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Assessment of the Suitability of Urban Residential Roof Catchments for Rainwater Capturing in Umuahia, Southeastern Nigeria

Ubuoh Emmanuel*, Kanu Samuel, Uzonu Ugona

Michael Okpara University of Agriculture, College of Natural Resources and Environmental Management, Department of Environmental Management and Toxicology, Nigeria.

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Abstract

Rainwater is an alternative source of potable water supply for urban dwellers in Abia State- Nigeria; however, little is known about the suitability of roof catchments for capturing rainwater. The current work focuses on the seasonal evaluation of rainwater captured from four sampled roof catchments (SRC_1-$_4$), namely Asbestos, Aluminum, Corrugated iron, and Harvey-tiles that are commonly used for roofing and atmospheric rain during rain events. One hundred and event samples of harvested rainwater from four different rooftops in three layouts are analyzed for selected physicochemical parameters and metals. The results of the analysis were subjected to mean separation and were compared with water-quality guidelines to evaluate the suitability for consumption and a correlation of parameters was established. Water quality and pollution indices were computed for rainwater quality and rooftop pollution status. Analysis of pH and Zn^{2+} in rainwater from the Asbestos and corrugated roofs during rain events were above the WHO permissible limits for drinking water. Tracers from the roofs that negatively correlated may have been originated from the atmosphere, and the positive correlation attributed to the kinetic energy of rainfall that impinged on the roofing material. Rainwater quality index from the roofs was greater than the 1.0 critical limit. The pollution index revealed strongly-polluted samples from the Asbestos rooftop, moderately-polluted samples from the Aluminum and Corrugated rooftops, and slightly- polluted samples from the Harvey-tile rooftop. The roofs exhibited a decreasing abundance of contaminants in the samples in the order of: Asbestos ≥ Corrugated ≥ Aluminum ≥ Harvey Tile. This, then, calls for designing first-flush devices, a regular maintenance of the RWH systems, and avoidance of catchments capable of releasing contaminants into the harvested rainwater.

Keywords: Rainwater, harvesting, Catchment, suitability, Water, pollution, index, Urban, environment

1. Introduction

The practice of domestic rainwater harvesting (DRWH) is an old tradition adopted in many parts of the world, in addition to being a new technology that is growing in popularity worldwide (Chukwuma et al., 2014). Several studies have explored the implementation of rainwater harvesting (RWH) technologies in response to the growing water demand in developed and developing countries (Chiang et al., 2015; Kahinda et al., 2007). Currently and because of the environmental and economic advantages, RWH systems are receiving increased attention as alternative sources of potable water, particularly in semi-arid areas (Kahinda et al., 2007), and urban areas as well (Teston et al., 2018; Campisano et al., 2017; Gurung and Sharma, 2014;Cook et al., 2013).

Generally, in a rainwater harvesting system, the household water saving is subjected to the amount of water harvested in wet seasons (Amos et al., 2018; Rahman and Eslamian, 2016; Abdulla and Al-Shareef, 2009; Hoque et al., 2004). For example, Herrmann and Schmida (2000) reported that, the installation of rainwater harvesting systems increased water saving from 30%to 60% depending on the roof area in Germany. Therefore, rainwater is a valuable source of water and is quite safe for drinking when harvested and stored in a properly installed and maintained water catchment systems (Mohammad et al., 2020; Olaoye and Olaniyan, 2012; Ubuoh et al., 2012). Accordingly, Ubuoh and Ekpo (2017), Chang et al. (2004) reported that many roofing materials can be serious sources of non- point pollution.

Chang et al. (2004) in Texas reported that residential roofing materials can negatively influence the rainwater quality and that the quality of harvested rainwater improved with roof flushing. Nicholson et al. (2009) compared harvested rainwater quality from different roof catchments and concluded that the quality of rain varied based on the type of roofs used. Roof surfaces in urban settlements also contribute excess nutrients and toxic metals to receiving waters (Van -Metre and Mahler, 2003).

Above all, the level of pollutants that may emanate from roof runoff depends on the roof materials, age, orientation and, slope of the roofs, atmospheric depositions, rain events, and meteorological conditions (Martinson and Thomas, 2005). Studies investigating roof-harvested rainwater quality were conducted in Australia, Canada, Denmark, India, etc. (Despins et al., 2009). Most of these locations are in temperate climate regions, where dry periods between consecutive rain events are relatively short. These significant

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Corresponding author email: ubuohemmanuel@yahoo.com

differences in weather conditions such as rain intensity and depth, rain distribution, dry periods between consecutive rain events, and forms of rain (light, heavy) may affect the quality of roof-harvested rainwater (Friedler et al., 2017).

Though some studies have examined the importance of various urban functions as sources of metals by Ezemonye et al. (2016), IKhioya et al. (2015), Aladenola and Adebayo (2009), Akhionbare (2009), Efe (2006), but none particularly paid attention to Harvey tile roof and rainwater pollution index. In Umuahia, public water supply has been a problem leading to commercial private boreholes. This has resulted in the high water bills due to the high cost of operations. Therefore, people relied on the storage of rainwater from rooftops including emerging Harvey tile roof without knowing the characteristic compositions meant for human consumption.

The study then has focused on the determination of the quality of rainwater from roof catchments using water quality and pollution indices to identify rooftops' suitability for rainwater harvesting for human consumption. The result will aid the State Ministry of Water Resources, Ministry of Environment, and Sister Agencies to take proactive steps toward harnessing rainwater as an alternative water supply in urban areas in developing countries that constantly suffer from water crises.

2. Materials and Methods

2.1. Study Area

The study was carried out in Umuahia Municipal, the capital city of Abia State. The area is a typical humid tropical area with its location at the intercept of latitude 05^0 29'N and longitude $7^0$33'E, and altitude, at the highest point of about 205m (Ozabor and Nwagbara, 2018) with a population of 147,167 (NPC, 2006). Annual rainfall totals vary from about 1900 mm to 2400 mm (Ozabor and Nwagbara, 2018). The high intensity tropical rainfall in the area produces a high volume of overland flow and run-off that possess high erosive energy (Nwilo et al., 2011). This rainfall is of the double maxima type with peaks in July and September. In recent times, September has been the month with the highest amount of rainfall as against July whereas December has the lowest amount (NRCRI, 2016). Air temperature ranges between 21°C and 34°C, and relative humidity ranges from 60% to 83% (NRCRI, 2016).According to Ishaku et al. (2010), the rainfall pattern generally decreases as distance increases from the coastal areas of the South to the Sahelian semi-arid lands of the North (Figure 1).

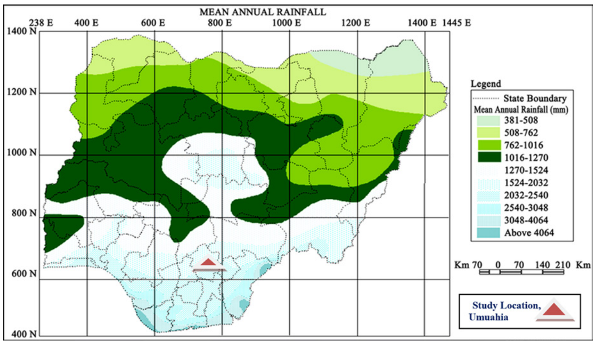

Figure 1. Map of Nigeria Showing Mean Annual Rainfall Pattern in Umuahia, Abia State. Source: Ishaku et al. (2010).

2.2 Experimental Design

A random sampling technique was adopted for the study within the three layouts: New town layout, Eghem layout, and Uzo Avoiteyi layout because they all had the roof catchments of interest (Figure 2). The technique was employed in selecting the sampled households with the four identified roof types, with the atmosphere as control from each of the layout, containing twelve buildings in the study area. The four types of the existing roof materials were designated, sample roof catchments (SRC): Asbestos (SRC$_1$), Aluminum (SRC$_2$), Corrugated iron (SRC$_3$), and Harvey-Tiles (SRC$_4$). Sample containers were rinsed with the sterile water and drained before they were used to collect the samples from the different roof types and directly from the atmosphere, during April as onset of rain, in July as peak of rain, and during October as late rain (cessation), 2017, respectively, with 108 rain samples from the four roof catchments and nine from the atmosphere constituting a total of 170 rainwater samples (New town layout:36, Eghem layout: 36, Uzo Avoiteyi layout:36) for the three rain events .Care was taken to ensure that the samples were representative of the water to be examined, and that no accidental contamination occurred during the sampling. The rainwater samples were harvested using stainless basins placed on elevated- wooden stands above the ground surface for rooftops rainwater and atmospheric rain at different intervals of rainfall. The samples were then crammed and put into clean polythene bottles, which were corked and labeled according to the different roof catchments. They were then placed in freezers that contained ice blocks.

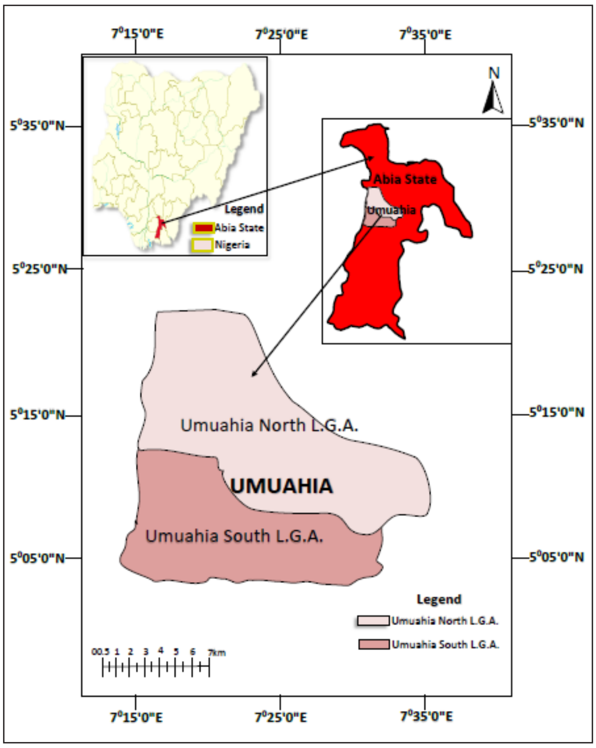

Figure 2. Map of Abia State showing the Study Area. Source: LA-cute consults, after Ishaku et al. (2010).

3. Physicochemical Analysis of Rainwater Samples

The pH was determined on-site using HannapH meter, Model 211.Total acidity was measured using titrimetric methods (Ademoroti, 1996). Electrical Conductivity was determined using Suntex 120 conductivity meter (USEPA, 1997). Nitrate (NO_3^-) was determined using the phenol disulphuric acidic method adopted by Ubuoh et al. (2016). Sulphate (SO_4^{2-}) was determined using the colorimeter at 440nm. A blank without $BaCl_2$ was prepared and run at the same wavelength. The total dissolved solids were determined by the HACH 44600-00 Conductivity/TDS meter. The concentrate of (Cl^-) was obtained by reference to a calibration curve using standard sodium chloride solution (Stern, 2006).

4. Heavy Metals' Determination

The determination of heavy metals such as $Cu^{2+,}$, $Pb^{2+,}$, Fe^{2+}, Zn^{2+} were carried out using the flame atomic absorption Spectrophotometer Perkin-Elmer A Analyst 200 (USA) described by APHA (1998).

5. Data Analysis

The results of data collected were subjected to descriptive statistics which illustrated the means and standard deviation from replicates of collected data. Means of the collected data were afterward subjected to mean separation using Ducan Multiple Range Test (DMRT). Means of the tested parameters were subjected toTwo-Tailed Pearson Correlation to illustrate the degree of relationship between the observed variables from difference roof catchments and atmospheric rain as control in the stud area.

6. Application of Water Quality Index and Water Pollution Index

6.1 Water Quality Index (WQI)

Water quality index was developed and used by Horton (1965); it is expressed mathematically as follows:

$$P_{ij} = (max\frac{C_i}{L_{ij}})^2 + (min_{C_i}/L) \quad \text{.............................. Equ. 1}$$

Initially, WQI was developed by Horton (1965) and was adopted by authors including Andreea-Mihaela (2018) in Romania, Ubuoh et al. (2013) in Nigeria, Shweta et al. (2013), Chaturvedi, and Bassin (2010), in India, Lumb et al. (2002) in Great Bear, Polkowska et al. (2005) in Poland. Horton (1965) used multiple items of water qualities as expressed as Ci's and permissible levels of the respective item expressed as L_{ij}'s then the pollution index, Pij is expressed as a function of the relative values of Ci/L_{ij} (Horton, 1965). Here, i is the number of the i^th^ item of the water quality, and j is the number of the j^th^ water use. Each value of (C_i/L_{ij}) shows the relative pollution contributed by the single item. A value of 0.1 is the critical value for each (Ci/L_{ij}).

i. Values greater than 0.1 indicate that the water requires some treatment prior to use for a specific purpose.

i i. Combining the mean value of C_i/L_{ij} into a common index, values over 1.0 signify a critical condition under which proper treatment is needed for portable water.

6.2 Water Pollution Index (WPI)

A pollution index (PI) of individual parameters can be equally used as adopted by Amadi et al. (2013), Udousoro and Ikpeme (2013), Ubuoh et al. (2013); it is expressed mathematically as:

$$\mathbf{WPI} = \frac{\sqrt{(C_I|S_i)^2 \max + (C_I|S_i)^2 \min}}{2} \quad \text{.. Equ. 2}$$

Where,

C_i is the mean value as determined in rainwater

S_i is the drinking water quality guideline (WHO, 2011).

The results of the water quality index based on water tracers were then interpreted with the help of the pollution index classification in Table 1.

Table 1. Parameter classification based on Pollution index (PI).

Class	PI	STATUS
1	<1	No pollution
2	1-2	Slightly polluted
3	2-3	Moderately-polluted
4	3-4	Strongly-polluted
5	>5	Seriously-polluted
Source: Juahir et al. (2008)		

7. Results and Discussions

Characteristics of the roof-harvested runoff mean values over all roof types during April, July, and October rain events are presented in Table 2.

7.1 Physicochemical Characteristics of Harvested Rainwater from Roof Catchments during Rain Events

The mean pH of harvested rainwater samples from the different roof catchments during onset of rain ranged from 6.20 to 6.75, with the mean pH of 6.55, which is less than the 6.90 pH value of the atmospheric rain (control), indicating that rainwater from the Asbestos and corrugated roofs was slightly acidic, signifying no cations from the roof and atmosphere (Ca^{2+} + Mg^{2+} + K^+NH^{4+}) to neutralize the acidity of rainwater (Mouli et al., 2005; Tang et al., 2005).

For July, pH ranged from 6.55 to 6.90, with a mean pH of 6.73, and the atmospheric rain having a 6.90 pH value. In October, pH ranged from 6.40 to 6.85 with the mean pH of 6.64, which is less than the 6.85 pH value of the atmospheric rain. During the three rain events, the mean pH of the harvested rainwater samples from the different roof catchments ranged from 6.20 to 6.90, with the Asbestos roof being more acidic below the values 6.5-8.5, 6.0-9.0mg/l of the WHO/ FME_{NV} permissible limits for drinking water. The Harvey roof and control showed results within the permissible limits respectively .The results of the low pH from the Asbestos roof during onset of rain disagrees with the pH value 7.6 for the rainwater harvested from Asbestos roof in the Ibadan metropolis by Olubanjo (2016). As for rainwater harvested from aluminum and corrugated iron rooftops, pH ranged from 6.55to 6.70, 6.35 to 6.60, with the corrugated rooftops recording the lowest values above the permissible limit for drinking water. The result is different from the findings of Chukwuma et al. (2013), Akharaiyi et al. (2007) who reported pH values in the rainwater from galvanized iron rooftops being below the WHO maximum permissible value. The pH values obtained in this study agreed with the results of Simmons et al. (2001) who reported a pH range between 5.2 and 11.4 for harvested rainwater. However, they disagreed with Ikhioya et al. (2015) who reported that pH in rainwater harvested from Aluminum-roofing sheet fell within the WHO allowable limit during the early rain event. It is also observed that the pH of rain increased to normal with the increase in the rain intensity during the peak period. This result of pH is in line with the finding of Rahman et al. (2019) who observed that the value of pH has increased to a normal value with the increase in the duration of rain. Accordingly, the tendency of the roofing materials to release and exhibit pH is in a decreasing order: Asbestos ≥ Corrugated iron roof≥ Aluminum roof≥ Harvey-tiles. From the results, the samples during the onset of rain were more acidic than those of the July and October rain (Table 2). This is suspected to be due to the built- up of dry deposition of gases in the atmosphere and catchments respectively. The result is in tandem with the findings of Akhionbare (2009); Boller and Steiner (2002); Gadd and Kennedy (2001), who reported that low pH in the harvested rainwater during early rain is due to the dry deposition of aerosols/gases emitted from human activities during the first-flush event. Kale (2016), reported that rainwater harvested in July had a higher pH value compared with the other months, which indicates that there was less CO_2 in the air.

Table 2. Physicochemical properties and heavy metals in harvested rainwater from different roof catchments during rain events.

CATCHMENT	pH	Acidity (mg/l)	TDS (mg/l)	EC (µhosm/cm)	NO_3^- (mg/l)	SO_4^{2-} (mg/l)	Cl^- (mg/l)	Cu^{2+} (mg/l)	Pb^{2+} (mg/l)	Fe^{2+} (mg/l)	Zn^{2+} (mg/l)
Onset of Rain : April											
Asbestos roof: SRC$_1$	6.20^{e}	28.58^{a}	46.00^{a}	64.00^{a}	2.66^{a}	13.16^{a}	14.03^{a}	ND	0.04	ND	1.16^{b}
Aluminum roof: SRC$_2$	6.55^{c}	22.19^{c}	28.50^{c}	52.00^{c}	0.22^{c}	3.86^{c}	9.18^{c}	0.07	ND	0.22^{b}	0.43^{c}
Corrugated iron:SRC$_3$	6.35^{d}	25.09^{b}	39.00^{b}	57.50^{b}	0.66^{b}	5.20^{b}	10.42^{b}	0.001	ND	0.40^{a}	4.35^{a}
Harvey tile roof:SRC$_4$	6.75^{b}	14.43^{d}	16.00^{d}	26.50^{d}	0.13^{cd}	1.09^{d}	6.45^{d}	ND	ND	ND	0.22^{cd}
Atmosphere Rain: (Control)	6.90^{a}	10.01^{e}	8.00^{e}	13.00^{e}	0.05^{d}	0.47^{d}	4.13^{e}	ND	ND	ND	0.03^{d}
Mean	6.55	20.06	27.50	42.60	0.74	4.76	8.84	0	0.008	0.044	1.238
S.E	0.05	0.31	0.71	1.00	0.06	0.42	0.23	0.04	0.00	0.03	0.12
Peak ofRain : July											
Asbestos roof: SRC$_1$	6.55^{c}	22.27^{a}	29.00^{a}	43.50^{a}	0.46^{a}	3.30^{a}	4.98^{a}	ND	ND	ND	1.42^{b}
Aluminum roof: SRC$_2$	6.70^{b}	13.44^{c}	19.00^{c}	32.00^{c}	0.08^{c}	0.06^{c}	2.32^{c}	ND	ND	0.10	0.09^{c}
Corrugated iron:SRC$_3$	6.60^{c}	19.33^{b}	23.00^{b}	36.00^{b}	0.21^{b}	0.11^{b}	3.40^{b}	ND	ND	ND	1.37^{a}
Harvey tile roof:SRC$_4$	6.90^{a}	8.98^{d}	7.00^{d}	12.00^{d}	0.04^{c}	ND	1.15^{d}	ND	ND	ND	0.04^{c}
Atmospheric Rain: (Control)	6.90^{a}	9.43^{d}	5.00^{d}	9.00^{d}	ND	ND	0.83^{d}	ND	ND	ND	ND
Mean	6.73	14.76	16.6	26.5	0.158	0.694	2.536	0	0	0.02	0.584
S.E	0.03	0.27	0.89	1.44	0.04	0.07	0.19	0.00	0.00	0.01	0.06
Late Rain: October											
Asbestos roof: SRC$_1$	6.40^{d}	24.48^{a}	37.05^{a}	55.50^{a}	1.24^{a}	6.58^{a}	9.51^{a}	ND	ND	ND	0.69^{b}
Aluminum roof: SRC$_2$	6.60^{b}	19.93^{c}	24.00^{b}	28.50^{c}	0.14^{c}	1.26^{c}	4.19^{c}	ND	ND	0.14^{b}	0.26^{c}
Corrugated iron:SRC$_3$	6.50^{c}	22.28^{b}	25.50^{b}	44.00^{b}	0.41^{b}	1.71^{b}	4.99^{b}	ND	ND	0.18^{a}	1.78^{a}
Harvey tile roof:SRC$_4$	6.85^{a}	10.22^{d}	13.00^{c}	19.00^{d}	0.09^{c}	0.22^{d}	2.65^{d}	ND	ND	ND	0.08^{d}
Atmospheric Rain : (Control)	6.85^{a}	9.33^{e}	7.00^{d}	11.00^{e}	0.04^{c}	0.08^{e}	1.35^{e}	0.10^{a}	ND	ND	ND
Mean	6.64	17.106	21.3	31.6	0.384	1.97	4.52	0.02	0	0.064	0.562
S.E	0.04	0.17	0.71	1.61	0.05	0.05	0.22	0.02	0.00	0.01	0.01
WHO 6.5-8.5	200	250	200	40	250	250	0.5	0.01	0.30	0.3	
FME$_{NV}$ 6.0-9.0	-	500	-	10	500	250	0.1	0.05	1.0	5.0	

Means with the same superscript are not significantly different ($P \geq 0.05$) TDS=Total Dissolved Solid: EC=Electrical Conductivity: NO_3^-=Nitrate: SO_4^{2-}=Sulphate: Cl^-=Chloride: S.E=Standard Error of Means: WHO=World Health Organization: FME_{NV} = Federal Ministry of Environment

Chloride (Cl^-) the in rainwater harvested during onset of rain ranged from 6.45to 14.03 mg/l with the atmospheric rain recording 4.13 mg/l, and a mean of 8.842 mg/l. During peak rain, chloride in the harvested rainwater ranged from 1.15to 4.98 mg/l, with a mean of 2.536 mg/l and the atmospheric rain recorded 0.83 mg/l. According to Daifullah and Shakour (2003), chloride ions originate from human activities such as industrial emission, automobile exhaust etc. Ultimately, Cl^- values of the analyzed harvested rainwater samples were below the250 mg/l WHO/FMEnv allowable limits for portable water, with Asbestos recording the highest value, while Harvey tile recorded the lowest value. The study is in tandem with the finding of Eruola et al. (2010) who observed that the highest concentration of chloride in rainwater came from the Asbestos roof and was followed by Aluminum, Zinc, and atmospheric rainwater respectively. During rain events, Cl^- in the rainwater from the four different roofs was in a decreasing order as follows: Asbestos ≥ Corrugated iron ≥ Aluminum ≥Harvey tile (Table 2). This implies that the rainwater harvested from the Asbestos rooftop recorded the highest chloride, while the Harvey–tile rooftop showed the least value. Meanwhile, chloride ions in very small concentrations or as an impurity in raw water can cause active corrosion (Egereonu, 2006).

7.2 Heavy Metal Concentrations in Harvested Rainwater from Roof Catchment during Rain Events

According to Table 2, during the onset of rain event, Cu^{2+} ranged from zero to 0.07mg/l, with the Asbestos and Harvey-tile rooftops recording a zero value, while the Aluminum roof exhibited the highest value, with a mean of 0.04mg/l. The results of Cu^{2+}during onset of rain from roofs are lower than 0.460 - 0.820mg/l obtained from the Aluminum-Asbestos roofs by Olubanjo (2016). The copper in rainwater from roofs was below the0.5mg/l, 0.1 mg/l WHO/ FMEnv permissible limits, with a decreasing abundance of Aluminum ≥ corrugated iron and Asbestos, Harvey tile. Asbestos rooftops and atmospheric rain recorded zero respectively. Olubanjo (2016) recorded 0.560 mg/l of Cu^{2+}in atmospheric rain compared to zero in the current study. The result is in tandem with the finding of Akhionbare (2009) who reported highest concentrations of Cu^{2+}in rainwater from the Aluminum roofing sheet during the first flush. Only Asbestos roof recorded Pb^{2+}: 0.04mg/l, a mean value of 0.008 mg/l, while the other sampled rooftops and atmospheric rain recorded none respectively. The result is in agreement with the finding of Ezemonye et al. (2016) who reported a higher concentration of Pb^{2+}in the rainwater samples from the Asbestos roof than other rooftops. The higher value of Pb could be due to the tendency of Pb to strongly adhere to particles (Dannecker et al., 1990). The Aluminum roof runoff samples recorded Fe^{2+} (0.22mg/l), while the galvanized roof samples recorded (0.40mg/l), with a mean of 0.044mg/l respectively, while others recorded none. Elevated values of Fe in the aluminum, and galvanized metal roof runoff samples may be due to the erosion of zinc roofing material, galvanized gutters and bulk atmospheric deposition (Chang et al., 2004; Uzoma and Sangodoyin, 2000).

The SRC1^{-4} and atmospheric rain recorded Zn^{2+}: 1.16mg/l, 0.43mg/l, 4.35mg/l, 0.22mg/l, 0.03mg/l respectively, with the mean of 1.238 mg/l. The highest value of Zn^{2+} was found in the rainwater from the corrugated iron roofing sheet. The result agreed with the finding of Chizoruo and Onyekachi (2016), who reported the highest Zn^{2+}concentration in rainwater from the galvanized iron rooftop in Orlu, Imo State, Nigeria.

Table 3. Pearson correlation matrix of physicochemical parameters of harvested rainwater from rooftops during rain events.

Tracer	pH	Acidity (mg/l)	TDS (mg/l)	EC (μhosm/cm)	**NO_3^-(mg/l)**	**SO_4^{2-}(mg/l)**
April: Onset of rain						
pH	1					
Acidity	-0.987**	1				
TDS	-0.999**	0.992**	1			
EC	-0.967**	0.995**	0.976**	1		
NO_3^-	-0.815	0.750	0.791	0.682	1	
SO_4^{2-}	-0.917*	0.878	0.902*	0.829	0.973**	1
Cl^-	-0.986**	0.978**	0.982**	0.955*	0.864	0.951*
July: Peak rain						
pH	1					
Acidity	0.973**	1				
TDS	-0.992**	0.964**	1			
EC	-0.990**	0.944*	0.997**	1		
NO_3^-	-0.863	0.935*	0.890*	0.853	1	
SO_4^{2-}	-0.637	0.736	0.693	0.648	0.918*	1
Cl^-	-0.954*	0.984**	0.967**	0.945*	0.974**	0.821
October: Late rain						
pH	1					
Acidity	0.992**	1				
TDS	0.965**	0.957*	1			
EC	0.965**		0.966**	1		
NO_3^-	-0.817	0.746	0.869	0.892*	1	
SO_4^{2-}	-0.828	0.767	0.891*	0.879*	0.990**	1
Cl^-	-0.907*	0.868	0.965**	0.951*	0.965**	0.975**

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

In the peak of rain, the result shows that Cu^{2+}andPb^{2+}were not detected across the roof catchments and atmospheric rain. Iron was only detected from the Asbestos roof runoff samples at 0.10 mg/l. Ikpoba (2002) observed that the lowest value of Fe2 in rainwater in July could be because the rain runs off on the roofs and washed off some Iron, which is part of the material used in their manufacturing. The Zn^{2+}ranged from 0.69to 1.42 mg/l with the Asbestos roof samples having the highest value and the Harvey-tile runoff samples having the lowest value, with a mean zinc of 0.584 mg/l that is less than the 0 mg/l value of the atmospheric rainwater. The highest value of Zn^{2+} was suspected to come from the eroded particles of zinc washed off by runoff water from the Corrugated Iron Sheet rooftop. Accordingly, zinc found in water could be attributed to the weathering of the Corrugated Iron sheets and industrial pollution (Eruola et al., 2010). Gromaire et al. (2002) reported that the elevated zinc in rainwater was related to zinc gutters, and the roofing as well as the galvanized iron roofing. Zinc levels found in the harvested rainwater samples do not cause any concern except for those of the corrugated Iron sheet rooftop during the early rain as the samples recorded concentrations higher than the WHO limits of 0.3 mg/l although these were still below the limit stated by FMEnv (5.0 mg/l). An overdose of zinc can depress the immune system, cause anemia, and copper deficiency, and decrease the high density lipoprotein cholesterol in the blood (Akhter et al., 2002). Moreover, Zinc causes an undesirable taste in water at a high accumulation.

During late rain,Cu^{2+} and Pb^{2+} were not detected across the SRC_{1-4}, except in the atmospheric rain as control which recorded 0.10 mg/l. Lead was also not detected in the harvested rain samples from SRC_1, SRC_3, SRC_3, SRC_4 and atmospheric rain respectively. Iron was detected in $SRC_2$and SRC_3 at 0.14 mg/l and 0.18 mg/l respectively, and was not detected in SRC_1, SRC_4 and the control respectively. The results show that Zn^{2+} ranged from 0.08 to 1.78 mg/l with SRC_1 having the highest value of 1.78 and SRC_4 the lowest value (0.08 mg/l), with a mean of 0.562 mg/l (Table 2). The highest concentration of dissolved Zn^{2+} and Fe^{2+} in the metal sheets suggests that either metal roofs galvanized iron or aluminum act as a potential source of the soluble fraction of heavy metals compared to other roof types (Ayenimo et al., 2006). Similarly, the maximum concentration of the sampled metals was observed in the Asbestos roof compared to other roofing materials. This observation agrees with the report of Gadd and Kennedy (2001) who suggested that the galvanized metal roofs contribute more zinc to the roof runoff. This report implies that products used in roofs appear to have a direct influence on the potential for the release of these soluble metals into storm-water. This implies that the Asbestos roofing sheet yielded to the heavy contaminants more than the Harvey tile sheet being the best for July rain event.

7.3 Correlation between Physicochemical Characteristics during the Onset of Rain

The correlation (r) was used to analyze the relationship between rainwater characteristics from four different roof catchments to analyze the strength of the relationship by using the value of r to understand the sources of the rainwater contaminants during rain events. The Pearson's correlation coefficients for the contents of pH, acidity, TDS, EC, NO_3^-, SO_4^{2-}, and Cl^-in the harvested rainwater from roof catchments during rain events are presented in Table 3.

A negative correlation was found between pH and acidity (r^2=-0.987**),TDS(r^2=-0.999**), EC(r^2=-0.967**), SO_4^{2-} (r^2=-0.917*) and Cl^-(r^2-0.986**), indicating that the parameters from the harvested rainwater may have a similar source or properties such as the atmosphere, i.e. due to the anthropogenic activities (air quality),outside the roof catchments. Acidity was positively but highly correlated with TDS, EC and Cl^-: r^2=0.992**, 0.995**, 0.978** respectively. The strong positive correlation between acidity and TDS, EC and Cl^-further emphasizes a common pathway and origin; this could be attributed to the kinetic energy of rainfall that impinges on the roof materials (Chukwuma et al., 2014). The TDS was positively but strongly correlated with EC (r=0.976**), SO_4^{2-}(r=0.902*), Cl^-=0.982**). The EC was positively and strongly correlated with Cl^-(r=0.955*), NO_3^- was positively and strongly correlated with SO_4^{2-}(0.973**) and SO_4^{2-} was positively and strongly correlated with Cl^-(r=0.951*). These positive correlations are indications that rainwater from the rooftops was acidic signifying the atmospheric composition of the area. In the same vein, Zunckel et al. (2003) found a strong correlation between the presence of contaminants in the catchments area and rainwater quality. The result agrees with Ramlall et al. (2015) who observed that SO_2 and NOx in the atmosphere are related to industrial activities and the combustion of fossil fuels. These compounds undergo oxidation in the atmosphere in combination with ozone, forming strong acids (sulphuric and nitric acids) which, when dissolved in rainwater, decrease its pH (Ubuoh et al., 2016).

7.4 Correlation between Physicochemical Characteristics during the Peak of Rain

During July, pH was positively and strongly correlated with acidity: (r^2=0.973**), while it was negatively and strongly correlated with TDS, EC, Cl^- (r^2=-0.992**, 0.990**,-0.954*) respectively which is suspected to come from the atmosphere through human activities. Acidity was positively and strongly correlated with TDS, EC, NO_3 Cl^-(r^2=0.964**, 0.944*, 0.935*, 0.984**) respectively, TDS was positively correlated with EC, NO_3^- and Cl^- : r^2=0.997**, 0.890*, 0.967** respectively. EC was positively correlated with Cl (r^2=0.945*) and $NO_3$was positively and strongly correlated with SO_4^{2-} (r^2= 0.918*), Cl^-(r^2=.974**). This correlation between nitrate and sulphate in rainwater from rooftops is attributed to the atmospheric composition of acid precursors due to anthropogenic activities. These results agree with the finding of Keller and Pitblado, (1986) who reported that the levels of sulfate in rainwater from rooftops and surface water correlate with emissions of sulfur dioxide from anthropogenic sources. The positive correlations signify that rooftops also contributed to the physicochemical contaminants in the rainwater through the weathering of the catchments despite the heavy rain that cleansed the rooftops and atmosphere respectively. Roof material and its features may also have a significant impact on rainwater runoff quality (Friedler et al., 2017). This is due to the reactions between rooftops and substances in the atmosphere as the result of human activities in the area (Cotton and Pielke 2007). Negative correlations revealed between most measured physicochemical parameters in the rainwater may probably be attributed to the scouring and transport of dry matter accumulated on the roof surfaces (Friedler et al., 2017). The result of the correlation is in line with the report that rainwater and roof drainage pollution is caused by constituents existing in the atmosphere (Hu et al., 2003; Khare et al., 2004) and/or accumulated on the roof area. Accordingly, acid pollutants in the atmosphere (e.g., H_2SO_4, HNO_3) mainly originate from the combustion of fossil fuels in automobiles and from heating in buildings, and the industry (Hu et al., 2003; Kulshrestha et al., 2003; Lee et al., 2000).

7.5 Correlation between Physicochemical Characteristics during Late Rain

During late rain, the pH was highly positively correlated with acidity (r^2=0.992**), TDS (r^2=0.965**), EC (r^2= 0.965**) and was highly negatively correlated with Cl^-(r^2=0.907*). Acidity was positively correlated with TDS (r^2=0.957*), EC (r^2= 0.940*), NO_3^- and SO_4^{2-} were strongly correlated with Cl^-: .965**, 0.975** respectively.

Table 4. Pearson correlation matrix of metal in harvested rainwater from roofs during rain events.

Metal/rain event	Cu^{2+} (mg/l)	Pb^{2+}(mg/l)	Fe^{2+}(mg/l)	Zn^{2+} (mg/l)
April: Onset of rain				
Cu^{2+}	-			
Pb^{2+}	.-	1		
Fe^{2+}	.-	-0.382	1	
Zn^{2+}	.-	-0.024	0.821*	1
July: Peak of rain				
Cu^{2+}	-			
Pb^{2+}	-	-		
Fe^{2+}	-	-	1	
Zn^{2+}	-	-	0.373*	1
October: Late rain				
Cu^{2+}	1			
Pb^{2+}	.$^-$			
Fe^{2+}	-0.403	.$^-$	1	
Zn^{2+}	-0.430	.$^-$	0.681	1

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

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

7.6 Correlation between Heavy Metals during Onset of rain

Lead (Pb^{2+}) was negatively but very weakly correlated with Fe^{2+} and Zn^{2+}:r^2=-0.382, -0.024 respectively (Table 4). Fe^{2+} was positively and moderately correlated with Zn^{2+} (r^2=0.821*). This is an indication of the influence of the roof types in the area. The result is in line with the finding of Friedler et al. (2017) who observed that the type of roof also affected the concentrations of some heavy metals in the harvested rainwater during the onset of rain.

7.7 Correlation between Heavy Metals during Peak of rain

The correlation analysis between metals in the harvested rainwater during the month of July recorded a very weak negative correlation between Fe^{2+} and Zn^{2+} (r^2 =0.373) (Table 4). This is thought to come from the corrugated iron roofing sheet through the weathering process during heavy rain. This result is in line with the findings of Ubuoh et al. (2016); Akhionbare (2009) who reported that corrugated iron roofing sheet recorded the highest concentration of Zn^{2+} in the harvested rain water after the first flush (AFF), because corrugated iron roofing sheets are known for their faster weathering (Akhionbare, 2009; Quek and Forester, 1993).

7.8. Correlation between Heavy Metals during Late Rain

The correlation between heavy metals in the rainwater harvested during late rain indicated that Cu^{2+} was weakly and negatively correlated with Fe^{2+} (r^2= -0.403) and Zn^{2+} (r^2=-0.430) and Fe^{2+} had a positive correlation with Zn^{2+} (r^2=0.681) (Table 4).

Table 5. Temporal variability of harvested rain quality during rain events.

Rain Events	Physicochemical Characteristics						Heavy **Metals**				
	pH	Acidity	TDS	EC	NO_3^-	SO_4^{2-}	Cl^-	Cu^{2+}	Pb^{2+}	Fe^{2+}	Zn^{2+}
April : onset of rain	6.55	20.06	27.50	42.60	0.74	4.76	8.84	0.07	0.01	0.04	1.24
July :peak of rain	6.73	14.76	16.6	26.5	0.158	0.694	2.536	0	0	0.02	0.6
October :late rain	6.64	17.106	21.3	31.6	0.384	1.97	4.52	0.02	0	0.06	0.6

Temporal variability of rainwater harvested during April, July, and October rain events indicates that the chemical parameters increased during the onset of rain, decreased during the peak of rain, and increased again during the late rain as cessation (Table 5). The result is in line with the observations of Balogun et al. (2016); Ubuoh et al. (2012); Mendez et al. (2010) who opined that the concentration of contaminants in roof runoff are highest at the beginning of the rain event compared to subsequent events of similar magnitudes. Accordingly, Leonard et al. (2015) classified the beginning of rain as onset, middle, and cessation respectively. Jamal et al. (2009) also opined that the concentration of various pollutants were higher in the first spill of rain in comparison with the next spills. Teemusk and Mander (2007) found out that values of pollutants were found to be higher in moderate rain, while in samples taken during a heavy rainstorm; the components were less concentrated, as the rain helped wash the contaminants.

8.1 Rainwater Quality Index (RWQI)

The water quality Index was computed for rainwater sampled from the four rooftop catchments in regard to the physicochemical characteristics and heavy metals (tracers) for onset, peak, and late rain events to give the weighted values (Ci/Lij) and the overall RWQI) (Table 6).

Table 6. Rainwater Quality Index (RWQI) of each parameter from different roof catchments during rain events.

Tracer	(WHO) Li	Asbestos (SRC$_1$)		Aluminum (SRC$_2$)		Corrugated (SRC$_3$)		Harvey Tile (SRC$_4$)	
		C_i	Ci/Lij	C_i	Ci/Lij	Ci	Ci/Lij	Ci	Ci/Lij
Onset of rain (April)									
pH	8.5	6.20	0.73	6.55	0.77	6.35	0.75	6.75	0.79
Acidity (mg/l)	100	28.58	0.29	22.19	0.22	25.19	0.25	14.43	0.14
TDS (mg/l)	250	46.00	0.18	28.50	0.11	39.00	0.16	16.00	0.10
EC(μhosm/cm)	100	64.00	0.64	52.00	0.52	57.50	0.58	26.50	0.27
NO_3^-(mg/l)	40	2.66	0.07	0.22	0.006	0.66	0.02	0.13	0.003
SO_4^{2-}(mg/l)	250	13.16	0.05	3.86	0.02	5.20	0.02	1.09	0.004
Cl^-(mg/l)	250	14.03	0.06	9.18	0.04	10.42	0.04	6.45	0.03
Cu^{2+}(mg/l)	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Pb^{2+}(mg/l)	0.01	0.04	4.0	ND	ND	ND	ND	ND	ND
Fe^{2+}(mg/l)	0.3	ND	ND	0.22	0.73	0.40	1.30	ND	ND
Zn^{2+} (mg/l)	3.0	1.16	0.37	1.16	0.14	4.35	1.45	0.22	0.10
RWQI	-	-	6.47	-	2.54	-	2.79	-	1.37
Peak of Rain (July)									
pH	8.5	6.55	0.77	6.70	0.79	6.60	0.78	6.90	0.81
Acidity (mg/l)	100	22.27	0.22	13.44	0.13	19.33	0.19	8.98	0.09
TDS (mg/l)	250	29.00	0.17	19.00	0.08	23.00	0.09	7.00	0.03
EC(μhosm/cm)	100	43.50	0.44	32.00	0.32	36.00	0.36	12.00	0.12
NO_3^-(mg/l)	40	0.46	0.01	0.08	0.002	0.21	0.005	0.04	0.001
SO_4^{2-}(mg/l)	250	3.30	0.01	0.06	0.0002	0.11	0.0004	ND	ND
Cl^-(mg/l)	250	4.98	0.02	2.32	0.009	3.40	0.01	1.15	0.005
Cu^{2+}(mg/l)	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Pb^{2+}(mg/l)	0.01	ND	ND	ND	ND	ND	ND	ND	ND
Fe^{2+}(mg/l)	0.3	ND	ND	0.10	0.3	ND	ND	ND	ND
Zn^{2+} (mg/l)	3.0	1.42	0.47	0.09	0.07	1.37	0.46	0.04	0.01
RWQI	-	-	2.11	-	1.66	-	1.90	-	1.066
Late rain (October)									
pH	8.5	6.40	0.75	6.60	0.78	6.50	0.76	6.85	0.81
Acidity (mg/l)	100	24.48	0.24	19.93	0.20	22.28	0.22	10.22	0.10
TDS (mg/l)	250	37.05	0.19	24.00	0.12	25.50	0.13	13.00	0.07
EC(μhosm/cm)	100	55.50	0.56	28.50	0.29	44.00	0.44	19.00	0.19
NO_3^-(mg/l)	40	1.24	0.03	0.14	0.004	0.41	0.01	0.09	0.002
SO_4^{2-}(mg/l)	250	6.58	0.03	1.26	0.005	1.71	0.007	0.22	0.0009
Cl^-(mg/l)	250	9.51	0.04	4.19	0.02	4.99	0.02	2.65	0.01
Cu^{2+}(mg/l)	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Pb^{2+}(mg/l)	0.01	ND	ND	ND	ND	ND	ND	ND	ND
Fe^{2+}(mg/l)	0.3	ND	ND	0.14	0.47	0.18	0.6	ND	ND
Zn^{2+} (mg/l)	3.0	0.69	0.23	0.26	0.09	1.78	0.59	0.08	0.03
RWQI		-	2.1	-	2.0	-	2.8	-	1.2

ND: Not detected, RWQI: Rainwater quality index

The result indicates that during the onset of rain, individual parameters such as pH, acidity, TDS, and EC from the four rooftops were greater than 0.1. This connotes that rainwater from roof catchments needs some treatment before consumption. For example, Pb^{2+} (4.0) from the Asbestos roof was greater than the critical value of 1.0, demanding a proper treatment of rainwater before use. Based on the overall tracers in the harvested rainwater from the different roof catchments during a n early rain event, rooftops recorded water quality indices that range between 1.4 and 6.5, which is greater than the critical 1.0 limit used for the assessment of water contamination; the roof catchments are put in a decreasing order as follows: Asbestos (6.5) ≥ Corrugated iron (2.8) ≥ Aluminum roof (2.5) ≥ Harvey-tile roof (1.4). This implies that the rainwater harvested from the Asbestos roof is more contaminated than the Harvey-tile rainwater during the early rain events.

During the peak of rain, regarding TDS in the samples from $SRC_{2\text{-}4}$only EC, $NO_{3,}$ SO_4^{2-}, Cl^-; Fe^{2+} and Zn^{2+} from SRC_2 were greater than the 0.1 value, which calls for little treatment for human consumption, while others did not require any treatment for human consumption (Table 6). Meanwhile, the overall tracers from the rainwater from the roof catchments during the peak of rain event, rooftops recorded water quality indices that ranged approximately from 1.07 to 2.11, which is greater than the critical limit of 1.0 used for WPI judgment. There is a decreasing abundance of contaminants in the samples from the four different catchments in the order of: Asbestos (2.11) ≥ Corrugated iron (1.90) ≥ Aluminum roof (1.7) ≥ Harvey tile roof (1.07). This implies that the rainwater harvested from The Asbestos roof is more polluted than that of the Harvey-tile roof which is less polluted during the peak of rain event. During late rain, acidity, TDS, EC Fe^{2+} and Zn^{2+} from some roofs were greater than the 0.1 value which means that the rainwater required little treatment for human consumption, while others did not require any treatment for human consumption (Table 6). The overall tracers in the rainwater harvested from the roof catchments during the late rain event recorded water quality indices that ranged between 1.21 and 2.78, which is greater than the critical limit of 1.0 used for WPI judgment, having a decreasing order as follows: Corrugated iron (2.8) ≥ Asbestos (2.1) ≥ Aluminum roof (2.0) ≥ Harvey-tile roof (1.2). This indicates that the rainwater harvested from the corrugated iron roof is more contaminated than that of the Harvey-tile roof during the cessation of rain events (Figure 3).

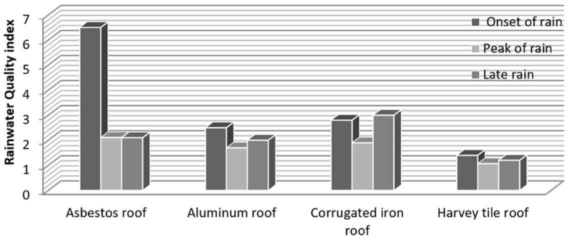

Figure 3. Rainwater Quality Index from rooftops during the rain events.

8.2 Rainwater Pollution Index (RWPI)

Total pollution indices and class status based on each rainwater characteristic during rain events are presented in Table 7.

Table 7. Rainwater Pollution Index (RWPI) for each rainwater characteristic during rain events.

Rainwater Quality	Total pollution index Onset of rain)	Pollution Class status (PCS)	Total pollution index (peak of rain)	Pollution Class status(PCS)	Total pollution index (Late rain)	Pollution Class status (PCS) (Table 1)
pH	3.04	STP	3.15	STP (4)	3.1	STP (4)
Acidity (mg/l)	0.9	NOP (1)	0.63	NOP (1)	0.8	NOP (1)
TDS (mg/l)	0.51	NOP (1)	0.4	NOP (1)	0.51	NOP (1)
EC(µhosm/cm)	2.01	MOP (3)	1.24	SLP (2)	1.5	SLP (2)
NO_3^-(mg/l)	0.1	NOP (1)	0.02	NOP (1)	0.05	NOP (1)
SO_4^{2-}(mg/l)	0.09	NOP (1)	0.012	NOP (1)	0.043	NOP (1)
Cl^-(mg/l)	0.17	NOP (1)	0.044	NOP (1)	0.09	NOP (1)
Cu^{2+}(mg/l)	ND	-	ND	-	ND	-
Pb^{2+}(mg/l)	4	STP (4)	ND	-	ND	-
Fe^{2+}(mg/l)	2.03	MOP (3)	0.3	NOP (1)	1.1	SLP (2)
Zn^{2+} (mg/l)	2.03	MOP (3)	1.01	SLP (2)	0.94	NOP (1)

PCS: Pollution class status, STP: Strongly polluted, NOP: No pollution, MP: Moderately polluted ,SLP: Slightly polluted

The pH and Pb^{2+} indicate a strong pollution suspected to be due to atmospheric pollution by human activities and soil-dust in the atmosphere (Ubuoh et al., 2016), and air pollution in form of CO_x, NO_x, and SO_x leading to acid rain formation (Ubuoh et al, 2012; Bogan et al., 2009; Menz and Seip, 2004; Velikova et al., 2000). Acidic rainwater will cause corrosiveness on the zinc roof (Ubuoh and Ekpo, 2017), and has a high solubility against heavy metals such as Pb (Bogan et al., 2009). The Pb in water can result to the formation of $Pb(OH)_2$ (Khayan et al., 2019), making it hazardous to environment (Patunru, 2015). The higher the level of Pb in rainwater, the bigger the chances for the public to suffer health disorders through drinking rainwater (Khayan et al., 2019 ; Alli, 2015; Al-othman et al., 2013), and the high the level of Pb in urine of the consumers of rainwater (Khayan et al., 2019). Acidity, TDS, NO_3^-, SO_4^{2-}, and Cl^-indicated no pollution. Moderate pollution was observed concerning EC, Fe^{2+}, Zn^{2+} during the onset of rain respectively (Table 7). During the peak of rain, pH indicated a strong pollution suspected to be due to urban air pollution. while acidity, TDS, NO_3^-, SO_4^{2-},

Cl^- and Fe^{2+} recorded no pollution, and EC and Zn^{2+}recorded slight pollution respectively. In the late rain, pH indicates a strongly polluted samples, while acidity, TDS, NO_3^-, SO_4^{2-}, Cl^- Zn^{2+}indicated no pollution. EC and Fe^{2+} showed a slight pollution. No pollution was observed concerningCu^{2+} during the rain events, and during the peak, and late rain events, no pollution was observed regardingPb^{2+}. The result of Cu is inconsistent with the findings of Udousoro and Unanaowo (2015) who reported that atmospheric rainwater at Urua Akpan- Andem, Akwa Ibom State, Nigeria shows a strong pollution concerning Cu^{2+} due to the commercial activities and heavy traffic flow. Ultimately, the results of rainwater pollution classes recorded during the rain events are as follows: strongly polluted rainwater (STP) constituted 14.3%, samples with no pollution (60.7%), moderately polluted samples (MOP) (10.7%), and the slightly polluted samples constituted (14.3%).

Table 8. Rainwater pollution index for roof catchments on temporal rain events.

Roof types	The Month of Rain Event				
	April	July	October	Mean	Ordering
Asbestos Roof (SRC_1)	6.46	2.11	2.07	3.55	4th
Aluminum Roof (SRC_2)	2.54	1.66	1.98	2.06	2nd
Corrugated Roof (SRC_3)	2.79	1.90	2.78	2.49	3rd
Harvey Tile (SRC_4)	1.37	1.07	1.21	1.22	1st
Total	13.16	6.74	8.04	9.32	-
Mean	3.29	1.69	2.01	-	-

It is observed that all of the selected roof catchments recorded values higher than the critical value of 1.0 used for judgment of unpolluted water, which implies that rainwater from these roof catchments in the study area must be subjected to treatment before any potable water use (Table 8). However, the pollution was at different levels during the months. In April: Harvey tile ≤ Aluminum ≤ Corrugated ≤ Asbestos, in July: Harvey tile ≤ aluminum ≤ Corrugated ≤ Asbestos, while in October: Harvey tile ≤ Aluminum ≤ Asbestos ≤ Corrugated. However, Harvey tile roof was observed to be the most suitable while July is observed as the most suitable period for rainwater harvesting. Asbestos roof recorded the worst water quality due to heavily loaded contaminants throughout the three rain events (Figure 4). This result disagrees with Opare (2012) who reported that the corrugated iron sheet is the most suitable for rainwater harvesting. The result is in line with the findings of Ezemonye et al. (2016); Ikhioya et al. (2015), who reported that rainwater harvested from Asbestos rooftop had more parameters and the highest contaminants. Differences that occur in the pollution index of rainwater from rooftops between April, July, and October may be due to the type of roof, human activities, and the intensity of the rain. Solids and dusts that are deposited on the roof were flush off in the early rain, reduced in July, and gradually built -up in October. The flush off' effect of the rain has cleared the contaminants on the roof of the building. Hence, the reading is decreasing with the increase of rain duration (Chu et al., 2001).

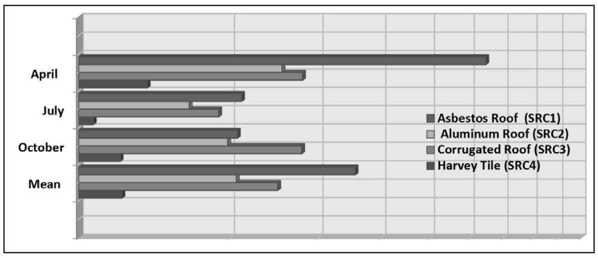

Figure 4. Rainwater pollution index of different roof catchments during rain events.

From the rainwater pollution index (RWP1) by roof catchments, Asbestos recorded 3.6 (i.e. strongly polluted), Aluminum 2.1 (moderately polluted), Corrugated 2.5 (moderately polluted) and Harvey-tile roof 1.2 (slightly polluted), with a decreasing abundance of contaminants in the samples from the four catchments in the order of: Asbestos ≥ Corrugated ≥ Aluminum ≥ Harvey Tile. This signifies that the Harvey-tile rooftop is the best, while the Asbestos rooftop is the worst for rainwater harvesting respectively. These results disagreed with the observation that rainwater harvested from rooftops is often considered unpolluted (Meera and Ahammed, 2006; Gonçalves et al., 2003) or at least being of a relatively good quality compared with the runoff from surface catchments (Göbel et al., 2007). The result is consistent with the observation by Adeniyi and Olabanji (2005) who raised disagreement about the quality of rooftop runoff ranging from good or acceptable to contaminated, and stated that rainwater quality is dependent on the roofing material (Adeniyi et al., 2002; Zobrist et al., 2000), environmental conditions, and atmospheric pollution (Friedler et al., 2017; Van -der Sterren et al., 2013).

4. Conclusion

Rainwater was collected from Asbestos, Aluminum, Corrugated iron and Harvey-tile roofs which are commonly used material for roofing houses, as well as from the atmospheric rain as control during early, peak and late rain. The samples were taken from the three selected housing locations (layouts), whenever rainfall occurs at different locations. However, apart from pH, other physiochemical properties and metals: Cu^{2+}, Pb^{2+} and Fe^{2+} were below the WHO/FMEnv permissible limits for drinking water. Physicochemical characteristics and heavy metals from the roofing sheets' samples were considerably higher than in the atmospheric rain during rain events: April> July < October. Positive and negative correlations existed between most examined rainwater tracers from rooftops, where the positive correlation is assumed to have originated from the weathering of roof catchments or probably from the scouring and transport of dry matter accumulated on the roof surface during the antecedent dry period. A negative correlation is also assumed to have resulted from the environmental conditions (air-borne dust and mists, bird droppings, and other debris), that accumulated in rain water via rooftop. The results indicated that the contamination of rainwater originated from the atmosphere outside the roof catchments; the common pathway and origin may be attributed to the kinetic energy of rainfall that impinged on the roof materials. Except for the Harvey-tile roof, the Zn^{2+} values in the rainwater samples from the Asbestos, Aluminum, and corrugated roofs were above the permissible limits of the 0.3mg/l set by the WHO, which produces the undesirable taste of the rainwater alongside health risks as a result of a Zn^{2+}overdose. From RWP1, roof catchments exhibited a decreasing abundance of contaminants in the order of: Asbestos ≥ Corrugated ≥ Aluminum ≥ Harvey-Tile, signifying that rooftops resulted in slightly-polluted samples and strongly-polluted ones, with the Harvey-tile being the best and Asbestos being the worst for rainwater harvesting. For urban dwellers that intend to harvest rainwater using roofs, Harvey-tile roofing sheets that are environmentally friendly should be recommended for the roofing of houses. However, if not feasible due to their high cost, Aluminum roofing sheets should be an alternative. However, the use of Asbestos is not recommended as its fibers can cause the Asbestosis disease. The use of Asbestos as a roofing sheet should be discouraged by developers and compliance must be enforced. Ultimately, Nigerians should be properly enlightened on the risks associated with the use of some roof materials that are not environmentally friendly .For roofs that are nontoxic, the operation and maintenance (O and M) strategy of the catchments must be strictly adhered to.

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