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Assessment of Roof Harvested Rainwater in Parts of Anambra State for Environmental Pollution Monitoring

J. N. Chukwuma[1], V. C. Nnodu[1], A. C. Okoye[1] and E. C. Chukwuma[2*]

[1]Department of Environmental Management, Nnamdi Azikiwe University Awka, Anambra State, Nigeria.
[2]Department of Agricultural and Bioresources Engineering, Nnamdi Azikiwe University Awka, Anambra State, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author VCN and ACO designed the study. Author ECC performed the statistical analysis. Author JNC wrote the protocol and wrote the first draft of the manuscript. All Authors managed the analyses of the study. Author JNC managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Questions have been raised about the quality of roof harvested rainwater which has been shown to be temporally and spatially variable and at times not in compliance with drinking water guidelines. This study is therefore an investigation on the quality of roof harvested

**Corresponding author: Email: ecchukwuma@yahoo.com;*

rainwater consumed by rural communities in parts of Anambra State Nigeria. The physico-chemical and microbiological parameters of the rainwater samples collected in the study area were analyzed with the view of determining the level of contamination as a result of anthropogenic activities in the study area. Roof harvested rainwater were collected from three stations, and a free-fall harvested rainwater sample was used as a control. The result shows that the physico-chemical parameters were all within permissible water quality standard as recommended by National Agency for Food and Drug Administration Control (NAFDAC) except for the presence of particles and for the micro-biological properties which were found quite unsatisfactory. Pearson Correlation Matrix of physico-chemical properties conducted indicated a strong positive correlation between Zinc and Iron which emphasizes common pathway and origin. The water samples were assessed using Water Quality Index (WQI), the WQI for the station 1, 2 and 3 were 71.68%, 60.19%, and 77.55% respectively. Low-cost microbial disinfection such as solar disinfection and pre-filtration or otherwise the proper maintenance of the entire Rain Water Harvesting (RWH) system could make the harvested roof rainwater potable for the study area.

Keywords: Roof harvested rainwater; water quality monitoring; environmental pollution; water quality index; Nigeria.

1. INTRODUCTION

Harvested rainwater (HRW) has been considered an effective alternative water source for drinking and various non-potable uses in a number of countries throughout the world. The most significant issue in relation to using untreated HRW for drinking or other potable uses, however, is the potential public health risks associated with microbial pathogens [1]. Rainwater harvesting can be classified into two broad categories: land-based and roof-based. Land-based rainwater harvesting occurs when rainwater runoff from the land is collected in ponds and small impoundments before it has a chance to reach a river or stream. Roof-based harvesting, on the other hand, involves collecting the rainwater that falls on a roof before the water even reaches the ground [2]. Roofs represent an important percentage of the large impermeable areas covered by cities and communities, hence offering a significant possibility for rainwater collection. Factors such as type of roof material; dry period and surrounding environmental conditions; faecal droppings by birds; lizards, rodents and cats, which can access rainwater catchments areas, may transfer pathogenic microbes that are harmful to health and influence rainwater quality [3,4]. The typical roofing materials that are commonly used in Nigeria today include ceramic tiles, metal sheets, galvanized iron, anodized aluminum and asbestos. All these materials are potential source of dissolved ions, alkalinity and trace metals [5]. Diseases caused through consumption of contaminated water, and poor hygiene practices are the leading cause of death among children worldwide, after respiratory diseases [6].

Experience of water shortage in developing countries and communities has made residents to resort to sourcing potable water from harvested rainwater. Oko community as in most communities in developing countries often depends on roof harvested rain water for their water use during raining season. There is no central water supply system in the study area, the geology of the study area is such that groundwater is not easily accessible; the tortuous path leading to the stream (available surface water) and poor quality of the stream as a result of upstream activities discourages people from sourcing potable water from it. Roof-harvested rainwater is used in areas having significant rainfall but lacking conventional water supply system, and where fresh surface water or ground water is lacking [7]. While studies, such as rooftop rainwater harvesting study in Bangladesh, show that ingesting untreated rainwater can pose a significant health burden, outbreaks of waterborne diseases attributed to rainwater use are frequently not reported [8]. Adeniyi et al. [9] analysed trace metals in bulk freefall and roof intercepted rainwater in Ile-Ife, Southwest Nigeria. The samples of bulk freefall and roof-intercepted rainwater were collected over five roof types. They observed that the mass concentrations and percent detection of the trace metals were generally higher in roof-intercepted samples than in the free-fall with an enrichment factor within the range of 1 and 5, and the potability of bulk rainwater sources did not fall completely within the allowable guidelines of most international organizations showing rainwater sources are non-compliment with set drinking guideline in terms of bacteriological quality. According to the Australian Drinking Water Guidelines (ADWG), monitoring includes “regular sampling and testing to assess whether water quality is meeting guideline values and any regulatory requirements or agreed levels of service” [10]. The aesthetic qualities of appearance, taste and odor are generally the characteristics by which the public judges water quality. However, the absence of any unpleasant qualities does not guarantee water safety. Therefore the safety of water, in public health terms, is determined by its microbial, physical, chemical and radiological quality [10]. Hence there is need for constant investigation and monitoring of quality of water consume by communities in developing countries. It would prove useful in management, control and investigation of pollution cases, classification of water resources, and collection of baseline data, water quality surveillance and forecasting water quality. The objective of this study is to assess the quality of roof harvested rain water in the study area for environmental pollution monitoring purpose, as a result of anthropogenic activities within the study area. This will help to detect at early stage environmental pollution leading to the incidence of water borne-diseases in the study area.

2. REGIONAL SETTING

2.1 Study Area

Oko is an autonomous community situated in Orumbah North L.G.A of Anambra state, South East of Nigeria (Fig. 1), it is comprised of five villages: Ezioko, Eziabo, Okeani, Iheagwu, and Ifite. Its geographic coordinates are latitude 6" 02' 00/6” 05’ 00 North and longitude 7" 06' 00/7” 08’ 00 East. Its climate is humid. The range of its average rainfall is about 2,000 mm/year. Most rainfall occurs in well-defined rainy seasons of six to seven months (April to October) and is typically associated with high intensity storms and often causes flooding and erosion leading to the formation of gullies. The study area is characterized by vast undulating landscape and of alluvial plain. Oko is a rain forest area; greater part of its vegetation is made up of forest (tropical vegetation). The study area location is shown on Fig. 1 below.

2.2 Data Collection and Analysis

Six random samples of roof run-off from Zinc roof material and a direct sample acting as a control of rainwater samples were collected from three different locations or stations (Ezioko, Okeani and Ifite) in the study area. The roof rainwater samples were collected during one storm event in the month of August 2011 with a sterilized rainwater collector at roof runoff of the various stations. The rainwater samples were labeled accordingly and transported immediately after collection to NAFDAC Zonal laboratory Agulu in Anambra state for examination. The water samples were analyzed for physicochemical and microbiological quality. The details of the laboratory analysis are given elsewhere [11].

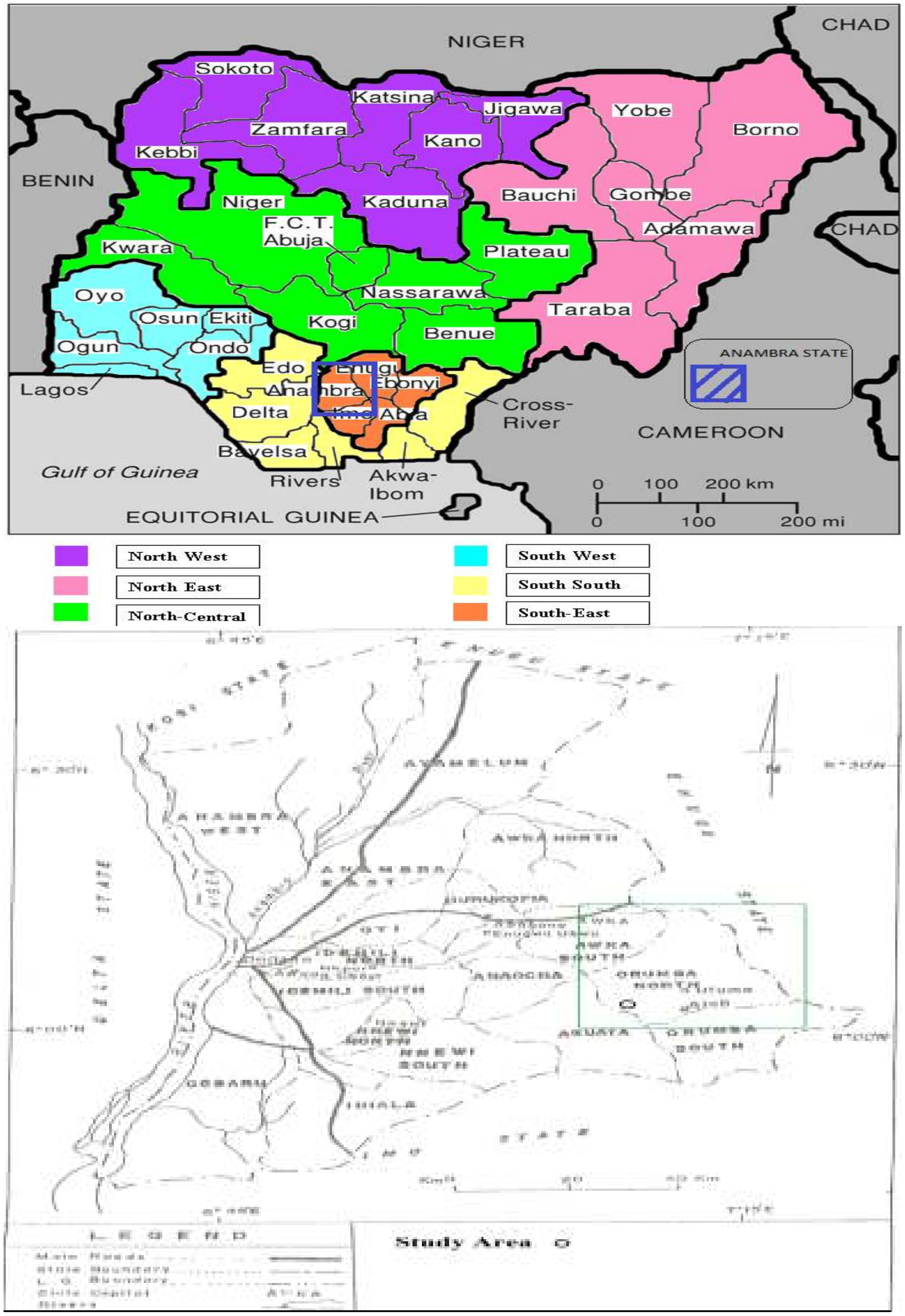

Fig. 1. Map of Nigeria and Anambra State, showing Orumbah North LGA and the study area

2.3 Water Quality Index Calculation

Water Quality Index (WQI) combines the measures of several water quality variables in such a way as to produce a single score that is representative of quality impairments or suitability of use [12]. The number of parameters used for specifying the WQI can be different in accordance with the available measured parameters. Accordingly, weighting factor for each parameter will be different; also relative impact of an individual water quality parameter can change depending on the number of parameters used for WQI [13]. The parameters used in this study are chemical water quality indicators [14] - pH, Total Dissolved Solid, Total Hardness, Calcium, Magnesium, Total Alkalinity, and Electrical Conductivity, this is also similar to [15] research work. According to [14]:

Wi α $\frac{1}{Vi}$ or Wi = $\frac{K}{Vi}$; K= $1/\sum_{i=1}^{7}\frac{1}{Vi}$

Where

$$\sum_{i=1}^{7}\frac{1}{Vi} = \frac{1}{Vi_{pH}} + \frac{1}{Vi_{TDS}} + \frac{1}{Vi_{Hardness}} + \frac{1}{Vi_{Ca}} + \frac{1}{Vi_{Total\ Alkalinty}} + \frac{1}{Vi_{EC}}$$

WQI is expressed as Wi× Vr

Where Wi is the unit weight and Vr is the rating scale, Vi is the maximum permissible limit recommended by NAFDAC. Rating scale (Vr) is divided equally and implies the level of pollution. Vr = 100 (Desirable value); Vr = 80 (Slight pollution); Vr = 60 (Moderate pollution); Vr = 40 (Excess pollution); Vr = 20 (Severe pollution)

Summation of the essential water quality parameters gives:

$Wi \times Vr = Wi_{(pH)} \times Vr_{(pH)} + Wi_{(TDS)} \times Vr_{(TDS)} + Wi_{(Total\ Hardness)} \times Vr_{(Total\ Hardness)} + Wi_{(Ca)} \times Vr_{(Ca)} + Wi_{(Mg)} \times Vr_{(Mg)} + Wi_{(Total\ Alkalinity)} \times Vr_{(Total\ Alkalinity)} + Wi_{(EC)} \times Vr_{(EC)}$

3. RESULTS AND DISCUSSION

The physiochemical and microbiological properties of the harvested rainwater samples is shown in Table 1 below.

3.1 Physico- Chemical Properties of the Roof Harvest Rainwater

Turbidity is a parameter used to assess physical contamination, it reflects the amount of particles such as silt, finely divided organic matter, and biological material collected from the rooftop during rainfall event. The table below, shows that the physical appearance of the water samples for all the stations were colorless with particles, while the control is colorless without particles. This physical contamination could be mainly due to dry deposition on the catchment surface. The odor and taste of all the water samples were satisfactory. The pH of the water samples ranged from 6.18-6.71 with an average value of 6.5. This shows that roof harvested rain water from the study area is slightly acidic. This could probably be as a result of anthropogenic activities. Since industrial activities is at the minimal at the study area, the major source of acidity could be attributed to vehicular activities, use of power generating sets of varying sizes by the residents, indiscriminate refuse burning and old practice of bush burning by few hunters and farmers in the study area. The conductivity at 23^0C ranged from 101to 680 µs. This variation could be attributed to the varying age of the roofing materials. The total solids ranged from 44.2 to 96.3mg/l while the control was 35.3mg/L, the dissolved solids ranged from 40.2 to 90.3mg/l while the control was 31.3mg/l. The catchment surface could be responsible for the slight increase of these water quality parameters above the control, however, all the sample stations falls within NAFDAC standards.

Table 1. Physiochemical and microbiological properties of rainwater sample

s/n	Test Performed	Station 1	Station 2	Station 3	Control	NAFDAC
1	Appearance	Colorless with Particles	Colorless with Particles	Colorless with Particles	Colorless	colorless
2	Odour	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	odorless
3	Taste	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	tasteless
4	Conductivity (µs) @ 23℃	$6.8*10^2$	$1.01*10^2$	$1.6*10^2$	$5.17*10^2$	1000 µs max
5	pH@ 23℃	6.61	6.18	6.71	5.59	6.5-8.5
6	Total Solids (mg/L)	44.2	62.4	96.3	35.3	500mg max
7	Total Dissolved Solid (mg/L)	40.2	61.4	90.3	31.3	500mg max
8	Suspended Solids (mg/L)	4	1	6	4	-
9	Carbon Dioxide (mg/L)	3	2	4	3	50mg max
10	Phenolphthalein Alkalinity (mg/L)	Nd	Nd	Nd	Nd	100mg max
11	Methyl Orange Alkalinity (mg/L)	8	12	20	4	100mg max
12	Total Alkalinity (mg/L)	8	12	20	4	100mg max
13	Total Hardness (mg/L)	12	6	4	Nd	100mg max
14	Chloride (mg/L)	13	11	10	8	200mg max
15	Sulphate (mg/L)	6	5	6	5	200mg max
16	Nitrate (mg/L)	0.44	2.28	0.96	1.98	50mg max
17	Nitrite (mg/L)	Nd	Nd	Nd	Nd	0.02mg max
18	Calcium	4	4	2.7	Nd	75 mg max
19	Magnesium	Nd	2	1.3	Nd	30 mg max
20	Potassium (mg/L)	0.8	0.4	0.4	0.7	10mg max
21	Iron	0.13	0.21	0.06	Nd	0.3 mg
22	Zinc (mg/L)	1.02	2.28	0.14	Nd	5.0 mg
23	Copper	Nd	Nd	Nd	Nd	1 mg max
24	Lead	Nd	Nd	Nd	Nd	0.01 mg
25	Cadmium	Nd	Nd	Nd	Nd	0.003 mg
26	Residual Chlorine	Nd	Nd	Nd	Nd	0.1 mg
27	Aerobic Mesophilic (cfu/ml)	116	183	223	10	Max not stated
28	Coliform (cfu/ml)	4	4	5	Nd	1 max
29	*E. coli* (cfu/ml)	3	1	2	Nd	0 max
30	*Pseudomonas*/ml	Negative	Negative	Negative	Negative	0 max

Nd: Not detected

Chemical contamination has been attributed to the effect of wet deposition; presence of atmospheric gases; pesticides; industrial waste gases; automobile emissions and the reaction of rainwater with the rain water harvesting system components – catchment surface, guttering etc.

For the chemical tests, the carbon dioxide ranged from 2 to 4mg/l, the total alkalinity from 8 to 20mg/l, total hardness from 4 to 12mg/l, chloride ranged from 10 to 13mg/l, sulphate between 5 and 6mg/l, and nitrate ranged from 0.44 to 2.28mg/l; all these fall within the limits of the reference standards. The trace metals, calcium ranged between 2.7 and 4mg/l, magnesium ranged from 0 to 2mg/l, and potassium ranged between 0.4 and 8mg/l. Iron and zinc ranged from 0.06 to 0.21 and 0.14 to 2.28mg/l respectively whereas copper and lead were not detected.

Worthy of note is the trend in concentrations of Iron and Zinc in all the stations, which were not detected in the control. This observation is similar to the trend observed by [15] which implies that the impinging of raindrops on roofs gradually erodes its material, which could be responsible for the presence of both metals in all the stations. Zn and Fe present in water do not pose serious health risk as they mainly affect the aesthetics but can become toxic or aesthetically undesirable at high concentrations [16].

Inter-elemental relationships provide interesting information related to metal sources and pathways [17]. Pearson's correlation coefficients of physico-chemical properties of the roof harvested rainwater samples are presented in Table 2 below.

Correlation is significant at 0.05 level between the Total Solid and Total Alkalinity indicating common origin. Correlation also is significant at 0.05 and 0.01 between Suspended Solid and Iron (-0.997), and between Suspended Solid and Zinc (-), indicating that Iron and Zinc may have a similar source or properties. A strong positive correlation between Zinc and Iron further emphasizes common pathway and origin; this could be probably from the kinetic energy of water drops that impinges on the roof materials.

3.2 Microbiological Properties of the Roof Harvest Rainwater

The result shows the presence of Aerobic Mesophilic ranging from 116-223 cfu/ml, while the control has a value of 10 (cfu/ml), coli-form were detected in all the stations, none was detected from the control sample. The coliform and E. coli parameters ranged between 4 and 5cfu/ml, 1 and 3 cfu/ml, respectively with pseudomonas giving negative throughout. Total coliform and *E.coli* presences are common indicators of disease-causing pathogens.

Generally, the values of the physiochemical and microbiological parameters in all the stations were higher than the control. This is an indicator that roof catchment area probably contributed to higher level of contamination in the stations. Faecal deposition on the catchment surface is the main source of microbiological contamination.

3.3 Water Quality Index Calculation

The WQI ranges is as follows: 90-100 (Excellent), 70-90 (Good), 50-70 (Medium), 25-50 (Bad) and 0-25 (Very bad). The unit weight and rating scale used for the study is presented in Table 3 below.

Table 2. Pearson correlation matrix of physico-chemical properties

	Cond	**pH**	**TS**	**TDS**	**SS**	**Co_2**	**TA**	**TH**	**Chloride**	**Sulphate**	**Nitrate**	**Cal**	**Mag**	**Potassium**	**Iron**	**Zinc**
Cond	1	.424	-.705	-.762	.206	.093	-.692	.944	.911	.578	-.780	.418	-.967	.996	-.131	-.194
pH	.424	1	.344	.264	.974	.941	.360	.102	.012	.984	-.898	-.646	-.642	.338	-.953	-.971
TS	-.705	.344	1	.996	.549	.641	1.000*	-.899	-.935	.171	.105	-.939	.499	-.768	-.611	-.559
TDS	-.762	.264	.996	1	.477	.575	.995	-.932	-.961	.088	.188	-.907	.570	-.818	-.543	-.488
SS	.206	.974	.549	.477	1	.993	.564	-.127	-.217	.918	-.774	-.803	-.450	.115	-.997*	-1.000**
Co_2	.093	.941	.641	.575	.993	1	.655	-.240	-.327	.866	-.696	-.866	-.345	.000	-.999*	-.995
TA	-.692	.360	1.000*	.995	.564	.655	1	-.891	-.929	.189	.087	-.945	.484	-.756	-.625	-.574
TH	.944	.102	-.899	-.932	-.127	-.240	-.891	1	.996	.277	-.530	.693	-.828	.971	.203	.140
Chloride	.911	.012	-.935	-.961	-.217	-.327	-.929	.996	1	.189	-.451	.756	-.774	.945	.291	.229
Sulphate	.578	.984	.171	.088	.918	.866	.189	.277	.189	1	-.962	-.500	-.768	.500	-.885	-.913
Nitrate		-.898	.105	.188	-.774	-.696	.087	-.530	-.451	-.962	1	.243	.914	-.718	.723	.765
Cal	.418	-.646	-.939	-.907	-.803	-.866	-.945	.693	.756	-.500	.243	1	-.171	.500	.846	.811
Mag	-.967	-.642	.499	.570	-.450	-.345	.484	-.828	-.774	-.768	.914	-.171	1	-.939	.381	.439
Potassium	.996	.338	-.768	-.818	.115	.000	-.756	.971	.945	.500	-.718	.500	-.939	1	-.038	-.102
Iron	-.131	-.953	-.611	-.543	-.997*	-.999*	-.625	.203	.291	-.885	.723	.846	.381	-.038	1	.998*
Zinc	-.194	-.971	-.559	-.488	-1.000**	-.995	-.574	.140	.229	-.913	.765	.811	.439	-.102	.998*	1

**. Correlation is significant at the 0.05 level (2-tailed)*
***. Correlation is significant at the 0.01 level (2-tailed)*

Table 3. Unit weight and rating scale for calculation of WQI

Water quality parameters	Unit weight	Rating scale (Vr)				
		Desirable 100	**Slight pollution 80**	**Moderate pollution 60**	**Excess pollution 40**	**Severe pollution 0**
*pH	0.62812	7.0	7-8.5	6.5-7	5-10	1-14
TDS	0.01068	0-375	375.1-750	750.1-1125	1125.1-1500	>1500
Total Hardness	0.05339	0-150	150.1-300	300.1-450	450.1-600	>600
Calcium	0.07119	0-20	20.1-40	40.1-60	60.1-75	>75
Magnesium	0.17797	0-12.5	12.6-25.0	25.1-37.5	37.6-50	>50
Total Alkalinity	0.05339	21-50	15.1-20	10.1-15	6-10	<6
*Electrical Conductivity	0.00534	<750	<1250	<2000	<3000	>12000

WQI_{min} Calculation
Source: [13,15]

The value of WQI for the station 1, 2 and 3 are 71.68%, 60.19%, and 77.55% respectively. This implies that roof rain water quality from station 1 and 3 are good, while station 2 has medium quality. It can therefore be inferred that physico-chemical water quality of the area is generally good base on WQI assessment and NAFDAC standard.

4. CONCLUSION AND RECOMMENDATION

The physico-chemical properties of harvested rainwater in this study falls within NAFDAC acceptable range, however, the presence of particles and the unsatisfactory micro-biological rain-water parameters makes the water unsuitable for portable use. Roof harvested rainwater can represent alternative water source in the present study area and areas of extreme water shortage when safety measures are implemented which include: adequate selection of roof material, replacement of roofing material especially when particle of the materials erodes as a result of aging of the roof catchment by kinetic energy of raindrops, regular inspection and cleaning of the roof gutter system to limit contamination of rainwater. The water quality from the present study requires a minimum treatment by simple disinfection methods, pre-filtration or otherwise the proper maintenance of the entire RWH system.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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