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# An Assessment of the Quality of Rainwater Harvested Using Rooftop Rainwater Harvesting (RWH) Technologies in Swaziland

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## Abstract

Rooftop rainwater harvesting is the interception of rainwater from rooftop catchments and storing it in surface or subsurface reservoirs. Rainfall is pure and clean when it is released from the clouds but it is polluted upon reaching the atmosphere and the intercepting surface. An experiment was designed to determine the water quality of the rooftop RWH technologies studied. There were five treatments with two replications. The treatments were CPP, CFP, TPP, CMC and CB. The WHO drinking water quality guidelines were used as a control. The water quality parameters investigated were physical, chemical and biological. The rainwater samples were tested at the Swaziland Water Services Cooperation laboratory and data were analyzed using one-way ANOVA utilizing SPSS computer software (version 20). The results reflected that the mean physical parameters of the rainwater harvested from the CPP, CFP, TPP, CMC and CB were 6.90, 6.76, .16, 6.57 and 7.05 for pH, respectively; 3.0 NTU, 2.0 NTU, 2.5 NTU, 4.0 NTU and 9.5 NTU for turbidity, respectively and 16.0 mg/L, 11.5 mg/l, 10.5 mg/L, 21.5 mg/L, and 14.0 mg/L, for colour, respectively). The mean chemical parameters i.e. zinc, fluoride, aluminium and sulphate were 2.04 mg/L, 0.16 mg/L, 0.0218 mg/L and 1.1 mg/L, respectively. The bacteriological quality results i.e. total and faecal coliforms had means of 129 counts per 100 ml and 21 counts per 100 ml, respectively. It was concluded that the quality of the rainwater harvested from the rooftop RWH technologies studied was polluted with faecal matter, hence not fit for domestic use without treatment. However, it was also concluded that with the exception of turbidity and colour, the physical water quality of the rainwater harvested from the rooftop RWH technologies was acceptable for domestic use.

## Keywords

Rooftop, Rainwater, Harvesting, Technologies, Swaziland

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## 1. Introduction

Population growth and the expansion of urban and industrialized areas have put great pressure on water resources (Luizzo *et al*, 2016). Climate change will intensify this pressure in some parts of the world, including the Mediterranean basin, Western United States and Southern Africa, resulting in a predicted decrease in water resources in the coming decades (EPA, 2017; Bates *et al*, 2008). A number of initiatives and interventions have been put in place by countries to address water shortages. These include dam and reservoir construction and water harvesting from land as well as roof catchments, including rooftop rainwater harvesting, to mention but a few. Rainwater harvesting (RWH) is the most popular alternative water source in many urban, peri-urban, and rural areas (Rahman, 2017). Work by Sultana *et al* (2015) concluded that among the solutions to the scarcity of water, rooftop rainwater harvesting is one of the best proposed solutions for urban and rural areas.

Rooftop rainwater harvesting is the interception of rainwater

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from rooftop catchments and storing it in surface or subsurface reservoirs. The interception of rainwater before it reaches the ground has the advantage that the water maybe collected without many contaminants and may be utilized for domestic use. Rainwater harvesting (RWH) and utilisation systems have been used since ancient times and evidence of roof catchment systems dates back to early Roman times. Throughout history archaeological evidence has revealed RWH sites that were implemented in Jordan, the Al-Negev desert, Syria, Tunisia and Iraq (Ali *et al*, 2016).

In Swaziland urban areas are supplied with water by the Swaziland Water Services Corporation (SWSC) while people in rural areas rely on rivers, dams, boreholes and rainwater for water supply and most recently, community based rural water supply schemes. Rainwater harvesting is practiced more in the drier Lowveld of Swaziland with 31.1% of the households using rooftop catchment materials made from corrugated iron sheets (Vilane and Mwendera, 2011). According to Ayob and Rahmat (2017) rooftop rainwater harvesting is the best and cost effective method of obtaining clean and safer water for drinking purposes in rural areas. However, the type and quality of rooftops affects the quality of the harvested rainwater. This was evident by Sultana *et al*. (2017) who concluded that the quality of the harvested rainwater basically depends on the type of roofing materials, the climatic conditions of the local area and the levels of atmospheric pollution.

Rooftop rainwater harvesting is ideal for domestic use because rainfall is pure and clean when it is released from the clouds but it is polluted upon reaching the atmosphere and the intercepting surface. However, water harvested from rooftops may have chemical, biological and physical contaminants. These contaminants come from the air that raindrops traverse before hitting the roof (Walker-Scott, Undated; Abbasi and Abbasi, 2011). Studies have revealed that the physico-chemical characteristics of rainwater harvested from rooftop catchments meets drinking water quality guidelines (Igbinosa and Aighewi, 2017; Vilane and Mtshali, 2015; Ghanayem, 2001; Pushpangadan *et al*., 2001). The technologies used to harvest rainwater from rooftop catchments may influence the quality of the water. Metal roofs under the atmospheric corrosion become sources of heavy metals, which affect water quality (Stewart *et al*, 2016). The effectiveness of storage tanks for preserving water quality depends on preventing sunlight, organic matter and macro-organisms from entering the tank (Issaka *et al*, 2015). Corroded metal tanks may contain high levels of heavy metals such as iron, which can be toxic to humans**.** Zinc, iron and copper levels were found to be high in rainwater stored in metal tanks with low pH (pH<5) compared to plastic tanks (Stewart *et al*, 2016; Achadu *et al*., 2013).

Rooftop rainwater harvesting systems or technologies include three components; the catchment area (roof), conveyance (gutter and down pipe) and storage facilities (above or below ground storage tanks). All these components are sources of pollution to the RWH system or technology, which should be investigated because they may result in the harvested rainwater being unsafe for domestic use, hence this study.

*0bjectives*

i. To assess the physical quality (pH, turbidity and colour) of the rooftop rainwater harvested from rooftop RWH technologies.
ii. To determine the chemical quality (zinc, fluoride, aluminium and sulphates) of the rooftop rainwater harvested from rooftop RWH technologies.
iii. To determine the biological quality (faecal coliforms and total coliforms) of the rooftop rainwater harvested from rooftop RWH technologies.

## 2. Methodology

### 2.1. Description of the Study Area

The study was conducted at KaPhunga, a rural area in the Manzini region of Swaziland. It is located at 26.46202 S and 31.28766 E with an average altitude of 929 m above sea level. KaPhunga receives an annual rainfall of between 850 mm and 1100 mm with a population of approximately 1742 people (Government of Swaziland, 2011). Due to the water scarcity in the area, as a result of climate change, amongst other causes, rooftop rainwater harvesting is practiced as a means of harvesting clean and safe water for domestic use.

### 2.2. Research Design

The research was an experiment with five treatments and two replications. The treatments were based on the rooftop RWH technologies (roof catchment, conveyance and storage) used in the 2016/2017 rain season. These were corrugated iron roof sheets catchment with PVC conveyance (gutters and downpipes) and PVC storage (CPP); corrugated iron roof sheets catchment with fabricated conveyance (metal gutters with 2 L bottles or PVC pipes) and 210 litres PVC storage (CFP); tiles roof catchment with PVC conveyance (gutters and downpipes) and PVC storage tank (TPP); corrugated iron roof sheets catchment with metal conveyance (gutters and downpipes) and concrete storage tank (CMC) and corrugated iron roof sheets catchment, free fall conveyance and 20 Litre storage buckets (CB). The WHO domestic water quality guidelines were used as a control (WHO, 2011).

### 2.3. Sampling Procedure

Sampling was conducted in the morning when the water temperature was still low. Water samples were taken at the top and at the bottom of the rooftop RWH technology storages using the grab sampling technique. This was achieved using two sterilised glass bottles (500 ml and 1 Litre). The 500 ml bottles were used to sample rooftop rainwater that was used for bacteriological and chemical quality analysis, while the 1 Litre bottles were used to take samples for the physical quality analyses. At each sampling site, four bottles (two 500 ml and 1 Litre) were used. A set of 500 ml and 1 Litre bottles were used to sample water at the top of the rain water storages and another set was used to sample at the bottom of the rainwater storages for the technologies studied.

## 2.4. Data Collection and Analysis

### 2.4.1. Physical Quality Analysis Methods

The physical quality analysis involved performing tests for; pH, turbidity and colour as outlined below.

a) pH

The table pH meter was used to measure the pH of the rooftop rainwater. The electrode was immersed in the sample. Readings were taken 20 – 30 seconds after the water readings have stabilized. After each test, the electrode was rinsed with distilled water and wiped dry.

b) Turbidity

The turbidity of the water samples was determined using the absormetric method adopted from the FWPCA methods for chemical analysis of water. A HACH DR6000 spectrophotometer was tuned to a wavelength of 450 nm and 25 ml of the water sample was poured into a sample cell. The sample cell was wiped and inserted into the cell holder. The results were then read from the screen and analysed using SPSS (version 20.0).

c) Colour

The colour of the rooftop rainwater samples was determined using a HACH DR6000 spectrophotometer tuned at 455 nm. 200 ml of the rooftop rainwater sample was collected in a 400 ml beaker. Fifty (50 ml) of deionized rainwater was then filtered through a 0.45 micron membrane filter and filled in a 10 ml sample cell to form a blank. 50 ml of the rainwater sample was filtered through the membrane and filled in a 10 ml sample cell. The sample cell with the blank was wiped, inserted in the cell holder and was used to zero the spectrophotometer. The sample cell with the rainwater sample was wiped, inserted into the cell holder and the results were read from the screen in mg/L Pt-Co.

### 2.4.2. Chemical Quality Analysis Methods

The chemical quality analysis involved preforming tests for zinc, fluoride, aluminium and sulphate using a HACH DR6000 spectrophotometer as outlined next.

a) Zinc

Zinc was tested using the powder pillows method. A 25 ml graduated mixing cylinder was filled with 20 ml of the rooftop rainwater sample in the 500 ml bottle. ZincoVer 5 Reagent Powder Pillow was added to the mixing cylinder and the mixing cylinder was inverted to completely dissolve the powder. Ten (10 ml) of the solution was poured into a sample cell which was used as a blank. A plastic dropper was used to add 0.5 ml of cyclohexanone into the remaining solution in the mixing cylinder. After a three minute reaction, the prepared sample solution from the mixing cylinder was poured into a second sample cell. The blank was wiped and inserted into the cell holder. The spectrophotometer was zeroed and the display showed 0.00 mg/L. The prepared sample was then inserted into the cell holder and the results were read in mg/L.

b) Fluoride

A pipet was used to pour 10 ml of the rooftop rainwater sample into a dry sample cell. Another 10 ml of deionized rainwater was poured into a second dry sample cell using a pipet which formed a blank. Two (2 ml) of SPADNS 2 reagent was added to each cell using a pipet. After a one minute reaction, the blank was inserted into the cell holder and was used to zero the spectrophotometer such that the display showed 0.00 mg/L. The prepared sample was then inserted into the cell holder and the results were read in mg/L.

c) Aluminium

Aluminium was determined using the powder pillows method. A 25 ml mixing cylinder was filled to the 20 ml mark with the rooftop rainwater sample. One ERC reagent powder pillow was added to the mixing cylinder and the mixing cylinder was closed using a stopper and inverted to completely dissolve the powder. After a 30 second reaction period one Hexamethylene tetramine buffer reagent powder pillow was added to the mixing cylinder. 10 ml of the solution from the mixing cylinder was poured into a sample cell and one drop of ECR masking reagent solution was added to the cell to form a blank. Another 10 ml of the solution was poured in a second sample cell. After a five minute reaction period the blank was wiped and inserted into the cell holder and was used to zero the spectrophotometer. The prepared sample cell was also wiped and inserted into the cell holder and the results were read in mg/L $Al^{3+}$.

d) Sulphate

Sulphate was determined using the powder pillows method. A sample cell was filled with 10 ml of the rooftop rainwater sample and one SulfaVer 4 reagent powder pillow was added to the sample cell. Another sample cell was filled with 10 ml of the rainwater sample to form the blank. After a five minute reaction period, the blank was wiped and inserted into the cell holder and used to zero the spectrophotometer. The prepared sample cell was also inserted into the spectrophotometer and the results were read in mg/L $SO_4^{2-}$.

### 2.4.3. Bacteriological Quality Analysis Methods

The bacteriological quality analysis involved performing tests for total and faecal coliforms as outlined below.

a) Total Coliforms

Total coliforms are a large group of bacteria with several similar characteristics. They indicate the presence of other bacteria in water and are more or less related to faecal contaminants. The total coliforms represent the whole group, and it is bacteria that multiply at 37°C. Total coliforms were determined by using reagents, deionized distilled water with a growth medium of 51 g of M-endo ager LES, 25 ml ethanol Abs. and 100 ml of tap water. The media was then boiled. To avoid burning of undissolved media during the process of drying, the media was stirred until it completely dissolved. The media was then allowed to cool to a temperature range between 45 - 50°C and then ±15 ml was dispensed in each of the 47 mm plastic petri dishes. 100 ml of water from 500 ml samples was filtered through a 47 mm filter membrane. The filter membranes were then placed on the petri dishes with the media for all the samples in 500 ml bottles. The petri dishes with the filtrates were placed in an oven placed at constant room temperature for 24 hours. Upon testing using the membrane filtration procedure, where 100 ml of the sample was used, all colonies that had a pink to dark red colour with a metallic surface were counted and the results expressed as total coliforms per 100 ml.

b) Faecal Coliforms

Faecal coliforms are the group of total coliforms that are able to ferment lactose at 44 – 45°C. They include the genus *Escherichia* and, to a lesser extent, species of *klebsiella*, *Enterobactor,* and *Citrobactor.* Out of these organisms, only *E.coli* is considered to be of faecal origin, being present in human faeces, other mammals, and birds in large numbers and rarely if ever, found in water or soil in temperate climates that have not been subjected to faecal pollution.

The analysis of faecal coliforms was done using deionized distilled water with the growth medium being 50 g m-FC broth and 100 ml of water. The broth was boiled with constant stirring being done to avoid burning of the undissolved media. 100 ml of water from 500 ml samples were filtered through a 47 mm filter membrane. The filter membranes were placed on 47 mm petri dishes with the media for all the samples in all the 500 ml bottles. The petri dishes with the filtrates were placed in an oven at 45°C for 24 hours. Upon testing using the filter membrane procedure discussed above, where 100 ml of the sample were used, all colonies that had a blue colour were counted and the results expressed as faecal coliforms per 100 ml.

## 3. Results and Discussion

### 3.1. Physical Water Quality Results

The physical water quality results included pH and turbidity as outlined below.

a) pH

The results indicated that the mean pH of the rooftop rainwater harvested using the CPP, CFP, TPP, CMC and CB RWH technologies were 6.90, 6.76, 6.16, 6.57 and 7.05, respectively (Table 2). The pH levels were within the acceptable WHO water quality guidelines values of 6.5 - 8.0. Water with a low pH has high corrosive levels, which may corrode metal gutters thus leading to the pollution of the harvested rooftop rainwater.

**Table 1.** pH of the rooftop rainwater harvested using different RWH technologies.

| Rainwater harvesting technology | Mean pH | Mean differences |
|---|---|---|
| Corrugated iron sheets catchment, PVC conveyance (gutter and downpipe) and PVC storage tank (CPP) | $6.90^{ac}$ | 0.264 |
| Corrugated iron sheets catchment, fabricated conveyance (metal gutters with 2 Liter bottles or PVC pipes) and 210 Liters PVC storage (CFP) | $6.76^{bc}$ | 0.095 |
| Tiles roof catchments, PVC conveyance (gutter and downpipe) and PVC storage tank (TPP) | $6.16^{abce}$ | -0.661 |
| Corrugated iron sheets, metal gutter with metal downpipe and concrete tank (CMC) | $6.57^{d}$ | -0.149 |
| Corrugated iron sheets catchment, free fall conveyance and 20 Liter storage buckets (CB) | $7.05^{ce}$ | 0.451 |

$^{abcde}$: Cells with similar alphabetical letters have means that are significantly different from each other (P<0.05).

The mean separation test results showed that the mean pH of the rainwater harvested using the rooftop RWH technologies studied were significantly different (P<0.05) from each other. The mean pH of the rooftop rainwater harvested using the TPP (Tiles roof catchments, PVC conveyance and PVC storage tank) was significantly different (P<0.05) from the rainwater harvested using the CPP, CFP and CB rooftop RWH technologies. The mean pH of the rainwater harvested using the CMC (corrugated iron catchment, metal conveyance and concrete storage tank) was not significantly different (P>0.05) from the rainwater harvested using all the other rooftop RWH technologies studied.

b) Turbidity

The results in Table 2 reflected that the turbidity of the rooftop rainwater harvested using the RWH technologies studied ranged from 2.0 NTU - 9.5 NTU. The highest (9.5 NTU) mean turbidity was detected in the rainwater harvested using the corrugated iron sheets catchment, free fall conveyance and 20 Liter storage buckets (CB) rooftop RWH technology.

**Table 2.** Rooftop turbidity in the rainwater harvested using different RWH technologies.

| Rainwater harvesting technology | Mean turbidity (NTU) | Mean differences |
|---|---|---|
| Corrugated iron sheets catchment, PVC conveyance and PVC storage tanks (CPP) | $3.0^{ae}$ | -1.500 |
| Corrugated iron sheets catchment, fabricated conveyance (metal gutters with 2 Liter bottles or PVC pipes) and 210 Liters PVC storage (CFP) | $2.0^{bde}$ | -2.750 |
| Tiles roof catchment, PVC conveyance and PVC storage tank (TPP) | $2.5^{cde}$ | -2.125 |
| Corrugated iron catchment, metal conveyance and concrete storage tank (CMC) | $4.0^{bcde}$ | -0.250 |
| Corrugated iron sheets catchment, free fall conveyance and 20 Liter storage buckets (CB) | $9.5^{abcde}$ | 6.625 |

abcde: Cells with similar alphabetical letters have means that are significantly different from each other (P<0.05).

The mean turbidity levels detected in the rainwater harvested using the CPP, CFP, TPP, CMC and CB rooftop RWH technologies were 3 NTU, 2 NTU, 2.5 NTU, 4 NTU and 9.5 NTU, respectively. The mean turbidity of the rooftop rainwater harvested using all the rooftop RWH technologies were above the WHO water quality guideline of 5 NTU. The high turbidity levels could be attributed to dust, which accumulated on the roof catchment areas during the dry season and then washed into the storage facilities by rainwater during the rainy season.

The results showed that the turbidity of the rainwater harvested using the CB rooftop rainwater harvesting technologies was significantly different (P< 0.05) from the rooftop rainwater harvested using all the other rooftop RWH technologies studied. The rooftop rainwater harvested using the CFP technologies were not significantly different (P> 0.05) from the rooftop rainwater harvested using the CMC (Corrugated iron sheets catchment, metal conveyance and concrete storage tank) technologies. This trend was similar between the rooftop rainwater harvested using the TPP (Tiles catchment, PVC conveyance and PVC storage tank) and the rooftop rainwater harvested using the CMC (Corrugated iron sheets catchment, metal conveyance and concrete storage tank) RWH technologies.

c) Colour

The results in Table 3 reflected that the rainwater harvested using the CPP rainwater harvesting technologies had the highest (16.0 mg/L) mean color concentration. The mean colour of the rainwater harvested from the corrugated iron sheets catchment, PVC conveyance and PVC storage tanks (CPP) RWH technologies was 16.0 mg/L, while it was 11.5 mg/L in the rainwater harvested using the CFP rainwater harvesting technologies. The rainwater harvested using the TPP, CMC and CB rainwater harvesting technologies was 10.5 mg/L, 21.5 mg/L and 14.0 mg/L, respectively. The mean colour of the rainwater harvested using all the rooftop RWH technologies studied were above the WHO water quality guideline (5 mg/L). High levels of color indicate the presence of organic molecules such as peat, leaves and branches in the water.

**Table 3.** Mean colour of rainwater from different RWH technologies.

| Rainwater harvesting technology | Mean color (mg/L) | Mean differences |
|---|---|---|
| Corrugated iron sheets catchment, PVC conveyance and PVC storage tanks (CPP) | $16.0^{abcde}$ | 1.625 |
| Corrugated iron sheets catchment, fabricated conveyance (metal gutters with 2 Liter bottles or PVC pipes) and 210 Liters PVC storage (CFP) | $11.5^{abde}$ | -4.000 |
| Tiles roof catchment, PVC conveyance and PVC storage tank (TPP) | $10.5^{acde}$ | -5.250 |
| Corrugated iron catchment, metal conveyance and concrete storage tank (CMC) | $21.5^{abcde}$ | 8.500 |
| Corrugated iron sheets catchment, free fall conveyance and buckets 20 Liter storage buckets (CB) | $14.0^{abcde}$ | -0.875 |

abcde: Cells with similar alphabetical letters have means that are significantly different from each other (P<0.05).

It was evident from the results that the mean colour of the rainwater harvested using all the rooftop RWH technologies studied were significantly different (P<0.05) from each other with the exception of the rainwater harvested using the TPP and CFP rainwater harvesting technologies. The low colour levels in the rainwater harvested from the CFP and CPP rainwater harvesting technologies indicated lower organic molecules and suspended solids in the rainwater, which may be attributed to the regular cleaning of these storage tanks.

## 3.2. Chemical Water Quality Results

The chemical quality results comprised zinc, fluoride, aluminium and sulphate as detailed below.

a) Zinc

The results indicated that the mean zinc of the rooftop rainwater harvested using the CPP, CMP, TPP, CMC and CB rooftop RWH technologies was 2.65 mg/L, 3.45 mg/L, 1.37 mg/L, 1.43 mg/L and 1.32 mg/L, respectively (Table 4).

**Table 4.** Mean zinc of the rooftop rainwater harvested using different RWH technologies.

| Rainwater harvesting technology | Mean zinc (mg/L) | Mean differences |
|---|---|---|
| Corrugated iron sheets catchment, PVC conveyance and PVC storage tanks (CPP) | $2.65^{abcde}$ | 0.759 |
| Corrugated iron sheets catchment, fabricated conveyance (metal gutters with 2 Liter bottles or PVC pipes) and 210 Liters PVC storage (CFP) | $3.45^{abcde}$ | 1.759 |
| Tiles roof catchment, PVC conveyance and PVC storage tank (TPP) | $1.37^{abc}$ | -0.848 |
| Corrugated iron catchment, metal conveyance and concrete storage tank (CMC) | $1.43^{abde}$ | -0.766 |
| Corrugated iron sheets catchment, free fall conveyance and 20 Liter storage buckets (CB) | $1.32^{abde}$ | -0.904 |

$^{abcde}$: Cells with similar alphabetical letters have means that are significantly different from each other (P<0.05).

The mean zinc of the rainwater harvested using the CPP, CMC, TPP and CB rooftop RWH technologies were below the WHO water quality guideline (3.00 mg/L). However, it is worth noting that the mean zinc of the rainwater harvested using the corrugated iron sheets catchment, fabricated conveyance (metal gutters with 2 Liter bottles or PVC pipes) was above (3.45 mg/L) the WHO water quality guideline (3.00 mg/L). High concentrations of zinc in water cause the water to have a bad taste.

The results indicated that zinc of the rainwater harvested using the various rooftop RWH technologies was significantly different (P<0.05). The rooftop rainwater harvested using the CFP technologies had the highest (3.45 mg/L) mean zinc concentration. The rooftop rainwater harvested using the CFP and CPP rainwater harvesting technologies had zinc that was significantly different (P<0.05) from the rainwater harvested using the other rooftop RWH technologies. The mean zinc between the rainwater harvested using the TPP, CMC and CB rainwater harvesting technologies was not significantly different (P>0.05). According to Golding (2006) major sources of zinc are galvanized surfaces such as metal roofs, metal gutters, fences and guard rails which explain the high concentrations of zinc in the CFP technologies.

b) Fluoride

The results reflected low (0.00 mg/L to 0.72 mg/L) fluoride levels in the rooftop rainwater harvested from all the rooftop RWH technologies studied (Table 5).

**Table 5.** Mean rainwater fluoride in water harvested from different RWH technologies.

| Rainwater harvesting technology | Mean fluoride s (mg/L) | Mean differences |
|---|---|---|
| Corrugated iron sheets catchment, PVC conveyance (gutter and downpipe) and PVC storage tank (CPP) | $0.00^{ac}$ | -0.2050 |
| Corrugated iron sheets catchment, fabricated conveyance (metal gutters with 2 Liter bottles or PVC pipes) and 210 Liters PVC storage (CFP) | $0.00^{bc}$ | -0.2050 |
| Tiles roof catchments, PVC conveyance (gutter and downpipe) and PVC storage tank (TPP) | $0.63^{abcde}$ | 0.5825 |
| Corrugated iron sheets, metal gutter with metal downpipe and concrete tank (CMC) | $0.11^{cd}$ | -0.0675 |
| Corrugated iron sheets catchment, free fall conveyance and 20 Liter storage buckets (CB) | $0.08^{ce}$ | -0.1050 |

$^{abcde}$: Cells with similar alphabetical letters have means that are significantly different from each other (P<0.05).

The mean fluoride in the rooftop rainwater harvested using the CPP, CFP, TPP, CMC and CB RWH technologies was 0.00 mg/L, 0.00 mg/L, 0.63 mg/L, 0.11 mg/L and 0.08 mg/L, respectively. The rooftop rain water harvested using the TPP RWH technologies had the highest (0.63 mg/L) fluoride levels. The fluoride in rainwater harvested uisng all the rooftop RWH technologies studied were below the WHO water quality fluoride guideline value of 1.5 mg/L. The higher fluoride in the rooftop rainwater harvested using the TPP rainwater harvesting technologies may be attributed to the longer water storage in the PVC storage tanks due to the higher storage capacities compared to the other storage facilities. This probably led to the accumulation of fluoride pollutants overtime.

It was evident from the results that the fluoride levels between the rainwater harvested using the different rooftop RWH technologies studied were significantly different (P<0.05). The rooftop rainwater harvested using the TPP rooftop RWH technologies were significantly different (P<0.05) from all the other rainwater harvested using the other rooftop RWH technologies. The rooftop rainwater harvested using the CPP, CFP, and CMC rainwater harvesting technologies were not significantly different (P>0.05) from the rooftop rainwater harvested using the CB rooftop rainwater harvesting technologies.

c) Aluminium

Table 6 indicated that aluminium was present in the rooftop rainwater harvested using only four of the five rooftop RWH technologies studied. The mean aluminium ranged from 0.000 mg/L to 0.046 mg/L. The mean aluminium concentration of the rainwater from all the rooftop RWH technologies was below the WHO water quality guideline value of 0.1 mg/L.

The mean separation test results indicated that the aluminium level was significantly different (P<0.05) between the rooftop rainwater harvested using the rooftop RWH technologies studied. However, the rooftop rainwater harvested using the CPP and CFP rainwater harvesting technologies were not significantly different (P>0.05), but were both significantly different (P<0.05) from the rooftop rainwater harvested using the TPP, CMC and CB rooftop RWH technologies. The rooftop rainwater harvested via the TPP and CMC rooftop RWH technologies were not significantly different (P>0.05). The corrugated iron sheets catchment, free fall conveyance and 20 Liter storage buckets (CB) RWH technologies had harvested rainwater with aluminium that was significantly different (P<0.05) from the rainwater harvested using all the other rooftop RWH technologies.

**Table 6.** Mean aluminium of the rainwater harvested using different RWH technologies.

| Rainwater harvesting technology | Mean aluminium (mg/L) | Mean differences |
|---|---|---|
| Corrugated iron sheets catchment, PVC conveyance (gutter and downpipe) and PVC storage tank (CPP) | $0.044^{acde}$ | 0.0131 |
| Corrugated iron sheets catchment, fabricated conveyance (metal gutters with 2 Liter bottles or PVC pipes) and 210 Liters PVC storage (CFP) | $0.046^{bcde}$ | 0.0305 |
| Tiles roof catchments, PVC conveyance (gutter and downpipe) and PVC storage tank (TPP) | $0.000^{abce}$ | -0.0270 |
| Corrugated iron sheets, metal gutter with metal downpipe and concrete tank (CMC) | $0.004^{abde}$ | -0.0244 |
| Corrugated iron sheets catchment, free fall conveyance and 20 Liter storage buckets (CB) | $0.015^{abcde}$ | -0.0083 |

$^{abcde}$: Cells with similar alphabetical letters have means that are significantly different from each other (P<0.05).

d) Sulphate

The results showed that the sulphate in the rooftop rainwater harvested using the rooftop RWH technologies studied ranged from 0 mg/L in the rainwater harvested using the CFP RWH technologies to 2.5 mg/L in the rainwater harvested from the CMC rooftop rainwater harvesting technologies (Table 7). All the rooftop rainwater harvested using the RWH technologies had a mean sulphate that was below the WHO water quality guideline (250 mg/L). The sulphate in the rooftop rainwater harvested using the various rooftop RWH technologies were significantly different (P<0.05). The mean sulphate of the rooftop rainwater harvested using the CMC, CPP, and CFP rooftop rainwater harvesting technologies was significantly different (P<0.05) from the rooftop rainwater harvested using the TPP rainwater harvesting technologies. This trend was also observed with the mean sulphate between the rooftop rainwater harvested using the CB rainwater harvesting technologies and the rooftop rainwater harvested using the CFP rooftop rainwater harvesting technologies.

**Table 7.** Mean sulphate of the rainwater harvested using different RWH technologies.

| Rainwater harvesting technology | Mean sulphate (mg/L) | Mean differences |
|---|---|---|
| Corrugated iron sheets catchment, PVC conveyance (gutter and downpipe) and PVC storage tank (CPP) | $1.0^{ad}$ | 0.500 |
| Corrugated iron sheets, fabricated conveyance and PVC drums Corrugated iron sheets catchment, fabricated conveyance (metal gutters with 2 Liter bottles or PVC pipes) and 210 Liters PVC storage (CFP) | $0.0^{bde}$ | -1.375 |
| Tiles roof catchments, PVC conveyance (gutter and downpipe) and PVC storage tank (TPP) | $0.5^{cd}$ | -0.750 |
| Corrugated iron sheets, metal conveyance (gutter and downpipe) and concrete tank (CMC) | $2.5^{abcd}$ | 1.750 |
| Corrugated iron sheets catchment, free fall conveyance and 20 Liter storage buckets (CB) | $1.5^{be}$ | 0.500 |

$^{abcde}$: Cells with similar alphabetical letters have means that are significantly different from each other (P<0.05).

### 3.3. Microbiological Water Quality Results

The microbiological water quality results included total coliforms and faecal coliforms as reflected next.

a) Total coliforms

The results revealed the presence of total coliforms in all the rooftop rainwater harvested using the different RWH technologies studied (Table 8). The mean total coliforms in the rooftop rainwater harvested using the CPP rainwater harvesting technologies was 203 counts per 100 ml, while it was 120 counts per 100 ml in the rooftop rainwater harvested using the CFP rooftop rainwater harvesting technologies. The rooftop rainwater harvested using the TPP, CMC and CB technologies was 130, 69 and 120 counts per 100 ml, respectively.

**Table 8.** Mean total coliform of the rainwater harvested using different RWH technologies.

| Rainwater harvesting technology | Mean total coliform (counts per 100 ml) | Mean differences |
|---|---|---|
| Corrugated iron sheets catchment, PVC conveyance (gutter and downpipe) and PVC storage tank (CPP) | $203^{abcde}$ | 93.375 |
| Corrugated iron sheets catchment, fabricated conveyance (metal gutters with 2 L bottles or PVC pipes) and 210 Liters PVC storage (CFP) | $120^{abcde}$ | -11.000 |
| Tiles roof catchments, PVC conveyance (gutter and downpipe) and PVC storage tank (TPP) | $130^{abcde}$ | 2.125 |
| Corrugated iron sheets, metal conveyance (gutter and downpipe) and concrete tank (CMC) | $69^{abcde}$ | -74.000 |
| Corrugated iron sheets catchment, free fall conveyance and 20 Liter storage buckets (CB) | $120^{acde}$ | -10.375 |

$^{abcde}$: Cells with similar alphabetical letters have means that are significantly different from each other (P<0.05).

The rooftop rainwater harvested using all the RWH technologies was above the WHO water quality guideline value of 0 counts per 100 ml. The highest (203 counts per 100 ml) total coliforms were detected from the CPP rainwater harvesting technologies, and the lowest (69 counts per 100 ml) was from the CB rooftop rainwater harvesting technologies. The high pollution of the CB sources may be birds, which defecate on the roof catchment and dust that is washed by rain during the rainy season into the storage together with the harvested rainwater.

The results indicated that the total coliforms in the rooftop rainwater harvested was significantly different (P<0.05) between the rainwater harvested using the RWH technologies studied. However, the rooftop rainwater harvested using the CFP technologies was not significantly (P>0.05) different from that harvested using the CB rooftop rainwater harvesting technologies.

b) Faecal coliforms

The results in Table 9 indicated that faecal coliforms were detected in all the rooftop rainwater harvested using the RWH technologies studied.

**Table 9.** Mean faecal coliforms of the rainwater harvested using RWH technologies.

| Rainwater harvesting technology | Mean faecal coliforms (counts per 100 ml) | Mean differences |
|---|---|---|
| Corrugated iron sheets catchment, PVC conveyance (gutter and downpipe) and PVC storage tank (CPP) | $7^{abe}$ | -17.750 |
| Corrugated iron sheets catchment, fabricated conveyance (metal gutters with 2 L bottles or PVC pipes) and 210 Liters PVC storage (CFP) | $32^{abcde}$ | 13.500 |
| Tiles roof catchments, PVC conveyance (gutter and downpipe) and PVC storage tank (TPP) | $2^{bce}$ | -23.375 |
| Corrugated iron sheets, metal conveyance (gutter and downpipe) and concrete tank (CMC) | $1^{bde}$ | -25.250 |
| Corrugated iron sheets catchment, free fall conveyance and 20 Liter storage buckets (CB) | $63^{abcde}$ | 52.875 |

$^{abcde}$: Cells with similar alphabetical letters have means that are significantly different from each other (P<0.05).

The faecal coliforms ranged from a minimum of 1 count per 100 ml in the rooftop rainwater harvested using the CMC RWH technologies to a maximum of 63 counts per 100 ml in the rainwater harvested using the CB RWH technologies. The high faecal level in the water harvested using the CB rainwater harvesting technologies could be attributed to contamination during storage in the 20 L open storage buckets. It is worth noting that these technologies were not planned, but brought into operation following rainfall events. The rooftop rainwater harvested using all the RWH technologies was above the WHO water quality guideline value of 0 counts per 100 ml.

The mean separation test results indicated that the concentration of faecal coliforms was significantly different (P<0.05) between the rainwater harvested using the different rooftop RWH technologies studied. The mean faecal coliforms detected in the rooftop rainwater harvested using the CB (63 counts per 100 ml) and CFP (32 counts per 100 ml) rainwater harvesting technologies were significantly different (P<0.05) from the rooftop rainwater harvested using the CPP (7 counts per 100ml), CMC (1 count per 100 ml) and TPP rooftop RWH technologies. The rooftop rainwater harvested using the CPP (7 counts per 100ml) and TPP (2 counts per 100 ml) rainwater harvesting technologies was significantly different (P>0.05) from the rooftop rainwater harvested using the CMC (1 m count per 100 ml)) rooftop RWH technologies.

## 4. Conclusions

The physical quality of the rooftop rainwater harvested using the RWH technologies with respect to pH (6.16 – 7.05), turbidity (2 NTU, -9.5 NTU) and colour (11.5 mg/L-16.0 mg/L) were assessed and found to be acceptable with the exception of turbidity and colour, which were above the WHO water quality guideline values of 5 NTU and 5 mg/L, respectively. It was thus concluded that the rooftop rainwater harvested using the RWH technologies studied was not safe for home consumption.

The chemical quality of the rooftop rainwater harvested using the RWH technologies studies were determined with particular reference to zinc, fluoride, aluminium and sulphates. It was concluded that the mean zinc, fluoride, aluminium and sulphates of the rooftop rainwater harvested using the RWH technologies studied were within the WHO water quality guidelines i.e. 3.00 mg/L for zinc, 1.5 mg/L for fluoride, 0.1 mg/L for aluminium, and 250 mg/L for sulphate.

The bacteriological quality of the rooftop rainwater harvested using the RWH technologies identified as total and faecal coliforms were determined. The mean total coliforms in the rooftop rainwater harvested using the RWH technologies studied were higher (69 counts per 100 ml to 203 counts per 100 ml) way above the WHO water quality guideline (0 counts per 100 ml). Faecal coliforms were also detected ranging from a minimum of 1 count per 100 ml in the rainwater harvested using the CMC RWH technologies to 63 counts per 100 ml in the rainwater harvested using the CB rainwater harvesting technologies. It was concluded that the rooftop rainwater harvested using all the RWH technologies studied was above the WHO water quality guideline value (0 counts per 100 ml), therefore not safe for home consumption without treatment.

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