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Roof age effect on the quality of harvested rainwater and its health implication in a selected location, Southwest Nigeria

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Rainwater for potable uses has increased in developing countries due to population increase and the failure of conventional means of water supply. However, the quality of roof harvested rainwater and its health implication are issues that require urgent attention. The quality of rainwater harvested from galvanized roofing sheets (GRS) of different ages was investigated. Rainwater samples were collected on monthly basis from roofs of 5, 10 and 15 years between July and September and for three consecutive years. The samples were analysed using standard methods for physical, chemical and microbial parameters. A comparison of means was done using the Duncan Multiple Range Test ($p < 0.05$). The water quality results were compared with 3 established standards (NSDWQ, 2007; WHO, 2011 and USEPA, 2012) for drinking water. There was no significant difference in the quality of harvested rainwater from roof of different ages. The pH of the samples fall within the standard range of 6.5 to 8.5, while an average of 41.96 mg/L for total hardness is far below the minimum permissible value of 150 mg/L. The Lead concentration which ranges between 0.0033 and 0.0055 mg/L is also below the permissible range of 0.01to 0.015 mg/L. The feacal coliform *Escherichia coli* count of 0 cfu/ml does not show biological contamination and is in tandem with the standards. However, treatment may be required for total coliform count as indicated in NSDWQ (2007). It is concluded that rainwater harvested from GRS of different ages in Ogbomoso, Southwest Nigeria is of a quality which does not have or indicate serious health impact.

Key words: Rainwater harvesting, alternative water sources, water security, water quality, roofs age, public health, Nigeria, Africa.

INTRODUCTION

Water scarcity is one of several issues facing the world today. Water demand has increased over the last half-century and signs of water shortages have become common place (Miller, 1989; IPPC, 1990; Matondo et al., 2005; Kaldellis and Kondili, 2007). In many developing and underdeveloped economies, water supply to communities by conventional means shows a shortfall. In rural and semi-urban communities of Nigeria, apart from

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high poverty levels, rainwater harvesting as a means of solving water supply problems of inhabitants is widespread (Coker, 1999 and Lucas et al., 2005) and even to urban communities (Oni et al., 2008). Rainwater harvesting is a term used for the collection and storage of rainwater from rooftops catchments using simple techniques such as pots, tanks and cisterns as well as complex techniques such as underground check dams (Appan, 1999; Makoto, 1999; Prinz, 1999). Rainwater harvesting systems has the potential to mitigate water scarcity experienced by major cities and may bea solution to water scarcity depending on regional conditions (Hatibu et al., 2006; Hartung, 2007; Ghisi and Ferreira, 2007). The rainwater collection system relies on the provision of catchment area such as building roofs, then the collection and transport channels (gutters and pipelines), followed by storage facility and then discharges (Han et al., 2004). Some studies have highlighted the economic, social and environmental benefits of harvesting rainwater as an alternative water source (Hatibuet al., 2006; Hartung, 2007; Sturm et al., 2009). The issue of quality of harvested rainwater compared to surface or reservoir water has become a controversial one (Zhu et al., 2004). Deteriorations during harvesting, storage and household use have been reported (WHO, 2011). External pollution sources have the potential to influence rainwater quality (Simmons et al., 2001; Chang et al., 2004; Zhu et al., 2004; Sazakli et al., 2007). Several types of contaminants have been found in harvested rainwater which include heavy metals (Forter, 1999; Lee et al., 2010) and pathogenic bacteria (Ahmed et al., 2008). Cleanliness, age of catchment and atmospheric condition also contribute to harvested rainwater quality (Yaziz et al., 1989; Simmons et al., 2001; Chang et al., 2004; Zhu et al., 2004). Roof materials and age may be a source of environmental chemicals to rainwater over time. To the best of our knowledge, only a few studies have focused on the effects of roof type and age on the quality of harvested rainwater and their implication on health. This study examines the level of some elements in harvested rainwater samples from the popular galvanized iron sheet roof of different ages and the implication on the public health in Ogbomoso, an urbanized area in Southwestern Nigeria.

MATERIALS AND METHODS

The study was carried out in Ogbomoso (8°10`N, 4°10`E) Southwestern Nigeria. The mean annual rainfall is about 1200 mm and the mean maximum and minimum temperatures are33 and 28°C respectively. The relative humidity of the area is relatively high (approximately 74%) throughout the year except in January when the dry wind blows from the North (Olaniyi et al., 2010). Majority of the residents depend on groundwater (Adetunde et al., 2011) due to inadequate supply from the Ogbomoso zone of the Oyo State Water Corporation (Toyobo et al., 2011).

Rainwater samples were collected on monthly basis during rainy season (July – September) of 2009 to 2011 in 750 ml sample bottles in triplicates from roof of ages 5, 10 and 15 years. Three samples were also collected from an open place where the rainwater has no contact with any roof to serve as control. The surface of the roof was allowed to be washed by the first few millimeter of rain otherwise referred to as first flush (Yaziz et al., 1989). Samples for heavy metals were acidified with concentrated HNO_3 to keep the metals in solution and to minimize their adsorption to the walls of the sample bottles.

Physico-chemical parameters tested in the samples include pH, conductivity, total hardness (TH), total solids (TS), total dissolved solids (TDS), turbidity, specific gravity, Pb^{2+}, Cd^{2+} , Ca^{2+} , Mg^{2+}, Fe^{2+}, Al^{3+}, Cu^{2+}, NO_3^-, Cl^- and NH_4^+. Microbial parameters analysed include total aerobic count, total coliform count, faecal coliform count and *Escherichia coli* count. Each water sample was analyzed following procedures described by APHA (1998). Comparison of means was done using Duncan's multiple range test at $p<0.05$ level of significance using SPSS V.17 statistical software. The results were compared with three drinking water standards namely NSDWQ (2007), WHO (2011) and USEPA (2012).

RESULTS AND DISCUSSION

The results of the physico-chemical and microbial analysis of the rainwater samples are presented in Tables 1 to 3. The means of the parameters for rainwater harvested from three roofs show no significant difference in quality. However, the results from the control indicate a significant difference for TH and TDS. This difference could be attributed to dry deposits carried by rainwater from the roofs (Rodrigo et al., 2009). It is to be noted that roofs when eroded by water running over them release reddish-brown rust material into the water this being responsible for the difference in Fe^{2+} content of rainwater from roofs as compared to the control. The differences in total aerobic and total coliform counts for the control and rainwater harvested from the roofs could be traced to bird droppings and organic decomposition on the roof catchment which were absent in the sample directly from the sky (Rodrigo et al., 2009).

Physical parameters

The pH of the harvested rainwater from different roof ages was in the near-neutral range (pH 6.0 to 7.5). The mean pH was 6.78, 6.71 and 6.8 for samples from roofs of ages 5, 10 and 15 years respectively. The pH from the control sample was 6.94 (Table 1). There was no significant difference in the pH of rainwater from galvanized roofing sheets (GRS) of different ages and the control. Although pH usually has no direct impact on consumers (NSDWQ, 2007), it is one of the most important operational water quality parameters. The pHs of the samples which are in 6.5 to 8.5 range would contribute minimally to the corrosion of water mains and pipes in household water systems. There was no significant difference between the mean values of conductivity of water from the roofs of ages 5 and 15 years (15.27 and 14.67 µs/cm) and that of the control (10.46 µs/cm). A significant difference however existed

Table 1. Physical parameters of harvested rainwater in Ogbomosho compared to control and standards.

Roof ages (years)	pH	Conductivity (µs/ cm)	Total hardness (mg/L)	Total solids (mg/L)	Total dissolved solids (mg/L)	Turbidity (mg/L SiO_2)	Specific gravity (g/cm^3)
15	6.84 [a*]	14.67 [a]	40.89[a]	1199.78 [a]	72.78 [a]	0.33 [a]	0.99 [a]
10	6.71 [a]	8.54 [b]	43.04 [a]	1212.33 [a]	66.67 [a]	0.33 [a]	0.99 [a]
5	6.78 [a]	15.27 [a]	42.72 [a]	1215.00 [a]	67.22 [a]	0.33 [a]	0.99 [a]
Control	6.94 [a]	10.46[ab]	35.77 [b]	942.56 [b]	33.33 [b]	0 [a]	0.99 [a]
Standards							
NSDWQ 2007	6.5 – 8.5	1000	150	NA	500	5	NA
WHO 2011	6.5 – 8.5	NA	NA	NA	600	5	NA
USEPA 2012	6.5 – 8.5	NA	NA	NA	500	5	NA

*Means in columns of same parameter followed by same letters are not significantly different ($p<0.05$, Duncan's multiple range test), NA means Not Available.

between the values for and that of the roof of age 10 years (8.54 µs/cm) as shown in Table 1.The value for roof of age 10 years is not significantly different from the control as well. The values are however, below the maximum permissible value of1000 µs/cm by the NSDWQ. Thus, consumption of rainwater from the roofs poses no health risk in terms of conductivity. The mean total hardness (TH) of water from the roofs ranged from 40.89 mg/l to 43.04 mg/l while that of the control is 35.77 mg/L. There was no significant difference in the TH of water from the three roofs, although there is a significant difference in the value of the control. The difference in the TH value for the roofs and the control may be attributed to the presence of impurities on the surface of the roofs. The value of TH is however, lower than the minimum permissible value of 150 mg/L by the NSDWQ. Thus the TH has no health implication. There is no significant difference in the values of TS obtained from water from the three roofs (Table 1). However, the values are significantly higher than 942.56 mg/L of the control. The values of TDS obtained for water from the roofs are far below the limits set by the standards (Table 1). This indicated that rainwater from GRS of different ages is suitable for potable use in terms of TDS as the water could be considered soft. However, the level of TDS may affect the use of the water for other purposes such as laundry, and may also affect plumbing fittings. This difference may be attributed to the presence of dust particles on the surface of the roofs. The mean value of turbidity of water from the three roofs is 0.33 mg/L SiO_2. The value is not significantly different from the 0 mg/L SiO_2 of the control. This indicated that age of roof has not significantly impacted on the turbidity of rainwater.The value of 0.33 mg/L SiO_2 falls far below the permissible value of 5 mg/L SiO_2 stipulated by the three drinking water standards considered. Thus the consumption of rainwater from GRS of ages 5, 10 and 15 years pose no health risk to the consumer.

Chemical parameters

The mean value of Pb^{2+} in water from the three roofs ranged from 0.0033 to 0.0055 mg/L whiles the value for the control is 0 mg/L (Table 2). There is no significant difference in the concentration of lead in water from the three roofs and the control. Traces of Pb^{2+} in the rainwater samples can be attributed to the washings from particulates in the air resulting from automobile emissions and other industrial sources in the collection areas (Olobaniyi and Efe, 2007). However, concentrations were below the permissible levels proposed by WHO, USEPA and NSDWQ (Table 2), and as such, the use of rainwater from the roofs may not pose any health risk. Cd^{2+} was not detected in all the water samples (and the control). The water from the roof may be considered safe for potable uses as far as cadmium contamination is concerned. The values obtained for Fe^{2+} concentration are 0.100, 0.067 and 0.013 mg/L for 15, 10 and 5 years GRS respectively. These values are not significantly different (Table 2). The values are however significantly different from the control (0.013 mg/L) except for the value of 10 year GRS that is not significantly different. All the values are below the maximum limit allowable for Fe^{2+} concentration in the drinking water standard considered. Water from the roofs of different ages is safe for potable use in terms of iron concentration. No trace of Al^{3+} was detected in water from the roofs and the control. The water seems to be free of Al^{3+} contamination. The levels of Cu^{2+} in water from the GRS ranged between 0.050 – 0.051 mg/L (Table 2). There is no significant different in the level of copper from samples collected from roofs of different ages. However, the roofs have significantly added to the levels of copper in the water samples (Table 2) as indicated by 0 mg/L value of Cu^{2+} in the control. There may not be any danger of using water from the roofs for domestic purposes in terms of copper contamination as the values in water from all the roofs fall far below the

Table 2. Chemical parameters of harvested rainwater in Ogbomosho compared to control and standards (mg/L).

Roof ages (years)	Pb^{2+}	Cd^{2+}	Fe^{2+}	Al^{3+}	Cu^{2+}	NO_3^-	Cl^-	NH_4^+
15	0.0044 [a*]	0 [a]	0.100 [a]	0 [a]	0.050 [a]	0.26 [a]	0.27[ab]	0 [a]
10	0.0055 [a]	0 [a]	0.067[ab]	0 [a]	0.050 [a]	0.27 [a]	0.39 [a]	0 [a]
5	0.0033 [a]	0 [a]	0.100 [a]	0 [a]	0.051 [a]	0.18 [a]	0.23[ab]	0 [a]
Control	0 [a]	0 [a]	0.013 [b]	0 [a]	0 [b]	1 [a]	0.013 [b]	0 [a]
Standards								
NSDWQ 2007	0.01	0.003	0.3	0.2	1	50	250	NA
WHO 2011	0.01	0.003	0.3	0.1	2	50	5	35
USEPA 2012	0.015	0.005	0.3	0.2	1	10	4	30

*Means in columns of same parameter followed by same letters are not significantly different ($p<0.05$, Duncan's multiple range test), NA means Not Available.

Table 3. Microbiological parameters of harvested rainwater in ogbomoso compared to control and standards (cfu/ml).

Roof ages (years)	Total aerobic count	Total coliform count	Faecal coliform count	*E. coli* count
15	2767 [a*]	157 [a]	0 [a]	0 [a]
10	3467 [a]	150 [a]	0 [a]	0 [a]
5	3267 [a]	127 [a]	0 [a]	0 [a]
Control	120 [b]	0 [b]	0 [a]	0 [a]
Standards				
NSDWQ 2007	NA	10	0	0
WHO 2011	NA	NA	NA	NA
USEPA 2012	NA	NA	0	NA

*Means in columns of same parameter followed by same letters are not significantly different ($p<0.05$, Duncan's multiple range test), NA means Not Available.

maximum limit set by the standards. Table 2 shows that the average values of NO_3^- ranged from 0.18 – 0.27 mg/L in the samples from the GRS while the value for the control is 1 mg/L. There was no significant difference between the levels of NO_3^- in all the samples including the control. Thus the roofs have no significant effect on the level of NO_3^- in rainwater. All the values are below the recommended maximum values by the standards considered. Care must be taken, especially with infants, in the use of rainwater. When water with high concentration of NO_3^- (above 10 mg/L) is consumed by infants less than three months, it may lead to cyanosis and asphyxia (blue baby syndrome) (NSDWQ, 2007). Although the concentration of NO_3^- in the rainwater were within the acceptable standards (Table 2), it is only USEPA standard that has a maximum permissible value of 10 mg/L. The Cl^-values of 0.27, 0.39 and 0.23 mg/L in water from 15, 10 and 5 years GRS are not significantly different. These values are not significantly different from the control (0.013 mg/L) except the value from the 10 years GRS (Table 2). The values of chloride in the tested samples were far below the maximum limit provided by the three drinking water standards considered. High concentration of chlorine has no health implication (WHO, 2011); it may however affect the taste of the water. There were no traces of NH_4^+ in all the water samples.

Biological parameters

Total aerobic count (TAC) ranged between 2767 to 3467 cfu/ml (Table 3). There is no significant difference in the values of the TAC in the water from the roofs. There is however, a sharp difference in the value of TAC contamination in the control (120 cfu/ml) when compared with the water from the roofs. This indicated that runoff from roofs have been contaminated. There are no recommended values for TAC. The values of 157, 150 and 127 cfu/ml were recorded for the total coliform count (TCC) for water from 15, 10 and 5 years GRS respectively. There is no significant difference in the values. A significant difference however exists between the values of TCC of water from the roofs and the control. The control has a value of 0 cfu/ml. This implies that roof has introduced coliform contamination to the water. This may be due to the fact that roof harbours animals (rodents, birds and bat) and dead leaves. These animals defecate on the roofs. Some of the animals may die and decay on the roof. While the dead animals and leaves are decaying, micro organism may be introduced. The values of TCC in water from all the roofs and the control are far above the limit of 10cfu/ml prescribed by the NSDWQ. This indicated that rainwater requires treatment for biological contaminations before it could be safe for potable use. One of the cheapest methods of achieving save rainwater is the application of first flush (Yaziz et al., 1989; Combees et al., 2000). Both the faecal coliform count and *E. coli* were 0 cfu/ml (Table 3). Thus the water is safe in terms of these contaminants.

Conclusion

There were no significant difference in the quality of water obtained from roof of different ages, though roofs impacted on the quality. The physical, chemical and microbiological parameters determined in the rainwater samples were found to be within the acceptable limits of the three standards for drinking water quality (NSDWQ, 2007; WHO, 2011; USEPA, 2012) except for the TCC that was found to be above the NSDWQ (2007) standard. However, the uses first flush and boiling will eliminate this problem. Thus waters collected from the roofs are suitable for drinking. However, care must be taken not to introduce impurities during storage and withdrawal.

Conflict of Interest

The authors have not declared any conflict of interest.

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