Multivariate Statistical Determination of Water Quality Indicator for Roof Harvested Rainwater in Umuahia South-East, Nigeria

Okosa, I[1*]; Umunna .M. Francis[2]; Paul, T[1]; Chidinma .E. Ikechukwu-Edeh[1]; Ehiomogue, P[1]; Ezeiruaku, A[1].

[1]Department of Agricultural and Bioresources Engineering, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria.

[2]Department of Agricultural Engineering, Delta State University of Science and Technology Ozoro, Delta State, Nigeria.

*Corresponding author.

E-mail address: okosa.ikechukwu@mouau.edu.ng
+2348068491443

Abstract

This study aimed to assess the quality of harvested rainwater from two (aluminum and corrugated zinc) commonly used roof materials in several urban and rural parts of Africa, and particularly in Nigeria for potable use, and to identify and select appropriate water quality indicator sensitive to variations in response to roof types and precipitation sampling time regimes. A total of 36 samples (first-flush and post-flush) were taken from two different urban residential roofs during six rainfall events, within the months of June (3events) and July (3events), and analyzed for selected water quality parameters. The results showed that concentrations were far below recommended guidelines (WHO and NSDWQ). However, concentration levels in First-flush samples for the two roofs were relatively higher than Post-flush. This implies that quality improves with initial roof wash-off as traditionally practiced. Results also showed that sampling (interval) time had significant influence on quality parameters than roof material. Multivariate statistical tool was employed to identify a sensitive quality indicator. Factor analysis (FA) was used to group parameters into significant factors that explained over 72% of variations in water quality parameters. Discriminant analysis identified Sulphate and

Chloride as the most sensitive parameters for residential roof harvested rainwater, and therefore, may be applied for water quality monitoring in the region.

Keywords: Water quality monitoring; rainwater harvesting; roof runoff; roof material; Multivariate analysis

1. INTRODUCTION

Water is one of the essential elements of nature which supports aquatic, plant and human life. However, this important natural resource seems to be depleting in recent years and may eventually become less abundant in the near future, even in areas without known occurrence of scarcity of this natural resource, as a result of climate change, increasing population, industrial and agricultural activities. These activities make substantial demands on the available freshwater resources. In Nigeria, towns, cities and villages usually face water shortages, attributed to increase in population and other factors (Oria-Usifo *et al.*, 2018).Umuahia is located in Abia State, South-East Nigeria. It is a developing town, more of an administrative than commercial and therefore most of its localities are housed by hundreds to thousands of families. As much as some compounds have boreholes drilled in their compounds, many others depend on rain water for their domestic needs while the ones with boreholes may augment their water supply with rain water. Therefore, provisions are usually made to collect rainwater whenever it rains and stored for future use.

Roof rainwater harvesting, which is the act of diverting precipitation water from a roof into a ready storage (Kirisits *et al.*, 2011), is a traditional practice in urban and rural areas in Nigeria, because of the stress and productive time involved in obtaining water from distant streams and rivers. Even with the growing popularity of water wells in rural areas and boreholes in urban areas, roof rainwater harvesting seemed not to be a thing of the past among the populace. The quality of this roof harvested water is of concern as this water is captured and stored for potable use such as; drinking, cooking and other domestic purposes. Therefore, possible contamination of this water source has been observed as one of the most critical environmental quality issues (Nosrati, 2017). These roof rainwater contaminants have been recognized to emanate from varying sources, including; atmospheric condition and scavenges from aerosols, gases and volatile particles; wash-off of particles deposited on roof surfaces as well as degradation of roof material (Nosrati, 2017).

Studies have revealed that water harvested from roofs can be highly polluted by heavy metals and bacterial pathogens, which poses a serious health risk (Ahmed et al., 2008; Simmons et al., 2011). It has also been reported that roof material type affects the quality of harvested rainwater (Karisits et al., 2011; Nosrati, 2017; Lee et al., 2012; Chaplot et al., 2018). In a study conducted by Chaplot et al. (2018), in South Africa, they noted that water harvested from metallic roofs and concrete floors contained heavy metals high above standard (WHO, 2011) recommendations. Kirisits et al. (2011), in another study involving five (5) roofing materials (Asphalt fiber glass shingle, Galvalume metal, Concrete tile, Cool and Green), reported that rainwater harvested from any of these roofing materials would require treatment for potable use after considerable quantity of initial first-flush diversion. Their study also showed that rainwater from metal roofs tends to have lower concentrations of fecal indicator bacterial compared to others. In a similar study of four (4) roofing material types to ascertain the effect of roofing material on chemical and microbiological quality of rainwater, Lee et al. (2012), reported that galvanized steel was found to be the most desirable for rainwater harvesting applications, which met the Korean guidelines for drinking water quality.

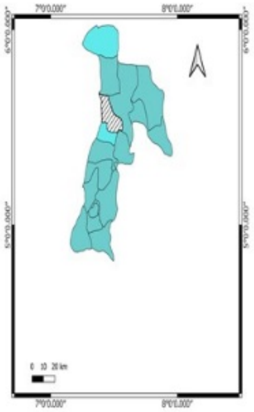
Multivariate statistical techniques such as principal component analysis (PCA), factor analysis (FA), discriminant analysis (DA), and cluster analysis (CA) are consistent tools widely employed in evaluation of surface and subsurface water quality (Singh et al. 2005; Papatheodorou et al. 2006; Shrestha and Kazama 2007; Omo-Irabor et al. 2008; Kvítek et al. 2009). However, Nosrati (2017) in his study,reported Phosphate and Nitrate as the most sensitive parameters for bitumen and mosaic tile roof material and could be employed in water quality monitoring.They also employed a combination of multivariate statistical tools in groundwater quality assessment (Nosrati and Van Den Eeckhaut, 2011).The use of water is very vital for growth of man, security of livestock and other living organisms within an environment, therefore it is pertinent to assess the quality of water consumed by the inhabitants of Umuahia Town in order to preserve lives and the well-being of the users of rainwater. A renewed interest in rain water harvesting (RWH) has emerged as a result of escalating environmental and economic costs of providing water by centralized water system or by well drilling. Rain water harvesting has the potential to supplement groundwater extractions in Umuahia metropolis owing to the growing population, hence, the need to ensure that residents are intimated on the quality of the water gotten from their rooftops. From available literature, multivariate statistical technique has scarcely been applied as a tool in assessing and monitoring harvested rainwater. Therefore, the aims of this study are: (1) To assess the quality of rainwater from different common residential roofing sheets in urban city of Umuahia, Abia State.

(2) To determine an indicator that could be employed in water quality monitoring of harvested rainwater from the roof materials (corrugated zinc and Aluminum) in Nigeria.

2. MATERIALS AND METHODS

2.1 Study area

Umuahia is the capital city of Abia State in Southeastern Nigeria. It is located along the rail road that lies between Port Harcourt to its south and Enugu city to the north. It is a developing town, more of an administrative than commercial city. The activities of the brewery and ceramics companies are considered the major contributing sources of air pollution. According to the 2006 census, Umuahia has a population of 359,230 inhabitants predominantly of Igbo tribe. The climate at Umuahia is classified as tropical with many months of the year experiencing significant rainfall; greater part of its vegetation is made up of forest (tropical vegetation). Precipitation averages 2153mm and is lowest in December with an average of 15mm and at September with an average of 322mm (Weather Spark).A survey of the urban areas of Umuahia revealed that corrugated zinc and aluminum sheets are the dominant roofing material type used for residential houses.Our choice of the study location (Fig. 1) was informed by the recent activation of brewery activities which contribute to atmospheric pollution in the area. Roof rainwater samples were collected from two representative roofs (corrugated zinc and aluminum sheet) in the study area for quality analysis.



Study Location

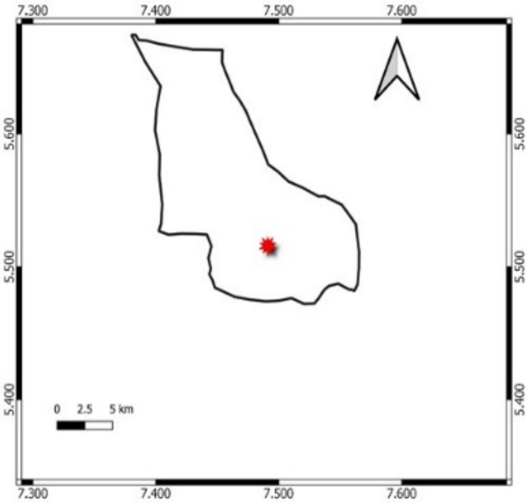


Fig.1 Study area map showing Umuahia-North L.G.A in Abia State

2.2 Sampling and sampling technique

We collected three samples each from residential houses with aluminum and corrugated zinc roofs of fairly same age in usage in urban city of Umuahia. First sample (first-flush) was collected at the start of rainfall, while subsequent samples were collected 15mins after at 5mins intervals and labelled as post-flush (PF) samples. Any samples collected during rainfall periods less than 30mins were discarded. Sterilized 300ml bottles were used for sample collection and sent to the laboratory for quality analysis. A total of 36 samples each from urban houses were taken during six rainfall events, within the months of June (3events) and July (3events) when precipitation was at its peak. Water quality parameters were analyzed in the laboratory using standard procedures.

Temperature was measured with conventional mercury bulb thermometer, pH was measured with a colorimeter (Hanna instrument, $H_1$9298), Electrical conductivity, EC was measured with a conductivity meter (model: DDS-307), Bicarbonate was determined by titration with H_2SO_4, Nitrate, Phosphate and Sulphate were determined using Atomic Absorption Spectrophotometer (Buck 210 VGP, USA).

2.3 Statistical analysis

Multivariate statistical analyses were conducted on the measured water quality parameters data. Preliminary statistics for normality and suitability of the data for factor analysis were carried out, and Mann-Whitney U-test (non-parametric) was applied to examine for significant effects of roof type and sampling time regime (first-flush and post-flush runoff) on individual water quality parameters. Additionally, Kaiser-Meyer-Olkin value of 0.65 and Bartlett's test of sphericity having a chi-square value of 211 ($p < 0.001$) confirmed the fitness of the data for factor analysis (FA). Also, water quality parameters were converted into standardized variables before applying FA to group the water quality parameters into statistical factors based on their correlation construction using principal component analysis for the detection and selection of an appropriate water quality indicator. Standardize values served to remove the effect of differences in measurement units for the calculation of factor loadings.

Eigenvalues are the measure of variance explained by each factor and factors having eigenvalues less than one, explained less variance in the data set (Nosrati, 2017). We considered factors with eigenvalues greater than one and subjected same to an orthogonal (varimax) rotation to minimize the number of variables loading highly on each factor. Additionally, communalities of individual water quality parameter for factor model were calculated to determine the proportion of variance in each water quality parameter explained by the rotated solution. When interpreting variable affinity to each factor, we marked water quality parameters with low communalities as less vital.

Furthermore, factor scores for each sample set were calculated and used to conduct ANOVA to examine significant differences among roof material/sampling time regimes. Significant factors were retained for further analyses. Discriminant analysis (DA) was finally conducted to select factors that were most discriminating among the roof type/sampling time runoff categories, likewise the dominant water quality parameters constituting the factors. All statistical analyses were performed using IBM SPSS Statistics 20 software.

3. Results and discussion

3.1 Effect of roof materials and sampling regime on roof harvested water quality

The results of the descriptive statistics of the water quality parameters from two different common roof materials (usually used for residence purposes) with respect to sampling time are presented in table 1. Samples were collected at 5 minutes' interval after the first-flush for every rainfall event. Average pH values of first-flush and post-flush samples for the two roof types were approximately same and within the permissible limit of the Nigerian Standard for Drinking Water Quality (NSDWQ, 2007). Water quality parameters values of first-flush were observed to be higher compared to post-flush for the two roof materials. However, Hardness, TSS, Sulphate, Nitrate; and Sulphate, TSS, Chlorine, EC followed a contrasting trend for Aluminum and Corrugated Zinc roofs respectively. This is fairly in contrast with results presented by Nosrati (2017), which showed higher values in all water variables of the first-flush sample compared with the posterior runoff sample. This difference could be as a result of the high pollution of the study area as indicated by Nosrati (2017). All water quality parameters values were far below the recommended or allowable value by the World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) except for Bicarbonate which could not be compared.

The results of the Mann-Whitney test carried out to observe the influence of roof types on selected water quality parameters being the dependent variable are presented in table 3. The result revealed that samples from corrugated zinc exhibited higher hardness value than that obtained from Aluminum roof. Additionally, alkalinity, total suspended solids, total dissolved solids and phosphate parameters of the two roof materials were significantly different at 5% level, while other water quality parameters showed no statistical significant difference among the roof materials. This is also in contrast with the observation of Nosrati, (2017), which stated that no significant difference between roof materials (Bitumen and Mosaic tile) in all the water quality materials tested at 1% level except for pH and suggested further investigation. The observation in my opinion could be that the two roof types perhaps may comprise of similar material constituent. Morrow et al. (2010), noted that elemental composition of roof harvested rainwater can vary at different points of harvesting system. They also revealed that concrete tile and cool roofs produce harvested rainwater similar to that from metal roofs indicating that these roofing material may also be suitable for rainwater harvesting applications.

Furthermore, same test was carried out to check for which variable/parameters the average values of the first-flush and post-flush runoff significantly differ (Table 4). All other water quality parameters exhibited high significant differences in mean values apart from pH, hardness, electrical conductivity, phosphate at 5% level (Table 4). This shows that first-flush and post-flush runoff have a significant influence on domestic water quality parameters. The test also revealed that water quality parameters in individual roof materials were greatly affected by the sampling time. These observations are in line with that reported by Nosrati (2017). Also, these results suggest that the sulphate, nitrate and Bicarbonate each presents a prospective property for water quality assessment within the study area since they displayed higher significant contrasts between the two sampling regime (first-flush and post-flush runoff).

riptive statistics of water quality parameters with different roof materials/runoff sampling regimes (n=36) and their allowable values (WHO & NSDQW)

Aluminum First Flush				Aluminum Post-Flush				Corrugated Zinc First Flush				Corrugated Zinc Post-Flush			
Mean	Max.	Min.	StD	Mean	Max.	Min.	StD	Mean	Max.	Min.	StD	Mean	Max.	Min.	StD
6.59	6.8	6.4	0.13	6.625	6.8	6.5	0.121	6.57	6.7	6.5	0.09	6.5	6.5	6.8	0.97
39.32	31.014	8.140	0.99	35.731	45.12	30.44	5.023	30.07	31.00	29.31	0.51	29.37	30.83	26.1	1.14
14.76	15.987	13.11	1.00	18.954	23.47	12.93	5.023	32.38	33.08	31.45	0.53	21.99	31.97	13.54	8.11
25.366	27.106	24.41	0.936	41.398	58.541	23.02	5.439	41.55	50.03	35.78	4.27	45.03	68.75	35.12	12.52
23.382	24.24	25.75	0.754	15.166	18.103	12.75	2.053	15.07	15.67	13.25	0.84	15.11	16.73	13.22	1.44
0.16	0.26	0.11	0.054	0.13	0.22	0.12	0.22	0.15	0.2	0.12	0.03	0.17	0.26	0.11	0.06
22.59	24.24	22.15	0.75	15.73	16.96	14.02	1.05	17.21	19.83	15.74	1.32	19.26	23.09	16.13	12.97
8.69	10.06	8.12	0.69	13.218	16.88	9.89	2.964	9.74	11.23	9.11	0.74	11.42	13.20	9.01	1.89
0.979	1.207	0.81	0.136	2.104	2.74	1.59	0.51	1.55	1.92	1.39	0.17	1.52	1.74	1.38	0.10
0.489	0.57	0.42	0.05	0.430	0.758	0.163	0.28	0.72	0.79	0.61	0.066	0.58	0.76	0.15	0.26
921.34	974.56	890.51	32.07	739.6	829.38	650.01	41.918	894.22	900.76	880.48	7.02	784.77	997.48	452.82	200.39

elation coefficients of water quality parameters within different roof type and sampling time regime

ality ers	pH	TSS	Cl	EC	Sulphate	Nitrate	Phosphate	Bicarbonate	Alkalinity
	1.000								
	-.066	1.000							
	-.084	-.060	1.000						
	.125	.147	.478*	1.000					
/l)	.040	.718*	-.126	.024	1.000				
)	.091	.645*	-.507*	-.206	.837*	1.000			
ng/l)	-.177	-.483*	-.227	-.255	-.567*	-.442*	1.000		
(mg/l)	-.088	-.503*	.137	-.145	-.432*	-.401*	.441*	1.000	
g/l)	-.014	.372*	-.385*	-.260	.679*	.737*	-.487*	-.309*	1.000
g/l)	-.320*	.235	-.333*	-.376*	-.046	.184	.350*	.162	-.009

orrelation at 0.05 level

Table 3. Results of Mann-Whitney test that compared water quality parameters within aluminum and corrugated zinc roof materials (n=36)

Water quality Parameters	Mean Aluminum	Mean Corrugated zinc	U-value	p-value
pH	6.61	6.57	149.0	0.332
Alkalinity(mg/l)	33.37	29.63	87.5	0.007
Hardness(mg/l)	17.41	25.82	72.0	0.002
TSS(mg/l)	35.49	43.75	99.0	0.017
TDS(mg/l)	18.19	15.10	111.0	0.042
EC(μS/cm)	0.14	0.10	150.0	0.380
Chloride(mg/l)	18.26	18.51	157.0	0.493
Sulphate(mg/l)	11.55	10.80	170.5	0.872
Nitrate(mg/l)	1.69	1.53	146.5	0.321
Phosphate(mg/l)	0.45	0.63	97.0	0.015
Bicarbonate(mg/l)	806.60	825.09	149.0	0.358

Table 4. Results of Mann-Whitney test that compared water quality parameters within runoff sampling regime (n=36)

Water quality Parameters	Mean First Flush	Mean Post-Flush	U-value	p-value
pH	6.57	6.60	151.0	0.570
Alkalinity	29.70	32.55	105.0	0.056
Hardness	23.57	20.48	109.0	0.074
TSS	33.46	43.21	98.0	0.034
TDS	19.23	15.14	88.0	0.015
EC	0.16	0.15	137.0	0.347
Chlorine	19.9	17.50	84.0	0.011
Sulphate	9.22	12.32	40.0	<0.001

Nitrate	1.26	1.81	40.5	<0.001
Phosphate	0.61	0.51	141.0	0.414
Bicarbonate	707.78	762.22	46.0	<0.001

3.2 Determination of water quality indicator for harvested roof runoff

Considering results in table 2, which shows the correlation matrix for ten (10) water quality parameters with significant correlations ($p < 0.05$) observed among 22 of 45 water quality parameter pairs. The selected water quality parameters employed in the study are; pH, Alkalinity, Hardness, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Chlorine, Electrical Conductivity (EC), Sulphate, Nitrate, Phosphate and Bicarbonate. Nosrati, (2017) reported significant correlations among 10 of 21 water quality pairs for seven (7) water quality parameters. TSS had the maximum number of correlations among water quality parameters followed by Chlorine and Sulphate. TSS had a positive correlation ranging from 0.37 – 0.72. Sulphate had fewer negative correlations than Chlorine for all water samples. TSS positively correlated with Sulphate, Nitrate, Alkalinity, and a negative correlation with Phosphate and Bicarbonate. The large number of correlations observed among the water quality parameters suggests that they can be arranged into homogenous groups of variables based on their correlation patterns (Nosrati, 2017). Hence, these parameters could be employed as indicator of water quality for roof harvested rainwater.

Results of table 5 of factor analysis performed on standardized values revealed that eigenvalues greater than one for the first three factors explained over 72% of variance in the measured water quality parameters. Considering the communalities of the individual water quality parameters, these factors explained over 70% of the variability observed among the ten water quality parameters with exception of pH, EC and Bicarbonate. Consequently, these parameters were regarded as least important as a result of their low communalities values.

Examining loading construct of the parameters to the three factors, factor 1 had high positive loadings for Sulphate, Nitrate, TSS, Alkalinity and high negative loadings for Phosphate and Bicarbonate (table 5). The second factor had high negative loading for Chlorine and EC, and factor 3 had high loading for pH and Hardness. It is important to state that TDS was removed from the analysis because it was not quite clear which factor it could be associated with as a result of its cross-loading. Also, factor loadings < 0.3 were suppressed and excluded from the table.

Factor scores were used to test for significant differences as regards roof type/sampling intervals using ANOVA. Apart from factor 3, the other two factors varied significantly with roof type/runoff sampling time (table 5). Means of factor scores for factor 1 were positive for aluminum/post-flush and corrugated zinc/post-flush runoff, and negative for aluminum/first-flush and corrugated zinc/first-flush. Also, aluminum/post flush had larger value than corrugated zinc/post-flush (table 5).

Following the result of ANOVA, factor 3 was excluded as a variable in the subsequent DA. Discriminant analysis was conducted with the roof type/sampling time as grouping variable and factors 1 and 2 as independent variables. Considering the canonical discriminant function coefficients, it revealed the weightings attributed to each factor to maximize differences between groups. DA of the two factors showed that discriminant coefficients (Eq.1) accounted for > 56% of the variance ($p < 0.001$).

$$Y = 0.963(\text{Factor }1) + 0.421(\text{Factor }2) \qquad (1)$$

Table 5. Proportion of variance of orthogonal (varimax) rotation and communality estimates of the water quality parameters

Water quality parameters	F1	F2	F3	Communality estimates
pH			**-0.811**	0.67
Alkalinity (mg/l)	**0.715**[1]	0.423		0.70
Hardness (mg/l)		0.429	**0.748**	0.75
TSS (mg/l)	**0.827**		0.325	0.80
EC (µS/cm)		**-0.791**		0.66
Chloride (mg/l)		**-0.867**		0.77
Sulphate (mg/l)	**0.909**			0.83
Nitrate (mg/l)	**0.838**	0.451		0.91
Phosphate (mg/l)	**-0.739**	0.322		0.74
Bicarbonate (mg/l)	-0.644			0.44
Eigenvalues	3.8	2.2	1.2	
% Total variance	38.1	22.2	12.4	
Cumulative % variance	38.1	60.3	72.7	

ANOVA results

F-value	4.538	25.320	0.660
p-value	0.04	<0.001	0.422

Mean scores of roof material/sampling time regimes		
Aluminum/first-flush	-0.919^{a}	-0.926^{a}
Aluminum/post-flush	0.756^{b}[2]	0.779^{b}
Corrugated zinc/first-flush	-0.457^{ab}	0.406^{b}
Corrugated zinc/post-flush	0.046^{ab}	-0.476^{ab}

[1] Bold values indicates strong (> 0.7) loadings

[2] Different small letters in each column indicate that scores are significantly different at 5% level based on Tukey HSD Post-Hoc test

Observing the values of the discriminant function coefficients in (Eq.1), factor 1 was the highest contributor. Thus, factor 1 was most dominant in discriminating between roof type/sampling time regimes, and considered as the most essential factor applicable for assessing water quality indicator. Water quality parameters constituting factor 1 are; Sulphate, Nitrate, TSS, Phosphate, Alkalinity, Bicarbonate.

Discriminant analysis was further conducted on the individual water quality parameters comprising factor 1. The canonical discriminant coefficients of water quality parameters that constitute factor 1 revealed thatSulphate, followed by Chloride, Hardness, Nitrate, TSS, Phosphate and EC were the most important discriminating water quality parameters among roof material/runoff sampling time (Eq.2).

$$\text{WQI} = 1.09\left(SO_4^{2-}\right) + 0.93(\text{Chlorine}) + 0.76(\text{Hardness}) + 0.40\left(\left(NO_3^{-}\right)\right) - 0.343(\text{TSS}) - 0.341\left(PO_4^{3-}\right) \quad (2)$$

However, the most dominant and sensitive measured water quality parameters were Sulphate and Chloride (Eq.2). Sulphate was not correlated to Chloride (r = – 0.126; table 2). Therefore, both parameters displayed high potential for observing and assessing variations in water quality with changes in roof material/runoff sampling time for roof harvested rainwater with the study area.

Conclusion

Water quality assessment was conducted on rainwater harvested from two (Aluminum and Corrugated Zinc) roof materials widely used for residential houses in Nigeria, using Umuahia in Abia State as case study. The selected water quality parameters assessed in the study are: Sulphate, Nitrate, Chloride, Phosphate, Bicarbonate, Alkalinity, Electrical Conductivity, pH, TSS, TDS and Hardness, which concentrations were compared with recommended guidelines (WHO and NSDWQ). All measured water quality parameters were below recommended guidelines, but concentrations observed in all first flush samples were higher than post-flush samples for the two roofs, except pH which was approximately same for all samples. The results also showed that sampling interval (first flush and post-flush) was the most influencing factor on the water quality parameters and should be considered in rainwater harvesting. Although roof material had significant effect on a few water quality parameters, the roof materials involved in the study could be regarded as appropriate for rainwater harvesting. Since biological quality assessment was not involved in the study, treatment of the harvested rainwater is recommended, as biological contaminants may be present in the samples and their levels may exceed guidelines. Overall, this study had established that applying a combination of statistical tools could serve as a useful prospect for assessment and selection of suitable quality indicator for roof rainwater. Also, from the result of this study, it could be inferred that ambient air quality of the focus environment is conducive enough for the residents. Lastly, since most studies on roof harvested water quality were focused on urban areas, and again, since the ambient air quality widely differ by location, additional study, we suggest could be investigating the sensitivity of the selected water quality indicators for other regions especially rural areas.

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Statements and Declarations

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Authors's contributions

Okosa I., Designed and analyzed the research data.

Paul T. and Ehiomogue P., Wrote the manuscript.

Chidinma .E. Ikechukwu-Edeh., Conducted the lab analysis.

Umunna .M. Francis and Ezeiruaku A., Carried out the field samples collection.