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PRILIMINARY ASSESSMENT OF CRITICAL FACTORS OF RAINWATER HARVESTING SYSTEM

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Abstract: Roof material, storage container and retention time are important considerations when designing a rainwater catchment system for present or future usage. This is because they affect the quality of the harvested rainwater which invariably affects the usage as potable or non- potable. In this study, two roof materials (galvanized steel and aluminium coated) was used as catchment surfaces for rainwater harvesting and stored in three different storage containers (clay, plastic and metal) for four weeks in the first instant in order to ascertain their quality against the Nigerian standard for Drinking Water Quality (NSDQW) and World Health Organization (WHO). Triplicate rainwater samples were collected and analysed for selected physicochemical, heavy metal and bacteriological parameters. Results obtained revealed that most of the physicochemical and selected heavy metal parameters of the analysed harvested rainwater were within the selected standards while the bacteriological parameters were above the permissible limits. Based on the results obtained it can be drawn that aluminium roofing coverage gave better result for harvesting rainwater compared to galvanized steel roof catchment. Among the various water storage containers used, plastic storage best preserves rainwater quality relatively. Harvested and stored rainwater does not meet the requirements for potable use. Harvested rainwater should be treated appropriately upon storage for any potable use.
Keywords: rainwater quality, roof material, storage material, storage days

1. INTRODUCTION

Rainwater harvesting is a simple and sustainable technique of getting and storing water where the conventional mains are not available and where the groundwater supply are insufficient to provide the required quantity of water needed (Rahman *et al.*2014). Rainwater collection is important as it provides water at point of need and on-the spot water supply in most developing countries (Rahman *et al.*2014, Balogun et al. 2016). However, major concern with rainwater harvesting and usage is its quality compared to other sources of water (Achadu *et al.*2013, Sabo and Karaye 2016). While the physicochemical quality often fall within the acceptable limits, the microbial qualities makes it most often unsuitable for potable use (Sazakli *et al.* 2007). Rainwater mixes with aerosols, gases and volatile particles from the atmosphere, mixes with faecal matters on the roof catchment either from animal droppings or leaves from overhanging trees and vehicular smoke from exhaust pipe of heavy vehicles. In addition, contaminants from plumbing, pipe fittings and fixtures also mixes with rainwater (Sanchez *et al.*2015) during collection as well as from storage devices, depending on the material for storage.

Several research had been conducted on assessment of rainwater quality as well as on the impact of roof material and storage on harvested rainwater. Olaoye and Olaniyan 2012 determined the quality of rainwater from different roof materials (asbestos, aluminium, concrete and corrugated plastic) and concluded that although, most physicochemical parameters fell within the standard values, coliform as bacterial indicator was present in samples from asbestos, concrete and corrugated plastic roof, only the aluminium roof was free from pathogenic contamination. Ayog *et al.*2016 assessed rainwater parameters and revealed that water quality results could be influenced by the roof age while Achadu *et al.*2013 assessed the impact of storage media on harvested rainwater in Wukari, Northern Nigeria and revealed that Plastic (PVC) tanks and well-constructed concrete tanks are the most suitable storage media. Olaoye *et al.*2018a assessed the effect of cement dust on different roof material on harvested rainwater in an industrial environment and revealed that activities of cement production, particulate emissions as well as pollutants from heavy vehicular movement in and out of the factory resulted in higher metal concentration in the harvested rainwater than permissible. Ubuoh and Nwakanma 2016 assessed the impact of surface and underground tanks on harvested rainwater. However, there is paucity of research on monitoring the combining effect of roof material, storage material and retention time on harvested rainwater quality. In this study, two roof materials (galvanized steel and aluminium) was used as catchment for rainwater harvesting and stored in three different storage containers (clay, plastic and metal) for four weeks in order to ascertain their quality.

The quality of rainwater harvesting system is affected by many factors; which include: the nature of the catchment system, roof materials, environmental pollution from industries, automobiles and anthropogenic activities, the presence of dirts, debris and birds or rodents dropping on roofs and rainwater catchments and the type of storage materials for harvested rainwater (Olaoye *et al*. 2018, Olaoye *et al*.2018a). Catchment material, storage material and treatment are three design considerations that are often considered (Achadu *et al*.2013). However, in-addition to these important consideration duration or retention time of stored rainwater should be considered. Criteria for roof selection includes roof's slope and roughness, roof surface and texture, accumulation of particulate matter on roof material and location and season of siting the roof catchment (Farreny *et al*.2011, Ahmed *et al*.2011, Magyar *et al*.2014, Sanchez *et al*.2015) while criteria for storage selection include colour, durability, cost etc. However, storage time require a lot of consideration, because most often rainwater does not usually meet the microbial standard limit in any 100ml of the sample (Ahmed et al.2011, Olaoye and Olaniyan 2012, Ubuoh and Nwakanma 2016, Ezemonye *et al*.2016).

2. METHODOLOGY

— Catchment area

The rainwater was harvested within the premises of the Ladoke Akintola University of Technology, Ogbomoso, Southwestern, Nigeria. The study area is located at Latitude: 8 08' 00'' Longitude: 4 16' 00''. It is located in a non-industrial area. However, pollution from exhaust pipe of cars, trucks and other heavy vehicles are inevitable. The study area falls within the humid forest zone of Nigeria with great potential for rainfall. The heavy rainy period is usually between April and October, low downpour is usually experienced in March, November and December with few dry months within the year. The average annual rainfall is between 1100 - 1400mm spreading over an average of between 90-120 days annually. The relative humidity varies between 60 and 80 percent. The study area was chosen because of non-availability of public or private water mains in the area, the major source of water for domestic use are from rain, hand dug well and borehole. Unfortunately, the majority of the wells dries up when the rain ceases while the borehole water is sold. The community relies extensively on the available rainwater because it is cheap and accessible in the raining season.

— Roof material and Sampling

Two types of roof material; aluminium coated roof and galvanized steel roof were selected for rainwater harvesting. Rainwater samples was collected in the month of June 2019 and analyzed for four (4) weeks in July 2019. The samples were taken at the middle depth of the containers using sterile sampling devices. The rainwater samples were placed in sterile plastic and glass bottles and stored in ice-storage bag for physicochemical and bacteriological characterization respectively. Samples were tested in triplicate. The colour, odour and smell of the water samples was determine using organoleptic technique. The initial pH, temperature and conductivity value of the rainwater was determined directly on site. The temperature and pH was measured using pH meter, turbidity using portable turbidity meter, total dissolved solid (TDS) and electrical conductivity using Multi-parameter instrument. Heavy metals were determined by atomic absorption spectrophotometer while microbial parameters ; after bacteria incubation, emergence colonies were counted and colony forming unit per ml calculated and recorded while coliform was determined by Most Probable Number (MPN) per 100ml and recorded. All analysis were performed according to standard methods for examination of water and wastewater (APHA, 1995).

3. RESULTS AND DISCUSSION

— Physicochemical characterization of harvested rainwater samples

≡ Temperature

Temperature measurements were taken at about 12 noon on the day of analysis. The initial average temperatures of the harvested rainwater samples from both catchment sources was found to be the same (24^{O}C) as shown in Table 1. Results obtained showed that both catchment materials (aluminium and galvanize steel) have no effect on harvested rainwater temperature on the day of harvesting. The variation in temperature occurred during storage and depended on the type and colour of material used in storage as well as the ambient temperature. Decrease in temperature of rainwater stored in clay pots was observed which can be attributed to the cooling caused by evaporation. The temperature was observed to gradually drop from 24 ^{O}C to 20 ^{O}C on the 21st and 28th day of retention. The plastic and metal storage vessels had water temperatures higher than those of the initial value, with the metal containers having the highest recorded water temperatures with a maximum value of 28.5 ^{O}C on the 21st day. This could be attributed to the fact that metals are good conductors of heat. Nevertheless, there was a drop in temperatures of rainwater in the metal container for both sources on the 28th day. This is as a result of the fact that, the surrounding environment on the day was cloudy (highly humid) hence, heat were rather lost to the surrounding from these reservoirs, as metals are good conductors of heat from an environment having a higher temperature, they are as well good emitters of heat to an environment with lower temperature. Temperature ranging from 12-29 ^{O}C was reported for rainwater stored in tanks (material unknown) by Daoud *et al.* 2011. Similarly, Olaoye and Olaniyan 2012 obtained a temperature of 27 ^{O}C from aluminium and plastic roofs

Table 1: Temperature Variation of Harvested Rainwater (^{O}C)

	GAC	GAP	GAM	Mean	S.D	C.V %	ALC	ALP	ALM	Mean	S.D	C.V %
Initial Tempt.	24	24	24	24	0	0	24	24	24	24	0	0
Day 7	22	25	25	24	1.73	7.21	23	25	26	24.67	1.53	6.20
Day 14	21	26	26.5	24.5	2.483	10.13	22.5	26	27	25.17	2.36	9.37
Day 21	20	26.5	28.5	24.7	3.399	13.76	21	27	28.5	25.50	3.97	15.57
Day 28	20	27	28	24.8	3.559	14.35	20	27.5	27	24.83	4.19	16.87
Mean	21.5	25.7	26	-	-	-	22.1	25.9	26.5	-	-	-
S.D	1.58	1.20	1.92	-	-	-	1.43	1.28	1.48	-	-	-
C.V %	7.35	4.67	7.38	-	-	-	6.47	4.94	5.58	-	-	-

Note: ALC – Rainwater from Aluminum roofing sheet stored in Clay Pot; ALM - Rainwater from Aluminum roofing sheet stored in Metal container; ALP - Rainwater from Aluminum roofing sheet stored in Plastic container; GAC - Rainwater from Galvanized steel roofing sheet stored in Clay Pot; GAM - Rainwater from Galvanized steel roofing sheet stored in Metal container; GAP - Rainwater from Galvanized steel roofing sheet stored in Plastic container

≡ **Colour (TCU)**

The average colour values recorded for rainwater samples from both roof materials (galvanized steel and aluminium roof) was 9 TCU and 7 TCU respectively. These remained constant throughout the retention period in the different storage containers (clay, plastic and metal). The observed value is less than the permissible limit of 15 TCU recommended by NSDQW although WHO recommends that the water remain colourless. The odour/smell of the rainwater was acceptable.

≡ **Turbidity**

The average turbidity values of the harvested rainwater from galvanized steel roof and aluminium coated roof is as shown in Table 2. Turbidity is the cloudiness of water caused by a variety of particles and is another key parameter in drinking water analysis. It is also related to the content of disease causing organisms in water, which may come from roof catchment runoff. Stored rainwater from galvanized steel roof catchment had higher turbidity ranging between 1.2-2.02 NTU while those from aluminium roof catchment ranged between 0.12-0.54 NTU. Higher turbidity value from galvanized roof indicates that the roof material had higher level of particles/dust which were washed with the rainwater into the storage containers while the aluminium roof catchment had lesser particles. It was observed that water stored in clay storage had the highest turbidity content, probably due to particles from the clay material. However, both roof materials met the turbidity level set by WHO and NSDQW standards. Olaoye and Olaniyan 2012 obtained turbidity value of 0.1 and 0.2 NTU in rainwater harvested from aluminium and plastic roof materials while Sanchez 2015 obtained higher values between 33 and 96 NTU from asphalt and galvanized roof respectively.

≡ **Electrical Conductivity (EC) µS/cm**

The observed EC values is as shown in Table 3. After the seventh day of storage, the highest EC value of rainwater harvested from galvanized and aluminium roof material was 843µS/cm and 654µS/cm respectively stored in metal container. The observed valued recorded revealed that the EC values of the rainwater harvested from galvanized steel roof stored in all the containers (clay, plastic, metal) had higher values indicating that they responded to changes more than those of the harvested rainwater from aluminium roof. It is important to note that irrespective of the EC variations displayed by both roof materials, EC recorded were within the NSDQW and WHO maximum permissible limit of 1000µS/cm. Report had shown that heavy rainfall and strong winds often result in high conductivity value of rainwater (Sazakli *et al.* 2007).

Table 2: Average Turbidity Variations of Stored Rainwater (NTU)

	GAC	GAP	GAM	Mean	S.D	C.V %	ALC	ALP	ALM	Mean	S.D	C.V %
Day 7	2.02	1.85	1.9	1.92	0.16	8.33	0.542	0.254	0.265	0.35	0.11	0.32
Day 14	1.82	1.67	1.58	1.69	0.11	6.51	0.356	0.17	0.27	0.27	0.04	0.14
Day 21	1.9	1.45	1.42	1.59	0.83	0.52	0.298	0.198	0.23	0.24	0.11	0.47
Day 28	1.65	1.2	1.3	1.38	0.94	0.68	0.312	0.162	0.12	0.20	0.11	0.57
Mean	1.85	1.54	1.55	-	-	-	0.377	0.196	0.221	-	-	-
S.D	0.16	0.28	0.26	-	-	-	0.113	0.042	0.070	-	-	-
C.V %	8.65	18.18	16.77	-	-	-	0.30	0.21	0.32	-	-	-

Table 3: Electrical Conductivity Values of Stored Rainwater (µS/cm)

	GAC	GAP	GAM	Mean	S.D	C.V %	ALC	ALP	ALM	Mean	S.D	C.V %
Day 7	789	715	843	782.33	64.26	8.21	521	502	654	559	82.82	14.82
Day 14	734	687	801	740.67	57.29	7.73	492	473	602	522.33	69.54	13.31
Day 21	768	712	827	769	57.51	7.48	514	496	632	547.33	73.87	13.5
Day 28	751	703	807	753.67	52.05	6.91	523	487	624	544.67	71.02	13.04
Mean	760.5	704.25	819.5	-	-	-	512.5	489.5	628	-	-	-
S.D	23.53	12.58	19.21	-	-	-	14	12.61	21.48	-	-	-
C.V %	3.04	1.79	2.34	-	-	-	2.77	2.58	3.42	-	-	-

≡ **pH**

The observed average pH is shown in Table 4. The initial pH value of 6.59 and 6.39 indicates that the harvested rainwater was slightly acidic. The 7th day pH values from galvanized and aluminium roofing materials were 7.0 and 6.6 respectively indicating that the rainwater became neutral and weakly acidic respectively, these values were within the WHO threshold. It was observed that the pH value of rainwater harvested from aluminium roof increased rapidly to higher values on the 21st and 28th day. This indicated that there is need to extend the retention days to be able to ascertain if pH increases with retention time. The variation in pH value as the rainwater deposits on the roof material indicates reaching of substances from the roof material along with the harvested rainwater. Similar records had been reported by Sazakli et al. 2007. At the observed pH level slight chemical reaction is likely to occur due to slight acidity of the rainwater samples. Sazakli et al.2007 obtained a pH value of between 7.63-8.8 for rainwater stored in ferroconcrete tank and between 7.36-8.6 from mixed rainwater samples while Daoud et al.2011 recorded pH values between 4.8-8.6 for rainwater stored in tanks during winter and between 7.4-9.9 for those stored in summer, indicating that pH changes with season. Similarly, Sanchez et al.2015 and Olaoye & Olaniyan 2012 reported a pH of 6.5 and 6.9 from galvanized steel and aluminium roof respectively.

≡ **Total Hardness**

The average hardness level of the harvested rainwater is shown in Table 5. The clay storage had the highest value on the 7th day of storage. Values obtained on the 7th day indicated that the harvested rainwater from galvanized steel roof was hard (257mg/l) while that from aluminium roof was moderately hard (197mg/l). The high level of hardness in water obtained from galvanized roof coverage compared to that from aluminium roof coverage is probably due to the fact that the galvanized steel roof is prone to corrosion and elements that could cause water hardness such as calcium could have been washed along with the harvested water into the storage. However, this is not conclusive because the harvested rainwater from galvanized roof into plastic storage had the lowest hardness value and slightly hard (109mg/l) on the 7th day. The variation of hardness in all the storage containers with time were not chronological nor of regular pattern but within the recommended threshold. Hardness value ranging from 24-74mg/l and 155-402mg/l had been reported for rainwater and mixed rainwater stored in ferroconcrete tanks respectively (Sazakli et al.2007) while Olaoye and Olaniyan 2012 obtained lower hardness value of 31-39 and 40-50mg/l from aluminium and plastic roofs respectively.

Table 4: pH Variation of Stored Rainwater Samples

	GAC	GAP	GAM	Mean	S.D	C.V %	ALC	ALP	ALM	Mean	S.D	C.V %
Day 7	7	7	7	7	0	0	6.6	6.6	6.6	6.6	1.0878E-15	1.6482E-14
Day 14	7.3	7	7.2	7.17	0.15	2.09	7.5	7	7.4	7.3	0.26	3.56
Day 21	7.5	7.2	7.6	7.43	0.21	2.83	8.2	8.1	8.3	8.2	0.1	1.22
Day 28	7.2	7.3	7.4	7.3	0.1	1.37	8	7.6	7.8	7.8	0.2	2.56
Mean	7.25	7.13	7.3	-	-	-	7.58	7.33	7.53	-	-	-
S.D	0.21	0.15	0.26	-	-	-	0.71	0.66	0.72	-	-	-
C.V %	2.9	2.1	3.56	-	-	-	9.37	9	9.56	-	-	-

Table 5: Hardness Values of Stored Rainwater (mg/L)

	GAC	GAP	GAM	Mean	S.D	C.V %	ALC	ALP	ALM	Mean	S.D	C.V %
Day 7	257	109	140	183	104.65	57.19	197	182	167	182	15	8.24
Day 14	204	138	184	171	46.67	27.29	174	157	142	157.67	16.01	10.15
Day 21	184	119	164	151.5	45.96	30.34	132	136	124	130.67	6.11	4.68
Day 28	157	104	152	130.5	37.48	28.72	123	121	119	121	2	1.65
Mean	200.5	117.5	160	-	-	-	156.5	149	138	-	-	-
S.D	42.3	15.02	18.76	-	-	-	34.97	26.5	21.71	-	-	-
C.V %	21.1	12.78	11.73	-	-	-	22.35	17.78	15.73	-	-	-

≡ **Alkalinity (mg/L CaCO3)**

The average alkalinity level of the harvested rainwater is shown in Table 6. The average maximum levels of alkalinity in the rainwater samples obtained from the galvanized steel roof and aluminium roof coverage was 216mg/L $CaCO_3$ and 48mg/L $CaCO_3$ respectively. Water from galvanized steel roof had higher alkalinity value due to intrusion of ions, although the concentrations reduces with storage days while alkalinity concentrations increases with retention time with rainwater from aluminium roof catchment in an irregular pattern. This explains why storage containers with rainwater from aluminium roof had higher pH variation with increased retention days than those with water from the galvanized steel roof because alkalinity acts as a buffer solution. Sazakli et al.2007 obtained an alkalinity value between 6-48 mg/l and between 150-340 mg/l for rainwater stored in concrete tank and mixed rainwater respectively while Olaoye and Olaniyan 2012 obtained alkalinity of 6 mg/l from aluminium roof and between 0.9-1.2mg/l from corrugated plastic roof.

≡ Dissolved Oxygen (DO)

All the rainwater samples had DO due to contact with the atmosphere. The observed average DO obtained from the harvested rainwater is shown in Table 7. Water harvested from galvanized steel roof contains more DO (5.4mg/L – clay container) on the 7th day of storage than the water harvested from the aluminium roof (4.8mg/L – clay container). This is probably because the water from galvanized roof has less steep slope which gives more time and chance for aeration which might have increased the dissolved oxygen content. Drop in DO was observed from all the rainwater samples on the 14th day in the three different storage containers due to rise in water temperature observed in the storage containers. Gikas & Tsihrintzis 2012 reported a DO of 0.87 and 1.29 in rainwater samples harvested from clay and concrete roofs respectively

Table 6: Average Concentration of Alkalinity in Stored Rainwater (mg/L CaCO3)

	GAC	GAP	GAM	Mean	S.D	C.V %	ALC	ALP	ALM	Mean	S.D	C.V %
Day 7	201	164	216	193.67	26.76	13.82	46	48	47.99	47.33	1.15	2.43
Day 14	189	128	176	164.33	32.13	19.55	52	50	56	52.67	3.06	5.81
Day 21	181	148	184	171	19.97	11.68	56	54	45.03	51.67	5.84	11.3
Day 28	176	136	168	160	21.17	13.23	53	58	56.21	55.74	2.53	4.54
Mean	186.75	144	186	-	-	-	51.75	52.5	51.3075	-	-	-
S.D	10.9	15.66	21.04	-	-	-	4.19	4.43	5.6	-	-	-
C.V %	5.84	10.88	11.31	-	-	-	8.1	8.44	10.91	-	-	-

Table 7: Average concentration of Dissolved Oxygen in Stored Rainwater (mg/L)

	GAC	GAP	GAM	Mean	S.D	C.V %	ALC	ALP	ALM	Mean	S.D	C.V %
Day 7	5.40	4.90	5.10	5.13	0.25	4.87	4.80	4.50	4.50	4.6	0.17	3.70
Day 14	4.00	3.70	3.40	3.70	0.30	8.11	3.50	3.70	3.10	3.43	0.31	9.04
Day 21	3.90	3.70	3.20	3.60	0.36	10.00	3.10	3.10	3.30	3.17	0.12	3.78
Day 28	3.70	3.30	3.20	3.47	0.26	7.49	3.40	3.40	3.10	3.30	0.17	5.15
Mean	4.25	3.90	3.73	-	-	-	3.70	3.67	3.50	-	-	-
S.D	0.78	0.69	0.92	-	-	-	0.75	0.60	0.67	-	-	-
C.V %	18.35	17.69	24.66	-	-	-	20.27	16.33	19.14	-	-	-

≡ Total Dissolved Solid (TDS)

Average concentration of TDS recorded is shown in Table 8. TDS are the inorganic matters and small amounts of organic matter, which are present as solution in water. The values obtained ranged from 102 – 120mg/l and 103- 117mg/l for samples harvested from galvanized steel and aluminium coated roof respectively. The allowable value of the TDS set by NDWQS and WHO is 1000 mg/L. The average TDS values obtained were within the limit of 1000 mg/L. The highest TDS values of 120 mg/L and the lowest TDS values of 102 mg/L corresponding to water samples harvested from galvanized steel roof and stored in clay container on the 7th day and metal container on the 14th day respectively. Reduction in average TDS occurred from the 14th day due to the fact that, upon storage, suspended particles and impurities larger than the water molecules settled down at the bottom of the containers thus reducing the concentration of TDS.

Table 8: TDS Variations in Stored Rainwater Samples (mg/L)

	GAC	GAP	GAM	Mean	S.D	C.V %	ALC	ALP	ALM	Mean	S.D	C.V %
Day 7	120	117	108	115	6.24	5.43	106	117	112	111.67	5.51	4.93
Day 14	114	115	102	110.33	7.23	6.55	112	115	107	111.33	4.04	3.63
Day 21	112	112	106	110	3.46	3.14	116	110	105	110.33	5.51	4.99
Day 28	106	110	109	108.33	2.08	1.92	113	110	103	108.67	5.13	4.27
Mean	113.75	113.5	106.25	-	-	-	111.75	113	106.75	-	-	-
S.D	5.77	3.11	3.10	-	-	-	4.19	3.56	3.86	-	-	-
C.V %	5.11	2.74	2.91	-	-	-	3.75	3.15	3.62	-	-	-

All the selected physicochemical parameters examined remains in the standardized range of WHO and NSDQW during the first week of retention in all the storage vessels used. Stored water in hygienic condition may remain within the permissible threshold for a period of one week after which the quality thereof cannot be guaranteed.

— **Heavy metal characterization of harvested rainwater**

≡ Lead

The lead content of the harvested rainwater from the two sampling roof points before and after storage was 0mg/L. This is due to the fact that the rainwater had no contact with lead pipes, faucets or fixtures in collection or storage process. Higher lead concentration in rainwater and mixed rainwater stored in ferroconcrete tank ranging from <2.0-6.9mg/l and <2.0-12.2mg/l respectively had been reported by Sazakli et al.2007. Particulate matters in the air either from pollutants from exhaust pipe of vehicles can result to high metal concentration in rainwater. Lani et al.2018 reported lead values between 1.45-2.54mg/l and 1.02-2.71mg/l in rainwater harvested from galvanized and concrete roofs respectively.

≡ **Iron**

The average iron content of the rainwater is shown in Table 9. The iron content of the water from the galvanized steel roof harvested into clay, plastic and metal container was 0.25, 0.20 and 0.22 mg/l respectively on the 7th day while those from aluminium roof was free of iron. The presence of iron in the water from galvanized steel roofing coverage may be as a result of rust and particles on the roof which has been washed along with the rainwater. The concentration of iron in the rainwater from galvanized roof reduces with retention days. The iron content was below the WHO and NSDQW recommended standard. Higher Iron concentration between 6-40mg/l and 7-130mg/l was observed by Sazakli et al.2007 in rainwater and mixed rainwater stored in ferroconcrete tanks similarly Achadu et al.2013 obtained iron content of 1.71, 0.9 and 0.91mg/l for rainwater stored in metal, plastic and concrete containers respectively while Olaoye and Olaniyan 2012 reported iron free rainwater from corrugated plastic roofs.

Table 9: Average Concentration of Iron in Stored Rainwater Samples (mg/L)

	GAC	GAP	GAM	Mean	S.D	C.V %	ALC	ALP	ALM	Mean	S.D	C.V %
Day 7	0.252	0.198	0.219	0.223	0.027	12.21	0	0	0	0	0	-
Day 14	0.216	0.177	0.207	0.2	0.02	10.21	0	0	0	0	0	-
Day 21	0.175	0.157	0.184	0.172	0.014	7.99	0	0	0	0	0	-
Day 28	0.143	0.152	0.132	0.142	0.01	7.04	0	0	0	0	0	-
Mean	0.197	0.171	0.185	-	-	-	0	0	0	-	-	-
S.D	0.048	0.021	0.039	-	-	-	0	0	0	-	-	-
C.V %	24.37	12.28	21.08	-	-	-	-	-	-	-	-	-

≡ **Copper**

The harvested rainwater was free of copper and all samples taken from the different containers were free of copper all through the 28 days of storage. Similarly, Olaoye and Olaniyan 2012 reported copper free rainwater samples. This indicate that both roof materials and the storage containers had no copper impact on the harvested rainwater. Samples met the requirement set by WHO and NSDQW. Higher concentration of copper ranging between <2.5-13 mg/l was obtained by Sazakli et al.2007 for rainwater stored in ferroconcrete tank and <2.5-39.2 for mixed rainwater. Similarly, Achadu et al. 2013 obtained mean copper concentration of 1.11 mg/l for rainwater stored in metal container while Olaoye and Olaniyan 2012 obtain copper concentration of 0.02 mg/l. Particulate matters in the air either from pollutants from exhaust pipe of vehicles can result to high metal concentration in rainwater.

— **Bacteriological Analysis**

Microbial indicators originates from the faeces of man and animal. The most common originator is bird droppings and other organic decaying materials on the roof catchment. As soon as rain falls, it comes in contact with the roof catchment which already houses faeces, leaves, dust, bird's droppings etc. which finds their way into the storage tank despite several first flushing.

≡ **Total Heterotrophic Bacteria (THB) CFU/ml**

The average THB content in the rainwater is shown in Table 10. The analysis of the THB count in the water samples revealed the presence of heterotrophic bacteria in the water harvested from both roofing coverage (galvanized steel and aluminium coated roofs). Heterotrophs microorganisms could be yeast, moulds or bacteria that uses organic carbon as food which are found in every type of water. Standards limit their concentration to 100CFU/ml in water and <500CFU/ml in distribution system. The average THB obtained from the galvanized steel roof into clay, plastic and metal container were 39, 42, 18 CFU/ml of rainwater respectively while the aluminium roof had 25, 21, 14 CFU/ml of rainwater on the 7th day. The THB content in all the rainwater samples increased with retention day, higher value was observed from those stored in clay container from both roof catchments throughout the storage days. Higher growth rate of bacteria suggests that the high concentration of irons in the clay container might have nourished some iron bacteria present in the storage tanks. Achadu et al.2013 reported bacteria count >500/ 100ml in rainwater stored in metal, plastic and concrete storage while Sabo and Karaye 2016 reported total bacteria count of 400 and 700 CFU/100ml in rainwater harvested in Northern Nigeria.

≡ **Coliform Count**

The observed average coliform count is as shown in Table 11. Values obtained revealed level of contamination of the rainwater through the roofing materials. It could probably be due to the presence of animal droppings on the roof. All samples taken from the different containers from both catchment was not free of bacteria indicating that the harvested rainwater was not adequate for potable use in its present state. Count decreased gradually to the 28th day. Total coliform count between 0-570 CFU/100 ml was observed in rainwater stored in ferroconcrete tank by Sazakli et al.2007 similar Achadu et al.2013 recorded counts ranging from 200-560 CFU/100ml. The study conducted in Greece by Sazakli et al. 2007 indicated that total coliforms, Escherichia coli and enterococci were detected in 80.3%, 40.9% and 28.8% of the rainwater samples, respectively, collected from ferroconcrete tanks and cement-paved catchment although they were found in low concentrations (E-Coli value ranging from 0-280CFU/100 ml of rainwater). Lani et al.2018 reported coliform count of 25-63 and 41-75 MPN/100 ml of rainwater from galvanized and concrete roofs respectively.

Table 10: Total Heterotrophic Bacteria Variations in Stored Rainwater (CFU/100mL)

	GAC	GAP	GAM	Mean	S.D	C.V %	ALC	ALP	ALM	Mean	S.D	C.V %
Day 7	39	42	18	33	13.08	39.64	25	21	14	20	5.57	27.85
Day 14	71	53	29	51	21.07	41.32	76	49	31	52	22.65	43.56
Day 21	120	81	59	86.67	30.89	35.64	104	78	55	79	24.52	31.04
Day 28	156	100	100	118.67	32.33	27.24	132	92	86	103.33	25.01	24.2
Mean	96.5	69	51.5	-	-	-	84.25	60	46.5	-	-	-
S.D	51.8	26.39	36.68	-	-	-	45.64	31.57	31.24	-	-	-
C.V %	53.68	38.24	71.22	-	-	-	54.17	52.62	67.18	-	-	-

Table 11: Coliform Count in Stored rainwater (CFU/100mL)

	GAC	GAP	GAM	Mean	S.D	C.V %	ALC	ALP	ALM	Mean	S.D	C.V %
Day 7	5.40	4.90	5.10	5.13	0.25	4.87	4.80	4.50	4.50	4.6	0.17	3.70
Day 14	4.00	3.70	3.40	3.70	0.30	8.11	3.50	3.70	3.60	3.43	0.31	9.04
Day 21	3.90	3.70	3.20	3.60	0.36	10.00	3.10	3.10	3.30	3.17	0.12	3.78
Day 28	3.70	3.30	3.20	3.47	0.26	7.49	3.10	3.20	3.10	3.30	0.17	5.15
Mean	4.25	3.90	3.73	-	-	-	3.70	3.67	3.50	-	-	-
S.D	0.78	0.69	0.92	-	-	-	0.75	0.60	0.67	-	-	-
C.V %	18.35	17.69	24.66	-	-	-	20.27	16.33	19.14	-	-	-

— **Determination of Best Storage Container Material in Terms of Water Quality Preservation**

The container material that best preserved water quality during storage was determined by calculating the coefficients of weekly variation of the examined parameters (Table 12 to 13). Thereafter, the minimum values (coefficients of weekly variation) of these parameters in each of the storage materials were noted. The information were represented in Figure 1 which clearly revealed the best storage container material in terms of preserving the harvested rainwater quality. Figures 1 and 2 showed that the highest percentage of minimum coefficients of variation, for the weekly changes of parameters is 70% (Figure 1) and 78% (Figure 2) which corresponds to water from galvanized roof and aluminium respectively stored in plastic containers (i.e. GAP and ALP), it simply suggests that plastic container best preserved the water quality parameters among the other water storage vessels used similar result was obtained by Achadu et al.2013. Retention days depended on useage; potable or non-potable. Rainwater for potable use must be treated adequately upon storage to meet the zero recommended micro- bacterial standard limit.

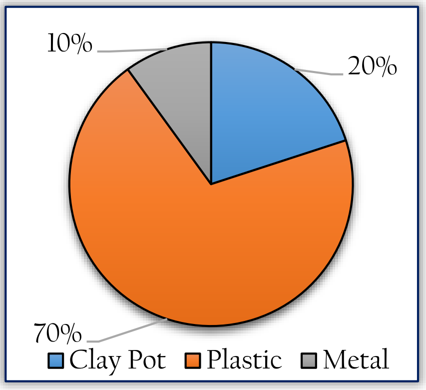

Figure 1: Minimum coefficients of weekly variation of parameters in tanks containing water from galvanized roof

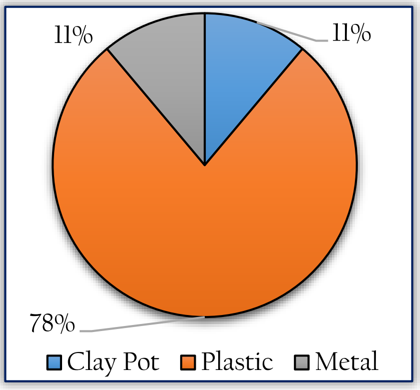

Figure 2: Percentage of minimum coefficients of weekly variation of parameters in containers containing water from Aluminium roof

Table 12: Parameters with Minimum Coefficients of Weekly Variations in Stored Rainwater harvested from Galvanized Steel Roof

Storage Container	Parameters	No. of Parameters
Clap	Turbidity, Alkalinity	2
Plastic	Temperature, Electrical Conductivity, pH, Total Dissolved Solid, Iron, D.O, Total Heterotrophic Bacteria	7
Metal	Total Hardness	1

Table 13: Shows Number of Parameters having Minimum Coefficients of Weekly Variations in Stored Water Harvested from Aluminium Roof

Storage Container	Parameters	No of Parameters
Clap	Alkalinity	1
Plastic	Temperature, Turbidity, Electrical Conductivity, pH, Total Dissolved Solid, D.O, Total Heterotrophic Bacteria	7
Metal	Total Hardness	1

Struk-Sokołowska et al.2020 analyzed rainwater stored in standard tiled cement underground tank for 30days in Europe and observed that multi-day storage of rainwater process changes water parameters in a safe range, stored rainwater can be directly used for washing purposes even after 30 days of storage but not for consumption.

4. CONCLUSION AND RECOMMENDATIONS

The analyzed physicochemical and heavy metal parameters were within the recommended threshold while the concentration of bacteriological parameters were above the permissible. The variation in physicochemical and heavy metal parameters reflect anthropogenic activities in and around the catchment area while the variation in bacteriological parameters reflect some significant level of intrusion of animal faeces and decay organic matter on the roof catchments as bacteriological parameters increases with the storage period. Based on the results obtained it can be drawn that aluminium coated roofing coverage gave better result for harvesting quality rainwater compared to galvanized steel roof catchment. Among the various water storage containers used, plastic storage best preserves rainwater quality. Stored rainwater should be treated appropriately before potable use.

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