result in high nitrate concentrations in storage tanks. 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.

Plastic tank material did not contribute to iron concentration of the rainwater stored. However, iron particles in water from plastic tank came from reaction of the slightly acidic rainwater with the aluminium roofing materials causing particles of iron to leach into the rainwater stored.

Faecal contamination of water from plastic tank may be the result of the accumulation of sediments after several periods of rainwater collection and storage without cleaning. Tambekar (2004) observed that inadequate cleaning of storage vessels leads to the accumulation of sediments and pathogens.

4.3 Metal tank

The pH of water from metal tank decreased significantly which was below WHO lower limit value of 6.5 after 12 weeks. The low pH in metal tanks might be the result of increase in metabolic activities due to increased micro-organisms population. This is confirmed by high faecal coliform count observed in water from metal tank. Popoola *et al.* (2007) established that the build-up of metabolites from micro-organisms in storage tanks can result in lowering pH values. Most of the metal tanks are constructed with ferromagnetic material (iron and nickel). The slightly acidic rainwater stored can facilitate the precipitation of Fe^{2+} due to chemical reaction with the metal tank material (Ziadat, 2005).

The total alkalinity of water from metal tank was reduced significantly after 12 weeks of storage. The increase in metabolic activities of micro-organisms such as bacteria that produces CO_2 which may have lowered the concentration of H^+ ions, thereby the total alkalinity of water from metal tank.

The conductivity of water from metal tank was higher than the entry point water but within WHO acceptable level after 12 weeks. 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. Additionally, 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.

Turbidity of water stored in metal tank was higher than that of the entry point water and above the WHO guideline value of 5 NTU. In corroded metal tanks, the release of metallic ions such as Fe^{2+} can change the colour of the water stored into ferric brown. The resuspension of accumulated sediments such as silt and food particles at the bottom of the metal tank from the surroundings and roof-tops can also increase the turbidity of the water stored when fetching water with usually cups, calabash or bowls.

The nitrate concentration of water stored in metal may be the result of lack of basic sanitation and proper water handling practices similarly found by Jussara *et al.* (2005). However, the presence of nitrate can provide nutrients that can facilitate the growth of biological organisms in the tanks and this must not be promoted or encouraged.

Total hardness of water from metal tank was higher than the entry point water and within WHO guideline value (500 mg/l) after 12 weeks. Since the metal 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.
The slightly acidic rainwater may have reacted with the metal tank material and facilitated the precipitation of Fe^{2+} which was above WHO guideline value of 0.3 mg/l. Ziadat (2005) indicated 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. 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).

The means of water withdrawal from metal tanks was by dipping cups, calabash and bowls into the water which can result in faecal contamination of water from metal tank. Theses containers for fetching water from storage tanks were mostly found lying on the ground as children may have played with. Trevett *et al.* (2004) confirms the finding that dipping of contaminated cups into storage tanks can introduce faecal matter into stored water. Additionally, the activities of children can introduce substances into the tank which lead to build-up of nutrient at the base of the tank, especially when they play around uncovered storage tanks in the house.

4.2 Concrete tank

The relatively high pH and total alkalinity of water from concrete tank may have been caused by the leaching of alkaline substances such as carbonates in the concrete. However, high pH may impart undesirable taste to water.

The conductivity of water from concrete tank fell within the WHO guideline value but was higher than the *entry point water* after 12 weeks. Eroding of construction materials, for instance $CaCO_3$, and other inorganic particles from the tank walls can increase the conductivity of water stored. This may have contributed to high turbidity of concrete water which was above the 5 NTU.

The nitrate concentration of water from concrete tank may be the result of lack of basic sanitation and proper water handling practices similarly found by Jussara *et al.* (2005). However, the presence of nitrate can provide nutrients that can facilitate the growth of biological organisms in the tanks and this must not be promoted or encouraged.

Total hardness of water from concrete tank was below WHO guideline value (500 mg/l) after 12 weeks. The low total hardness concentration may be ascribed to leaching of $CaCO_3$ and other substances from the construction materials into the water stored. The leaching of $CaCO_3$ from the concrete tanks can increase the total hardness of the water stored (Lundgren and Akerberg, 2006).

The leaching of the construction materials, for instance lateritic sand from the wall of concrete tank wall may have released iron particles into the water stored. This suggest that iron contamination of the water stored in concrete tank was to a large extent the result of dissolution of iron from the iron roofs and dissolution from the wall of the tank as confirmed by Ayenimo *et al*. (2006) and Ziadat (2005).

Faecal coliform in water from concrete tank may have resulted from the accumulation of sediments and pathogens at the bottom of tank, since users did not clean their tanks for a long time. Inadequate cleaning of storage tanks leads to the accumulation of sediments and pathogens (Tambekar and Banginwar, 2004).

V. Conclusion

The results showed that except for conductivity, plastic tanks had lower values of pH, total alkalinity, turbidity, nitrate and total hardness which fell within the WHO guideline for drinking water. The pH, total alkalinity, total hardness and iron was high whilst conductivity, turbidity and nitrate levels fell below the guideline values in metal tanks. It observed that concrete tanks resulted in high pH, total alkalinity, and total hardness of stored rainwater. Faecal contamination of water stored 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. Faecal contamination of the water stored was the result bad storage practices on the part of households.

VI. Acknowledgement

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