  Journal of Water Supply: Research and Technology—AQUA | 68.3 | 2019

# Effect of storage on rainwater quality of selected locations within Benue State, Nigeria

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## ABSTRACT

Samples of stored rainwater were collected from Ojo and Adoka areas of Benue State and analysed for physicochemical properties, heavy metals and antimicrobial parameters using standard methods in order to determine the quality of stored rainwater. The results of the study indicate physicochemical parameters such as temperature, colour, pH, electrical conductivity, total dissolved solids (TDS) and total hardness to be within the acceptable limit for drinking water, while nitrates, chloride, phosphates and sulphates were observed to be 3.33–14.00 mg/L, 24.83–59.90 mg/L, 0.13–0.19 mg/L and 7.55–8.39 mg/L, respectively. Dissolved oxygen (DO), biochemical oxygen demand (BOD) and chemical oxygen demand (COD) had values of 1.40–1.70 mg/L, 1.63–1.66 and 163.33–193.33, respectively. Heavy metal ions in the samples were found to be aluminum (0.104 mg/L) and chromium (0.012 mg/L). Zinc was found to range between 0.451 and 1.47 mg/L, while iron ranged from 0.57 to 1.606 mg/L. Cadmium, nickel and lead were in the range of 0.014–0.020 mg/L, 0.54–2.332 mg/L and 0.006–3.143 mg/L, respectively. Coliform count ranged between 130.00 and 402.00 (cfu/100 mL). All the parameters tested except coliform count were found to be within acceptable limits by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines.

**Key words** | analysis, contamination, harvested, metals, physicochemical, rainwater

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## INTRODUCTION

The problem of potable water in our environment has become a subject of concern. This is because many communities lack potable water. The situation is further compounded due to increasing population, unstable government policies, inadequate water sources, etc., and even where there are water sources, anthropogenic activities usually render the water sources unsafe for drinking purposes. For example, the release of agricultural and industrial chemicals and effluents into rivers, streams and ponds usually render such water undrinkable. This situation has compelled many communities to explore other means of sourcing for drinking water (Aladenola & Adeboye 2010).

The harvesting and storage of rainwater during the rainy season to be used during the dry season is one of the promising ways of supplementing the surface and underground scarce water resources in areas where the existing water supply system is inadequate to meet the growing demand. Although rainwater is regarded as one of the purest forms of water on Earth, it is pertinent to note that it is still contaminated. Despins *et al.* (2009) reported that the problem

doi: 10.2166/aqua.2019.098

associated with the use of rainwater for any applications is its quality. Achadu *et al.* (2015) and Ebong *et al.* (2016) observed that the quality of rainwater is affected by many factors, e.g., the nature of the collecting and storage system, type of pollutants in the environment, the presence of dirt and debris, birds or rodents dropping onto roofs and even automobiles and other anthropogenic activities around the area. Also, the time of collecting the water contributes to its quality.

People who usually depend on harvested rainwater without treatment are vulnerable to water-borne diseases like dysentery, diarrhoea, typhoid fever, etc., and as such, it is pertinent to investigate the quality of stored rainwater in order to determine how long the quality will be retained before contamination and hence becoming unfit for drinking. It is a notable factor that water stored over a period of time may be affected by the storage materials and runoffs. Where the water is stored in reservoirs, sediments, which consist of organic matter and minerals are washed or blown from the land into the reservoirs and this may affect the quality of the water (Wu *et al.* 2017). The indiscriminate discharge of flue gases, agrochemicals, pesticides and other toxic contaminants into the atmosphere and the environment in general without recourse to environmental laws could also affect the water quality. The nature of the roofing materials, the presence of toxic gases such as $SO_2$, $NO_X$, CO, etc. in the atmosphere could also contaminate the harvested rainwater. Another source of worry is the nature of the storage material, the length of storage time and the conditions of storage.

In Benue State, water scarcity has been a major source of concern, due to the lack of adequate potable water sources. Residents of Makurdi and other major towns rely on rainwater as a major source of drinking water and for other applications. For example, the residents of Adoka, a town in Otukpo Local Government Area and those of Oju in Oju Local Government Area and other major villages collect rainwater, to store and use during the dry season to cushion the effect of water scarcity. The residents of these towns do not have access to potable water and depend on available water sources such as streams. Utsev & Aho (2012) observed that most communities in Benue State lack potable water. The main sources of drinking water are streams and wells which are contaminated with *Escherichia coli* and a coliform count causing pathogenic diseases like diarrhoea. Orpin & Mzungo (2017) reported that cases of urinary schistosomiasis, a disease caused by the infection of freshwater parasitic worms, are prevalent among residents of Oju town.

In most cases, the collected rainwater is stored in a large barrel, cistern or tanks. The rainwater harvesting systems in these areas consist of a collection area, a conveyance system and a storage vessel or cisterns. The collection area is the roof of zinc houses. The conveyance system consists of gutters, and in some places, pipes that deliver rainwater falling on the rooftop to the reservoir for storage. The reservoir may be a storage tank or cistern, which is usually built underground with bricks and plastered with cement or sometimes made of concrete. The cisterns in most cases are built some distance away from the buildings. They usually have an opening where water can be drawn when the need arises.

It is possible that the storage container or method applied in fetching the water for use may contaminate the water by introducing microorganisms or other substances that may be injurious to health. Therefore, depending on the amount and the type of contaminants or pollutants present, the water quality may become contaminated with time. It is therefore important to continuously assess the quality of stored rainwater in order to ascertain when its quality may become unfit for consumption.

## MATERIALS AND METHODS

### Study area

Oju town is the headquarters of Oju Local Government Area of Benue State. It has a population of about 227,400. It is located on latitude 6° 51′ 31.7″N and longitude 8° 22′ 55.2″E. It has an elevation of 137 m above sea level. Similarly, Adoka is a town located in Otukpo Local Government Area also of Benue State, and it has a population of about 174,152. It is located on latitude 6° 27′ 13″N and longitude 7° 58′ 42″E (Figure 1). The residents of these towns are mostly farmers.

### Sample collection

Stored rainwater samples were collected from three locations at Adoka and Oju towns. The samples were collected using a 500 $cm^3$ plastic container, and water was drawn four times

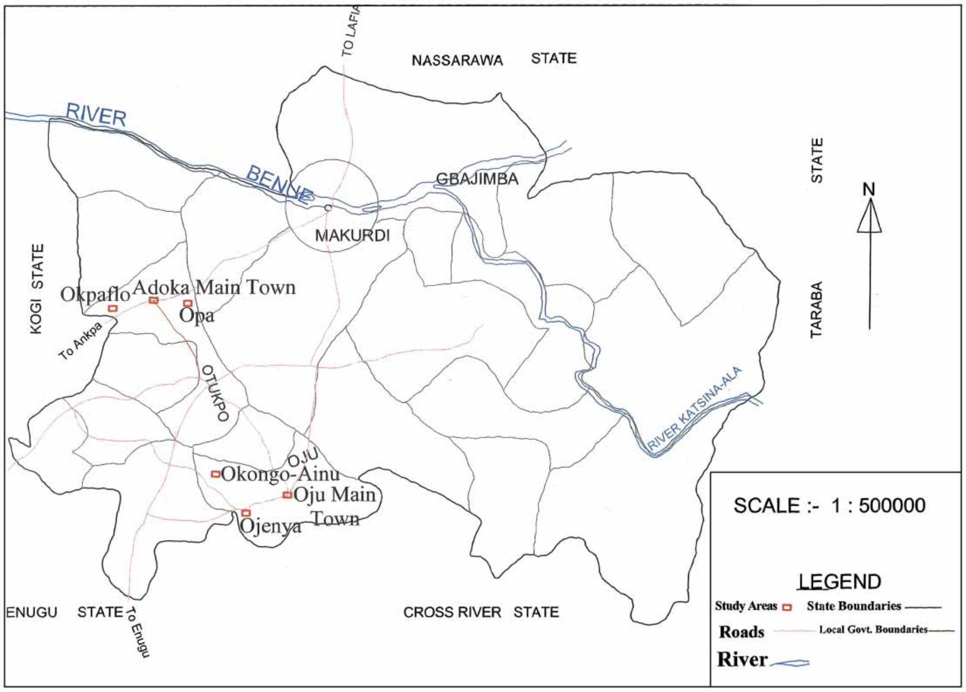


**Figure 1** | Map of sample site.

from a particular cistern into a 2 L container as a composite sample. This was done in three locations in each of the towns.

The temperature was measured at a site using mercury in a glass thermometer. Colour, suspended solids, turbidity, dissolved oxygen, chemical oxygen demand, phosphate, sulphate and nitrate were measured using direct reading spectrophotometer (DR/2000 HACH Company). Total dissolved solids and conductivity were measured using TDS kit (Model 50150 HACH). pH was measured using a pH meter. Water hardness was measured using hardness EDTA titration. All the instruments were calibrated before use, and biochemical oxygen demand was measured using the following mathematical expression:

$$\mathrm{BOD\,mgL^{-1}} = \mathrm{DO_i} - \mathrm{DO_f}/\mathrm{dilution\,factor}$$

where $DO_i$ = dissolved oxygen before incubation and $DO_f$ = dissolved oxygen after incubation for 5 days.

The analysis of heavy metals was done by an atomic absorption spectrophotometer (AAS), while total coliform was measured using multiple tube fermentation technique (Wohlson *et al.* 2006).

## RESULTS AND DISCUSSION

### Descriptive statistics of physicochemical parameters and heavy metals in the samples

The results of the stored rainwater qualities from the two locations (Oju and Otukpo) are presented in Tables 1 and 2, respectively. The average temperatures in the study area ranged from 26.4 to 28.37 °C which is normal for dry season water samples. The colour of the rainwater samples ranged from 2.00 to 3.00 (PtCo colour) which is normal with the small range of pH.

The average pH of the stored rainwater was in the nearly neutral range from 6.47 to 7.79, although stored rainwater samples from Adoka location had a higher pH than samples from the Oju samples. Storage of harvested rainwater in makeshift concrete reservoirs could shift the pH of water towards alkalinity. This result is in agreement with the result reported by Despins *et al.* (2009). The dispersion of the pH was little with percentage coefficient of variation (% CV) 2.1–5.02% (Table 3), indicating a minimal change in pH from the month of February to April 2017 in the stored rainwater samples. These values of pH are in

**Table 1** | Physicochemical properties and heavy metal concentration in stored rainwater samples at Otukpo LGA between the months of February and April 2017

| | Rain water samples collected at various points from Otukpo LGA and water quality standards | | | | |
|---|---|---|---|---|---|
| **Parameter** | **Okpaflo** | **Adoka main town** | **Opa** | **WHO (2011)** | **NSDWQ (2007)** |
| Temperature/°C | 27.00 ± 0.50 (26.5–27.5) | 26.5 ± 0.9 (25.6–27.4) | 28.2 ± 0.5 (27.7–28.7) | 20–32 | |
| Colour/Hu | 2.67 ± 0.58 (2.00–3.00) | 2.33 ± 0.58 (2.00–3.00) | 2.67 ± 0.57 (2.00–3.00) | | |
| pH | 7.79 ± 0.39 (7.46–8.22) | 7.63 ± 0.16 (7.54–7.82) | 7.55 ± 0.22 (7.40–7.80) | 6.5–8.5 | 6.5–8.5 |
| Electrical conductitivity/$\mu SCm^{-1}$ | 6.45 ± 5.22 (0.45–9.96) | 6.47 ± 0.86 (5.97–7.46) | 10.94 ± 0.86 (10.44–11.94) | 1,000.0 | 1,000.0 |
| Turbidity/NTU | 0.73 ± 1.27 (ND–2.2) | 1.46 ± 1.65 (0.01–3.26) | 0.67 ± 0.58 (ND–1.01) | 0–5 | 5.0 |
| Total dissolved solids (TDS)/$mgL^{-1}$ | 6.33 ± 0.58 (6.00–7.00) | 4.33 ± 0.58 (4.00–5.00) | 7.33 ± 0.58 (7.00–8.00) | 1,000.0 | 500.0 |
| Total suspended solids (TSS)/$mgL^{-1}$ | 133.33 ± 188 (10.00–350) | 250.00 ± 200 (50.00–450.00) | 163.33 ± 125.03 (20.00–250.00) | 250.0 | |
| Total hardness/$mgL^{-1}$ | 185.17 ± 207 (60.6–424.2) | 205.37 ± 259.93 (40.4–505) | 188.53 ± 230.39 (50.50–454.50) | 100–500 | 150.0 |
| Nitrates ($NO_3^-$)/$mgL^{-1}$ | 4.00 ± 0.00 (4.00–4.00) | 3.33 ± 0.58 (3.00–4.00) | 5.67 ± 0.58 (5.00–6.00) | 50.0 | 50.0 |
| Chloride ($Cl^-$)/$mgL^{-1}$ | 35.45 ± 14 (21.27–49.63) | 35.45 ± 7.09 (28.36–42.54) | 24.82 ± 6.14 (17.73–28.36) | 250.0 | 250.0 |
| Phosphate ($PO_4^3)^-$/$mgL^{-1}$ | 0.13 ± 0.03 (0.1–0.15) | 0.15 ± 0.03 (0.12–0.18) | 0.13 ± 0.03 (0.10–0.16) | 5.0 | |
| Sulphate ($SO_4^{2-}$)/$mgL^{-1}$ | 8.32 ± 3.01 (5.04–10.96) | 8.14 ± 2.81 (5.08–10.59) | 8.39 ± 2.96 (4.99–10.41) | 250.0 | 100.0 |
| BOD/$mgL^{-1}$ | 0.50 ± 0.17 (0.3–0.6) | 0.57 ± 0.55 (0.20–1.20) | 0.37 ± 0.21 (0.20–0.60) | 30.0 | |
| COD/$mgL^{-1}$ | 173.33 ± 156 (30–340) | 140.00 ± 112.69 (70–270) | 193.33 ± 185.83 (40.00–400.00) | 255.0 | |
| DO/$mgL^{-1}$ | 1.40 ± 0.79 (0.5–2.00) | 1.70 ± 0.89 (0.70–2.40) | 1.53 ± 0.95 (0.60–2.50) | 5–7 | |
| Al/$mgL^{-1}$ | ND | 0.019 ± 0.006 (0.014–0.026) | 0.066 ± 0.014 (0.054–0.081) | 0.1–0.2 | 0.2 |
| Cr (mg/L) | ND | ND | 0.009 ± 0.016 (ND–0.027) | 0.05 | 0.05 |
| Fe/$mgL^{-1}$ | 0.57 ± 0.91 (0.052–1.62) | 0.677 ± 0.681 (0.300–1.464) | 0.702 ± 0.849 (0.201–1.682) | 0.3 | 0.3 |
| Zn/$mgL^{-1}$ | 1.47 ± 0.84 (0.6–2.27) | 1.459 ± 0.925 (0.560–2.408) | 1.442 ± 0.909 (0.540–2.358) | 3.0 | 3.0 |
| Cd/$mgL^{-1}$ | 0.02 ± 0.02 (ND–0.031) | 0.015 ± 0.010 (0.005–0.025) | 0.014 ± 0.014 (ND–0.028) | 0.003 | 0.003 |
| Ni/$mgL^{-1}$ | 0.54 ± 0.84 (ND–1.51) | 0.654 ± 1.032 (ND–1.843) | 0.584 ± 0.935 (ND–1.663) | 0.07 | 0.02 |
| Pb/$mgL^{-1}$ | 0.04 ± 0.04 (ND–0.081) | 1.205 ± 2.018 (0.027–3.535) | 0.006 ± 0.011 (ND–0.019) | 0.01 | 0.01 |

Values are mean ± standard deviation and range (in parentheses).

**Table 2** | Physicochemical properties and heavy metal concentration in stored rainwater samples at Oju LGA between the months of February and April 2017

| | Rain water samples collected at various points from Otukpo LGA and water quality standards | | | | |
|---|---|---|---|---|---|
| **Parameter** | **Ojenya** | **Oju main town** | **Okongo-Ainu** | **WHO (2011)** | **NSDWQ (2007)** |
| Temperature/°C | 26.4 ± 0.4 (26.2–26.9) | 28.37 ± 0.78 (27.5–29.0) | 27.53 ± 0.51 (27.1–28.1) | 20–32 | |
| Colour/Hu | 2.00 ± 0.00 (2.00–2.00) | 2.33 ± 0.58 (2.00–3.00) | 3.00 ± 1.00 (2.00–4.00) | | |
| pH | 7.58 ± 0.30 (7.38–7.92) | 6.52 ± 0.27 (6.25–6.79) | 6.47 ± 0.31 (6.20–6.8) | 6.5–8.5 | 6.5–8.5 |
| Electrical conductivity/μSCm$^{-1}$ | 5.08 ± 0.79 (4.48–5.97) | 48.26 ± 3.44 (46.27–52.23) | 19.90 ± 2.28 (17.91–22.39) | 1,000.0 | 1,000.0 |
| Turbidity/NTU | 0.98 ± 1.19 (ND–2.30) | 0.70 ± 0.61 (ND–1.09) | 0.68 ± 0.61 (ND–1.19) | 0–5 | 5.0 |
| Total dissolved solids (TDS)/mgL$^{-1}$ | 3.33 ± 0.58 (3.00–4.00) | 32.33 ± 2.31 (31.00–35.00) | 13.33 ± 1.53 (12.00–15.00) | 1,000.0 | 500.0 |
| Total suspended solids (TSS)/mgL$^{-1}$ | 170.00 ± 127.67 (30.00–280.00) | 133.33 ± 115.90 (10.00–240.00) | 146.67 ± 179.54 (10.00–350.00) | 250.0 | |
| Total hardness/mgL$^{-1}$ | 181.70 ± 262.23 (30.30–484.50) | 155.87 ± 67.26 (90.90–225.2) | 188.53 ± 239.08 (50.5–464.6) | 100–500 | 150.0 |
| Nitrates ($NO_3^-$)/mgL$^{-1}$ | 3.67 ± 0.58 (3.00–4.00) | 5.67 ± 1.15 (5.00–7.00) | 14.00 ± 4.58 (10.00–19.00) | 50.0 | 50.0 |
| Chloride ($Cl^-$)/mgL$^{-1}$ | 25.98 ± 14.76 (14.18–42.54) | 37.74 ± 14.88 (21.05–49.63) | 59.90 ± 52.56 (27.27–120.53) | 250.0 | 250.0 |
| Phosphate ($PO_4^{3-}$)/mgL$^{-1}$ | 0.18 ± 0.02 (0.16–0.20) | 0.19 ± 0.06 (0.14–0.26) | 0.15 ± 0.07 (0.10–0.23) | 5.0 | |
| Sulphate ($SO_4^{2-}$)/mgL$^{-1}$ | 7.55 ± 3.95 (3.22–10.97) | 8.30 ± 3.01 (4.89–10.57) | 8.02 ± 3.29 (4.24–10.22) | 250.0 | 100.0 |
| BOD/mgL$^{-1}$ | 0.55 ± 0.40 (0.30–1.00) | 0.67 ± 0.35 (0.30–1.00) | 0.43 ± 0.23 (0.30–0.70) | 30.0 | |
| COD/mgL$^{-1}$ | 206.67 ± 195.53 (20.00–410.00) | 263.33 ± 237.98 (50.00–520.00) | 163.33 ± 135.03 (30.00–300.00) | 255.0 | |
| DO/mgL$^{-1}$ | 1.66 ± 0.81 (0.70–2.30) | 1.63 ± 1.03 (0.50–2.50) | 1.63 ± 0.86 (0.70–2.40) | 5–7 | |
| Al/mgL$^{-1}$ | 0.104 ± 0.020 (0.090–0.127) | 0.096 ± 0.050 (0.063–153) | 0.056 ± 0.034 (0.027–0.094) | 0.1–0.2 | 0.2 |
| Cr (mg/L) | 0.012 ± 0.021 (ND–0.037) | (ND) | 0.008 ± 0.013 (ND–0.023) | 0.05 | 0.05 |
| Fe/mgL$^{-1}$ | 0.596 ± 1.026 (ND–1.781) | 1.606 ± 2.043 (ND–3.906) | 0.829 ± 0.037 (0.802–0.871) | 0.3 | 0.3 |
| Zn/mgL$^{-1}$ | 0.902 ± 0.258 (0.660–1.174) | 0.451 ± 0.108 (0.345–0.560) | 0.817 ± 0.154 (0.650–0.954) | 3.0 | 3.0 |
| Cd/mgL$^{-1}$ | 0.020 ± 0.011 (0.008–0.030) | 0.016 ± 0.015 (ND–0.029) | 0.019 ± 0.017 (ND–0.032) | 0.003 | 0.003 |
| Ni/mgL$^{-1}$ | 1.798 ± 2.995 (ND–5.255) | 1.768 ± 2.959 (ND–5.184) | 2.332 ± 3.957 (ND–6.901) | 0.07 | 0.02 |
| Pb/mgL$^{-1}$ | 0.043 ± 0.045 (ND–0.090) | 28.37 ± 0.78 (27.5–29.0) | 0.014 ± 0.024 (ND–0.041) | 0.01 | 0.01 |

Values are mean ± standard deviation and range (in parentheses).

**Table 3** | Variation in concentrations of properties of the stored rainwater from the months of February to April at the various sampling sites (% coefficient of variation)

| Parameter | Okpaflo | Adoka main town | Opa | Ojenya, | Oju main town | Okongo-Ainu |
|---|---|---|---|---|---|---|
| Temperature | 1.9 | 3.4 | 1.8 | 1.5 | 2.7 | 1.9 |
| Colour | 21.7 | 24.7 | 21.7 | 0.0 | 24.7 | 33.3 |
| pH | 5.0 | 2.1 | 2.9 | 3.9 | 4.14 | 4.7 |
| Electrical conductivity | 80.9 | 13.3 | 7.9 | 15.5 | 7.13 | 11.5 |
| Turbidity | 173.2 | 112.9 | 86.6 | 121.7 | 86.8 | 90.4 |
| Total dissolved solids (TDS) | 9.1 | 13.3 | 7.9 | 17.3 | 7.1 | 11.5 |
| Total suspended solids (TSS) | 141.2 | 80.0 | 76.6 | 75.1 | 86.9 | 122.4 |
| Total hardness | 111.8 | 126.6 | 122.2 | 144.3 | 43.2 | 126.8 |
| Nitrates ($NO_3^-$) | 0.0 | 17.3 | 10.2 | 15.8 | 20.4 | 32.7 |
| Chloride ($Cl^-$) | 40.0 | 20.0 | 24.7 | 56.8 | 39.4 | 87.7 |
| Phosphate ($PO_4^{3-}$) | 20.4 | 19.9 | 23.1 | 11.1 | 31.6 | 44.4 |
| Sulphate ($SO_4^{2-}$) | 36.20 | 34.5 | 35.3 | 52.4 | 36.2 | 41.0 |
| BOD | 34.6 | 97.2 | 56.8 | 75.8 | 52.7 | 53.3 |
| COD | 90.2 | 80.5 | 96.1 | 94.6 | 90.4 | 82.7 |
| DO | 56.7 | 52.3 | 62.0 | 51.2 | 62.9 | 52.8 |
| Al | 173.2 | 31.6 | 20.8 | 19.0 | 51.6 | 60.8 |
| Cr | – | – | 173.2 | 173.2 | – | 173.2 |
| Fe | 158.4 | 100.6 | 121.0 | 172.2 | 127.2 | 4.4 |
| Zn | 57.05 | 63.4 | 63.0 | 28.6 | 23.8 | 18.9 |
| Cd | 86.6 | 68.3 | 100.0 | 55.8 | 90.9 | 88.0 |
| Ni | 156.01 | 157.8 | 160.1 | 166.6 | 167.3 | 169.7 |
| Pb | 98.80 | 167.4 | 173.2 | 105.9 | 172.1 | 173.2 |

agreement with other studies reported for previously harvested rainwater in Benue State, other parts of Nigeria, and even other parts of the world (Adeniyi & Olabanji 2005; Sazakli *et al.* 2007; Lee *et al.* 2010; Oklo & Asemave 2011; Musa *et al.* 2017), but are more neutral compared to the more acidic pH of harvested rainwater in Anambra State, Nigeria and Texas in the USA (Mendez *et al.* 2011; Chukwuma *et al.* 2012). The pH values reported in this study imply that the rainwater may be void of undesirable reactions that may occur at extreme pH ranges during storage (Zhu *et al.* 2004). The range of pH values reported is, however, within the range of 6.5–8.5 recommended by the World Health Organization (WHO) (2011) and the Nigerian Standard for Drinking Water Quality (NSDWQ) (2007) guidelines.

Electrical conductivity (EC) across the samples was in the range of 6.45–48.26 $\mu SCm^{-1}$ which implies high dilution and very low salinity. Higher values of EC were observed at the Oju sample location with the exception of the stored rainwater collected at the Ojenya site. This may have resulted from the method of collection as rainwater is collected over corrugated iron sheets prior to storage. The values are in agreement with those reported in other studies (Table 4). The difference in conductivity of harvested rainwater could arise from the type and age of roofing material over which it was collected. This can be clearly seen in studies by Adeniyi & Olabanji (2005), where rainwater harvested over different roofing materials revealed varying conductivities. There was a fair variation in the conductivities of the studied samples with % CV ranging from 7.13 to 15.52% except at the Okpaflo site where it varied markedly with 80.94% CV during the storage time of the samples. The conductivities of the samples, however, were below the 1,000 $\mu SCm^{-1}$ limits set by WHO and NSDWQ guidelines.

Low total dissolved solids (TDS) values reported in the present study (3.33–32.33) mg/L are affirmative of the low

Journal of Water Supply: Research and Technology—AQUA | 68.3 | 2019

**Table 4** | Comparison of physicochemical parameters reported in stored region water in the study area with harvested rain water samples from other regions in Nigeria and other parts of the world

| Parameter | | This study Benue State, NC-Nigeria (2017) | Benue State, NC-Nigeria (Oklo & Asemave 2011) | Niger State, NC-Nigeria (Musa *et al.* 2017) | Osun State, SW-Nigeria (Adeniyi & Olabanji 2005) | Anambra State, SE-Nigeria (Chukwuma *et al.* 2012) | Texas, USA (Mendez *et al.* 2011) | Gangneung, China (Lee *et al.* 2010) | Erisos, Kefalonia, Greece (Sazakli *et al.* 2007) |
|---|---|---|---|---|---|---|---|---|---|
| Physical parameters | Temp./°C | 26.4–28.37 | n.m | 23.2 | n.m | n.m | n.m | n.m | n.m |
| | Colour/Hu | 2.00–3.00 | 5.0–11.0 | colourless | 0.5–310.5 | n.m | n.m | n.m | n.m |
| | Total suspended (TSS)/mgL$^{-1}$ | 133.33–250.00 | | | 6.71–12.7 | 1–4 | 10–150 | n.m | n.m |
| | Turbidity/NTU | 0.67–1.47 | 1–5 | 1.8–6.7 | 0.2–38.3 | | 5–30 | n.m | n.m |
| Secondary physicochemical parameters | pH | 6.47–7.79 | 6.0–6.9 | 6.9–7.5 | 6.11–8.41 | 5.46–5.98 | 5.4–6.9 | 6.7–7.8 | 7.63–8.80 |
| | EC/μSCm$^{-1}$ | 6.45–48.26 | | 367–478 | 4.5–174.2 | 45.5–510 | 9–102 | 50–340 | 56–220 |
| | TDS (mg/L) | 3.33–32.33 | 4.0–9.0 | 52–115 | 1.0–79.8 | 31.3–42.6 | n.m | 40–230 | |
| | Total hardness/ mgL$^{-1}$ | 155.87–205.37 | 20v40 | 39–93 | 0.0–49.5 | ND | n.m | n.m | 24–74 |
| Majorions/nutrient compounds | Nitrates ($NO_3^-$)/mgL$^{-1}$ | 3.33–14.00 | 6.8–18.7 | 18–28 | 0.00–22.64 | 0.13–1.98 | 0.00–4.7 | 2.9–9.8 | 5.28–13.02 |
| | Chlorides ($Cl^-$/)mgL$^{-1}$ | 24.82–59.90 | 5.93–65.67 | 4–12 | 0.00–21.2 | 8–16 | n.m | 5–18 | 3–16 |
| | ($PO_4^{3-}$)/mgL$^{-1}$ | 0.13–0.19 | | n.m | n.m | n.m | n.m | 0–0.04 | 0.01–0.62 |
| | Sulphates ($SO_4^{2-}$)/mgL$^{-1}$ | 7.55–8.39 | 2.0–12.0 | 0.9–29 | 0.0–10.5 | 3–5 | | 2–7.2 | 1–13 |
| Biochemical parameters | BOD/mgL$^{-1}$ | 0.37–0.67 | n.m | n.m | n.m | n.m | n.m | n.m | n.m |
| | COD/mgL$^{-1}$ | 140.00–263.33 | n.m | n.m | n.m | n.m | n.m | n.m | n.m |
| | DO/mgL$^{-1}$ | 1.40–1.70 | n.m | n.m | n.m | n.m | n.m | n.m | n.m |
| Trace/heavy metals | Al/mgL$^{-1}$ | ND–0.104 | n.m | n.m | n.m | n.m | n.m | 0.1–0.4 | n.m |
| | Cr/mgL$^{-1}$ | ND–0.012 | n.m | n.m | n.m | n.m | n.m | 0–0.01 | <0.0013–0.0048 |
| | Fe/mgL$^{-1}$ | 0.57–1.606 | 0.03–0.08 | n.m | n.m | ND | | | 0.006–0.04 |
| | Zn/mgL$^{-1}$ | 0.451–1.47 | 0.00–0.36 | 0–2 | n.m | 0.02 | 0.001–0.362 | 0.12–0.28 | 0.01–0.077 |
| | Cd/mgL$^{-1}$ | 0.014–0.020 | n.m | n.m | n.m | ND | n.m | 0–0.04 | <0.0001–0.00019 |
| | Ni/mgL$^{-1}$ | 0.54–2.332 | n.m | n.m | n.m | n.m | n.m | n.m | <0.01–0.0122 |
| | Pb/mgL$^{-1}$ | 0.006–3.143 | n.m | n.m | n.m | ND | 0.003–0.086 | 0.01–0.04 | <0.002–0.0069 |

ND, not detected; nm, not measured; NC, north-central; SW, south-west; SE, south-east.

salinity of the stored rainwater samples. The range of TDS values reported here is higher than those reported by Oklo & Asemave (2011); however, the values were below the WHO and NSDWQ standards.

The turbidity of the samples was very low (0.67–1.46 NTU) and within the permissible limits of 0–5 NTU by the earlier cited drinking water quality standards. However, % CV indicates a wide dispersion of colour on storage (8.84–173.21%). This is much to be expected as suspended solids are sedimented during storage. The turbidities of samples are also lower than those reported in similar studies (Table 4). This implies that the rainwater samples had a low content of hydrocarbons, heavy metals and phosphorous which are associated with particles, and their presence could effectively reduce the transparency and penetration of light rays into the water body (Atobatele & Ugwumbe 2008; Sánchez *et al.* 2015).

Total suspended solids (TSS) of the samples were 133.33, 250.00 and 163.33 mg/L at Okpaflo, Adoka main town and Opa sampling sites in the Adoka location and 170.00, 133.33 and 146.67 mg/L at Ojenya, Oju main town and Okongo-Ainu sampling sites in the Oju local government area. The values of TSS reported in the present study were far greater than those reported in south-west and south-east Nigeria (Table 4). This could result from dust deposition which is prevalent in the study area and may have found its way into the stored rainwater resulting in high values of TSS. However, the values observed were below the maximum permissible limits given by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines. This implies that the samples will have low tendency for sorption of hydrophobic contaminants usually found associated with suspended particulate matter in water. The result of the study indicates a wide dispersion of TSS within the study period (% CV: 75.10–141.18).

The results of total hardness indicate varying amounts, which range from 155.87 mg/L to 205.37 mg/L. Thus, the water samples fall in the category of 'very hard' as can be seen in the classification in Table 5. The high total hardness observed in this study could be linked to the concrete structures used in storing the rainwater.

The adverse effects of hard water are well known and documented. For instance, hard water produces white scaly deposits on plumbing fixtures and cleaning appliances, furring of kettles and water heaters as well as decreasing the cleaning action of soaps and detergents. Hence, these rainwater samples must be softened through cheaper means like boiling if economic benefits are to be derived from their use (Parrott & Ross 2009). The total hardness values reported in this study are different from the widely reported softness of rain waters harvested in other parts of Nigeria and the world (Table 5). These values of total hardness also fall short of the NSDWQ guidelines of 150 mg/L.

**Table 5** | Hardness classification

| Hardness concentration (mg/L) | Relative hardness level |
|---|---|
| Below 60 | Soft |
| 60 to 120 | Moderately hard |
| 120 to 180 | Hard |
| 180 and above | Very hard |

Parrott & Ross (2009).

The presence of some major ions and nutrient compounds was also detected in the studied samples. Their ranges were as follows: nitrates 3.33–14.00 mg/L, chlorides 24.83–59.90 mg/L, phosphates 0.13–0.19 mg/L and sulphates 7.55–8.39 mg/L. The variation of these ions within the study period of three months was fair with their various % CV below 50% except for chloride at Ojenya and Okongu-Ainu sampling sites. The amount of nutrients in rainwater is a function of the amount and time of precipitation during a certain period of the annual cycle when it was harvested (Henderson *et al.* 1977). Concentrations of sulphate ions reported in this study are higher than those reported in harvested rainwater from other locations in Nigeria (Table 4). However, all the ions were in conformity with the regulatory guidelines earlier referenced in this study. The low ionic content of this stored rainwater is good to know since some of these ions produce undesirable characteristics in a water body. For instance, chloride produces a salty taste in water and is corrosive, while sulphates give a bitter taste and are also corrosive, and which can sometimes result in an offensive odour of the water source (Parrott & Ross 2009).

The biochemical parameters of water samples showed very low values of dissolved oxygen (DO) and biochemical oxygen demand (BOD), but with high chemical oxygen demand (COD). DO was present in the range of 1.40–1.70 mg/L at Adoka location and 1.63–1.66 at Oju sample locations. These values are far below the WHO recommended limit of 5–7 mg/L. The implication is that the stored rainwater is poorly aerated and is susceptible to contamination arising from either biochemical process, oxidation of substances in them or decomposition of organic matter (Sekabira *et al.* 2010). Hence, this can be seen in the high COD values recorded in the range of 140.00–193.33 mg/L at Adoka and 163.33–206.67 mg/L at Oju locations; this is a measure of the extent to which oxygen was required to break down both inorganic and organic particles in the rainwater samples (Tyohemba *et al.* 2017).

Biochemical processes in the water samples were very minimal, as can be observed in the range of values reported in Tables 1 and 2, but varied greatly during the period of study (% CV: 34.5–97.2). The low values of BOD and COD indicated the presence of non-biodegradable matter in the samples (Liu *et al.* 2016). These levels of biochemical parameters are, however, in conformity with regulatory limits (WHO and NSDWQ) for drinking water.

The results of trace/heavy metal ions in the stored rainwater samples are also presented in Tables 1 and 2. While aluminium and chromium were found to be below the detection limit of the instrument, their highest concentration was 0.104 and 0.012 mg/L, respectively. Zinc concentration in the samples was found to be in the range of 0.451–1.47 mg/L. These average ranges of Al, Cr and Zn found in the samples are below the corresponding drinking water standards by the WHO and NSDWQ. The concentration of iron (Fe) in all the studied rainwater samples (0.57–1.606) mg/L is above the regulatory standards (WHO and NSDWQ) of 0.3 mg/L (Tables 1 and 2). Iron produces a metallic taste in water and causes yellowish stains on laundry and has a strong influence on the colour of a water body (Parrott & Ross 2009).

The other heavy metals, cadmium, nickel and lead, investigated in this study were also found to be above the maximum recommended limits in all the rainwater samples. Their concentrations were found to vary widely during the three months of study. Rainwater polluted with heavy metals is known to be associated with corrosion of roofing materials. Urban roof catchments can also be a source of inorganic contaminants for rainwater (Sánchez *et al.* 2015).

## Microbial analysis

Total coliform (Table 6) indicates the absence of coliform bacteria in all the samples collected in February. However, coliform bacteria were detected in samples collected in March and April with values ranging between 130 and 270 (cfu/100 mL) and 170 and 182 (cfu/100 mL) in Adoka and Oju, respectively. The presence of coliform as usage time increases could be as a result of improper handling as the water is being used. The results were higher than the permissible limits set by regulatory bodies (WHO and NSDWQ). The high coliform values could be as a result of high temperatures associated with the season (Palamuleni & Akoth 2015), or due to the droppings of waste from insects and lizards which may have entered the water as it is used. Studies by Achadu *et al.* (2015) indicate that there is a correlation between pH and the growth of coliforms in rainwater stored in tanks. This shows that microorganisms tend to grow more at high pH. From the result of the coliform count, stored water in some of the locations was heavily contaminated and therefore unfit for drinking after the first month of usage.

**Table 6** | Microbiological result of stored rainwater for February 2017 sampled at Adoka and Oju

| | Total coliform count (cfu/100 mL) | | | Regulatory standards | | |
|---|---|---|---|---|---|---|
| Sample ID | February | March | April | WHO (2011) | SON (2017) | NSDWQ (2007) |
| Okpaflo | ND | 130.00 ± 1.4 | 342.00 ± 3.6 | 800 | 0 | 10 |
| Adoka main town | ND | 270.00 ± 2.9 | 402.00 ± 16.9 | 0 | 0 | 10 |
| Opa | ND | 242.10 ± 1.7 | 350.00 ± 2.9 | 0 | 0 | 10 |
| Ojenya | ND | 192.00 ± 4.2 | 394.00 ± 6.5 | 0 | 0 | 10 |
| Oju main town | ND | 170.00 ± 0.00 | 286.00 ± 2.5 | 0 | 0 | 10 |
| Okonga-Ainu | ND | 178.00 ± 0.4 | 340.00 ± 4.3 | 0 | 0 | 10 |

**Table 7** | Correlation between physicochemical parameters and heavy metals

**(a)**

| | Temp. | Colour | pH | EC | Turbidity | TDS | TSS | TH |
|---|---|---|---|---|---|---|---|---|
| Temp. | 1 | | | | | | | |
| Colour | 0.396 | 1 | | | | | | |
| pH | −0.101 | −0.131 | 1 | | | | | |
| Electrical conductivity | 0.729 | 0.036 | 0.308 | 1 | | | | |
| Turbidity | −0.705 | −0.511 | −0.413 | −0.413 | 1 | | | |
| Total dissolved solids | 0.730 | 0.057 | 0.333 | 0.997 | −0.438 | 1 | | |
| Total suspended solids | −0.552 | −0.344 | −0.660 | −0.453 | 0.944 | −0.489 | 1 | |
| Total hardness (TH) | −0.604 | 0.196 | −0.611 | −0.824 | 0.607 | −0.836 | 0.728 | 1 |
| Nitrates ($NO_3^-$) | 0.321 | 0.749 | 0.214 | 0.276 | −0.471 | 0.263 | −0.354 | −0.031 |
| Chloride ($Cl^-$) | 0.095 | 0.666 | 0.301 | 0.310 | −0.201 | 0.313 | −0.202 | 0.018 |
| Phosphate ($PO_4^{3-}$) | 0.030 | −0.650 | 0.538 | 0.599 | 0.084 | 0.572 | −0.088 | −0.651 |
| Sulphates ($SO_4^{2-}$) | 0.660 | 0.516 | −0.464 | 0.317 | −0.299 | 0.349 | −0.174 | −0.093 |
| BOD | −0.109 | −0.658 | 0.379 | 0.524 | 0.345 | 0.528 | 0.095 | −0.504 |
| COD | 0.599 | −0.372 | 0.449 | 0.758 | −0.501 | 0.757 | −0.585 | −0.957 |
| DO | −0.216 | −0.432 | −0.096 | 0.192 | 0.568 | 0.131 | 0.576 | 0.085 |
| Al | 0.318 | −0.447 | 0.340 | 0.467 | −0.273 | 0.424 | −0.268 | −0.617 |
| Cr | −0.091 | −0.049 | 0.103 | −0.332 | −0.235 | −0.372 | −0.112 | 0.100 |
| Fe | 0.687 | −0.082 | 0.253 | 0.990 | −0.305 | 0.984 | −0.354 | −0.809 |
| Zn | −0.360 | 0.170 | −0.660 | −0.799 | 0.350 | −0.781 | 0.458 | 0.784 |
| Cd | −0.494 | 0.002 | 0.835 | −0.235 | −0.213 | −0.204 | −0.433 | −0.107 |
| Ni | 0.096 | 0.034 | 0.662 | 0.475 | −0.290 | 0.447 | −0.356 | −0.439 |
| Pb | 0.426 | −0.335 | 0.085 | 0.838 | 0.087 | 0.833 | −0.012 | −0.622 |

**(b)**

| | $NO_3^-$ | $Cl^-$ | $PO_4^{3-}$ | $SO_4^{2-}$ | BOD | COD | DO | Al |
|---|---|---|---|---|---|---|---|---|
| Nitrates ($NO_3^-$) | 1 | | | | | | | |
| Chloride ($Cl^-$) | 0.867 | 1 | | | | | | |
| Phosphate ($PO_4^{3-}$) | −0.076 | −0.008 | 1 | | | | | |
| Sulphates ($SO_4^{2-}$) | −0.012 | 0.025 | −0.496 | 1 | | | | |
| BOD | −0.412 | −0.076 | 0.782 | −0.149 | 1 | | | |
| COD | −0.129 | −0.251 | 0.689 | 0.044 | 0.493 | 1 | | |
| DO | 0.113 | 0.150 | 0.630 | −0.523 | 0.392 | 0.021 | 1 | |
| Al | 0.099 | −0.182 | 0.760 | −0.460 | 0.238 | 0.742 | 0.484 | 1 |
| Cr | 0.287 | −0.133 | 0.051 | −0.616 | −0.539 | 0.014 | 0.192 | 0.571 |
| Fe | 0.159 | 0.215 | 0.648 | 0.302 | 0.606 | 0.773 | 0.257 | 0.481 |
| Zn | −0.394 | −0.372 | −0.850 | 0.297 | −0.520 | −0.722 | −0.436 | −0.745 |
| Cd | 0.179 | 0.285 | 0.120 | −0.568 | 0.042 | −0.064 | −0.250 | −0.040 |
| Ni | 0.666 | 0.596 | 0.652 | −0.547 | 0.197 | 0.346 | 0.496 | 0.635 |
| Pb | −0.180 | 0.027 | 0.653 | 0.292 | 0.818 | 0.627 | 0.355 | 0.296 |

*(continued)*

**Table 7** | continued

| | Cr | Fe | Zn | Cd | Ni | Pb |
|---|---|---|---|---|---|---|
| Cr | 1 | | | | | |
| Fe | −0.372 | 1 | | | | |
| Zn | −0.109 | −0.777 | 1 | | | |
| Cd | 0.211 | −0.302 | −0.197 | 1 | | |
| Ni | 0.395 | 0.416 | −0.868 | 0.414 | 1 | |
| Pb | −0.603 | 0.901 | −0.573 | −0.402 | 0.159 | 1 |

### Correlation between physicochemical parameters

Tables 7(a) and 7(b) show the correlation analysis carried out to detect common sources of chemical species determined in the stored rainwater samples. Electrical conductivity correlated to species such as $PO_4^{3-}$, $Fe^{2+}$, $Pb^{2+}$, TDS, COD and BOD with r = 0.599, 0.990, 0.838, 0.944, 0.758 and 0.599. Conductivity is a function of ionic species in a solution, which in turn are strongly dependent on the total dissolved solids in a solution. TDS also showed fair to strong correlation with all the species mentioned above. There is a strong correlation between turbidity and TSS (r = 0.944), an indication that the turbidity arose from the suspended particles in the stored rainwater. Another species that showed a marked relationship with many others was phosphate which showed a fair to strong correlation with BOD, COD and DO as well as $Al^{3+}$, $Fe^{2+}$ and $Pb^{2+}$ (r = 0.782, 0.689, 0.630, 0.760, 0.648 and 0.653). Nickel was found to show a fair to good positive correlation with $PO4^{3-}$, $NO^{3-}$ and $Cl^{-}$ anions (r = 0.652, 0.666 and 0.867). The metal Al was found to be positively correlated with Cr and Ni while Fe and Pb were strongly correlated (r = 0.901). As pointed out earlier, some of these metals in rainwater could originate from the same source of corroding roofing materials.

## CONCLUSION

The assessment of the stored rainwater in the study area indicates that the water is a good source of water in terms of physiochemical qualities, but as the time of storage and usage increases the water became polluted. All the quality parameters tested were found to be within the accepted limits by WHO and NSDWQ guidelines. The presence of metallic ions, iron, cadmium, nickel and lead in the water was found to be above the maximum regulatory limits. The stored rainwater could be a source of potable water for up to three months if care is taken during usage. Also, the water should not be collected from old roofing materials which may corrode easily.

## ACKNOWLEDGEMENT

The authors are grateful to the Tertiary Education Trust Fund (TETFund) for providing the grant for this study. We acknowledge the staff of the Analytical Laboratory, Federal Ministry of Agriculture, Kaduna State for allowing us to use their laboratory equipment.

## REFERENCES

Achadu, O. J., Ochefu, A. A., Akogwu, S. A., Ako, F. E. & Ochimana, I. O. 2015 Assessment of the levels of cadmium and lead in wells and boreholes water within Wukari, North-Eastern Nigeria. *International Journal of Chemistry and Aquatic Sciences* **1** (1), 11–19. http://chemistryjournal.kypublications.com/.

Adeniyi, I. & Olabanji, I. 2005 The physico-chemical and bacteriological quality of rainwater collected over different roofing materials in Ile-Ife, southwestern Nigeria. *Chemistry and Ecology* **21** (3), 149–166.

Aladenola, O. O. & Adeboye, O. B. 2010 Assessing the potential for rainwater harvesting. *Water Resources Management* **24** (10), 2129–2137.

Atobatele, O. E. & Ugwumbe, O. A. 2008 Seasonal variation in the physicochemistry of a small tropical reservoir (Aiba

Reservoir, Iwo, Osun, Nigeria). *African Journal of Biotechnology* **7** (12), 1962–1972.

Chukwuma, E., Nzediegwe, C., Umeghalu, E. & Ogbu, K. 2012 Quality assessment of direct harvested rainwater in parts of Anambra State, Nigeria. *Special Publication of the Nigerian Association of Hydrological Sciences* 201–207.

Despins, C., Farahbakhsh, K. & Leidl, C. 2009 Assessment of rainwater quality from rainwater harvesting systems in Ontario, Canada. *Journal of Water Supply: Research and Technology-Aqua* **58** (2), 117–134.

Ebong, G. A., Etuk, H. S., Ekong, C. I. & Dan, E. U. 2016 Impact of human activities on rainwater quality in south-south region of Nigeria. *Journal of Applied Life Sciences International* **9** (3), 1–11.

Henderson, G., Harris, W., Todd Jr, D. & Grizzard, T. 1977 Quantity and chemistry of throughfall as influenced by forest-type and season. *The Journal of Ecology* **65** (2), 365–374.

Lee, J. Y., Yang, J.-S., Han, M. & Choi, J. 2010 Comparison of the microbiological and chemical characterization of harvested rainwater and reservoir water as alternative water resources. *Science of the Total Environment* **408** (4), 896–905.

Liu, X., Li, Y., Liu, C., Zhang, L., Yuan, H., Fu, C. & Ashraf, M. A. 2016 Identification of residual non-biodegradable organic compounds in wastewater effluent after two-stage biochemical treatment. *Open Life Sciences* **11**, 396–401. DOI: 10.1515/biol-2016-0053.

Mendez, C. B., Klenzendorf, J. B., Afshar, B. R., Simmons, M. T., Barrett, M. E., Kinney, K. A. & Kirisits, M. J. 2011 The effect of roofing material on the quality of harvested rainwater. *Water Research* **45** (5), 2049–2059.

Musa, J. J., Anijiofor, S. C., Saidu, M. & Bake, G. G. 2017 Effects of roofing materials on harvested rain water quality in Minna, Nigeria. *Asia Pacific Environmental and Occupational Health Journal* **3** (1), 44–51.

NSDWQ 2007 *Nigerian Standard for Drinking Water Quality*. Standards Organization of Nigeria, Abuja, Nigeria.

Oklo, D. & Asemave, K. 2011 Potability of harvested rain water in some Local Government Areas of Benue State of Nigeria. *International Journal of Research in Environmental Science and Technology* **2** (3), 65–68. http://www.urpjournals.com.

Orpin, J. B. & Mzungo, I. 2017 *Prevalence of Urinary Schistosomiasis in Oju Local Government Area of Benue State Nigeria*. https://www.researchgate.net/publication/320689959_Prevalence_of_Urinary_Schistosomiasis_in_Oju_Local_Government_Area_of_Benue_State_Nigeria (accessed 2 October 2018).

Palamuleni, L. & Akoth, M. 2015 Physico-chemical and microbial analysis of selected borehole water in Mahikeng, South Africa. *International Journal of Environmental Research and Public Health* **12** (8), 8619–8630.

Parrott, K. R. & Ross, B. 2009 *Interpreting Your Water Test Report*. Virginia Cooperative Extension Publication 356-489, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA.

Sánchez, A., Cohim, E. & Kalid, R. 2015 A review on physicochemical and microbiological contamination of roof-harvested rainwater in urban areas. *Sustainability of Water Quality and Ecology* **6**, 119–137. doi:10.1016/j.swaqe.2015.04.002.

Sazakli, E., Alexopoulos, A. & Leotsinidis, M. 2007 Rainwater harvesting, quality assessment and utilization in Kefalonia Island, Greece. *Water Research* **41** (9), 2039–2047.

Sekabira, K., Origa, H. O., Basamba, T., Mutumba, G. & Kakudidi, E. 2010 Heavy metal assessment and water quality values in urban stream and rain water. *International Journal of Environmental Science & Technology* **7** (4), 759–770.

SON 2017 Nigerian standards for drinking water quality (NSDWQ), Industrial standards. SON, 554.

Tyohemba, R. L., Atsar, F. S., Ajegi, J. O., Ukpelle, U. C. & Uzah, T. T. 2017 Evaluation of pollution potential of wastewaters from some hair dressing salons in Makurdi metropolis. *Journal of Life & Physical Sciences* **9** (1), 90–96.

Utsev, J. T. & Aho, M. I. 2012 Water shortage and health problems in Benue State-Nigeria: impacts and prospects for solutions. *International Journal of Scientific and Technology Research* **1** (8), 79–85.

WHO 2011 *Guidelines for Drinking-Water Quality*, Vol. 38. WHO Chronicle, Geneva, pp. 104–108.

Wohlson, T., Bates, J., Vesey, G., Robinson, W. A. & Katouli, M. 2006 Evaluation of the methods for enumerating coliform bacteria from water samples using precise reference standards. *Letters in Applied Microbiology* **42** (4), 350–356. doi:10.1111/j.1472-765X.2006.01854.x.

Wu, L., Gao, J., Zhao, W., Xu, X., Yin, Y. & Wu, L. 2017 Quality assessment of rainwater and harvested rainwater stored in different types of cisterns. *Water Science and Technology: Water Supply* **17** (3), 652–664.

Zhu, K., Zhang, L., Hart, W., Liu, M. & Chen, H. 2004 Quality issues in harvested rainwater in arid and semi-arid Loess Plateau of northern China. *Journal of Arid Environments* **57** (4), 487–505.

First received 16 July 2018; accepted in revised form 26 January 2019. Available online 29 March 2019