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Assessment of Rainwater Quality in Warri and Environ, Southern Nigeria for Domestic Purposes

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Abstract

The study aimed at assessing the physiochemical characteristics of rainwater in Warri and it environ was investigated. Pb, Zn, Cd, Cu and Cr concentrations in rainwater from roof and non-roof sources were determined using Atomic Absorption Spectrophotometry. Three geospatial locations comprising Jakpa, Udu, and Ubeji were selected based on prevailing anthropogenic activities. The rainwater samples were systematically collected from (aluminum) roof and non-roof sources for the months of April, June, and August and October 2022, treated and analyzed in the laboratory for sixteen physicochemical parameters. Results were statistically analyzed using ANOVA, and T-test for the determination of the level of relationships and variations across geospatial locations. Significant correlations ($r = 0.72$) exist between Cr in rainwater from roof and non-roof sources. Implying point-source contaminations and may be emanating from the influence of roof materials. Furthermore, high concentrations of Cd and Pb in roof source above WHO standards were mostly in Jakpa and Ubeji. Calculated Health Risk Index (HRI) for children and adult is greater than 1. The results showed that most samples from the locations are considered not safe (HRI > 1) especially for Cd, which means that there are potential health risks consuming rainwater from Jakpa, Udu and Ubeji. Therefore, there is need for prompt sensitization program to dissuade people from directly drinking rainwater from these locations.

Keywords

Water Quality, Health Risks, Rainwater, Heavy Metals, Warri Environs

1. Introduction

Due to water scarcity, rainwater is increasingly used for both potable and non-potable purposes in Nigeria. This is due to increased urbanization, industrialization, global warming and climate change (Okudo et al., 2023). Due to industries' massive emissions of pollutants into the environment, urbanization and rapid industrialization have had a significant negative impact on water quality. Oil and gas industry activities and has impact negatively on water and air in Southern Nigeria. The likelihood of rainwater becoming contaminated is very high. Despite the widespread use of rainwater, especially in southern Nigeria, there is no evidence that its use is standardized for safety. Environmental pollution has affected the quality of water in general, and it also has a negative effect on the quality of rainwater. Rainwater quality is impacted by a number of factors, including animal faeces and debris on roofs, leaching roofing materials, and vehicle exhaust emissions (Zdeb et al., 2020).

Because the place where the rain falls may have an impact on the quality of the precipitation, rainwater is not always clean and safe to drink. Emissions from houses, companies, and factories can easily dissolve in water without changing the colour or flavour and may not be physically detectable, contaminating rainwater in established communities (Khayan et al., 2019). The community's overall health can be impacted by the quality of the water that is available to them, and when the water is of high quality, it becomes essential for leading a productive and healthy life (Aryal et al., 2012). Globally, Bełcik et al. (2024) reported concentrations of some heavy metals (Cu, Pb, Cr, Ni and Cu) in run-off rainwater from Białystok in Poland. Similarly, the concentrations of As, Sb, Cr, Pb, and Cd in rainwater runoff from antimony mine area in Lengshuijiang City, Hunan Province, were reported by Chen et al. (2024). According to the authors, As and Sb pose the most serious health risks to residents in the village, with HI values of As and Sb greater than 1.

If values of the physicochemical parameters are higher than acceptable limits, humans and other living forms may be at risk for health problems (Aryal et al., 2012; Okpoebo et al., 2014). Ebong et al. (2016) conducted research on collected rainfall from regions in the southern part of Nigeria that experience ongoing gas leaks caused by the operations of multinational oil corporations. The pH, Fe, Pb, Cd, and Ni values were above the allowable limits, and an investigation of the physicochemical characteristics and certain trace and heavy metals revealed potential health effects. According to Olowoyo's (2011) research, the pH and total suspended solids in rainwater exceeded the World Health Organization's recommended values. The proximity to the refinery and petrochemical company, where gases are carelessly flared into the environment, could be the cause, the authors speculated.

In their study, Imarhiagbe & Osarenotor (2020) evaluated the quality and health risk of non-roof-harvested rainwater in a southern Nigerian oil-producing community. The ranges of concentrations for iron and lead were 0.27 to 1.79 mg/l and 0.0 to 0.025 mg/l, respectively; the ranges for chromium were 0.0 to 0.028 mg/l and 0.0 to 0.021 mg/l. Fe, Pb, and Cd values are higher than the necessary tolerance level. But the health risk index is not equal to one.

The amounts of certain heavy metals found in rainwater samples, as reported by Itodo et al. (2021). Their findings show that Pb, Fe, and Cr are present in the rainwater samples, with Pb metal being present at levels higher than the 0.3 mg/L WHO maximum allowable limit.

The quality of rainwater collected is impacted by the ongoing growth in industrial activities and population growth, both of which have a significant impact on air quality (Marlier et al., 2015). Rainwater has the ability to dissolve different particulates and air pollutants. It is crucial to keep an eye on the quality of rainwater, particularly in industrial areas where gas flaring is a regular occurrence. The work done by Itodo et al. (2021) showed that the level of some metals is alarming. However, the health implications were not as certain. It is imperative to keep monitoring the levels of these metals and to advise relevant government bodies of the necessary actions. The goals of this investigation are:

1) To investigate the concentrations of Cr, Cd, Pb, Cu and Zn of rainwater samples collected from roof and non-roof sources.

2) Compare the physicochemical parameters of samples collected from roof and non-roof sources.

3) Estimate the health risk index (HRI).

2. Materials and Methods

2.1. Sampling and Methods Data of Collections

The strata comprise three Local Government Development Areas within Warri and it environ. The geospatial locations purposely selected for samples collections comprised Jakpa, Udu, and Ubeji (as seen in **Table 1**) were purposely selected based on the uniqueness of the prevailing anthropogenic activities such as industries, agriculture, housing, population, and urbanization.

The rainwater samples were systematically collected from (aluminum) roof and non-roof sources for a four month period during the rainy season in 2022. The months comprised early raining season (April), peak rainy season (June), short dry season (August) and end of the rainy season (October) all in the year 2022 to ensure randomness and avert bias. In each month, three set of samples were collected during first week, middle week, and toward the last week for the purpose of randomization and adequate representation. **Figure 1** shows the map of the study locations.

Table 1. Geographical locations of sampling points in the communities.

Town	Latitude	Longitude
Udu	5.5601683	5.7768867
Jakpa	5.5601933	5.7768433
Ubeji	5˚35'28"	5˚42'22"

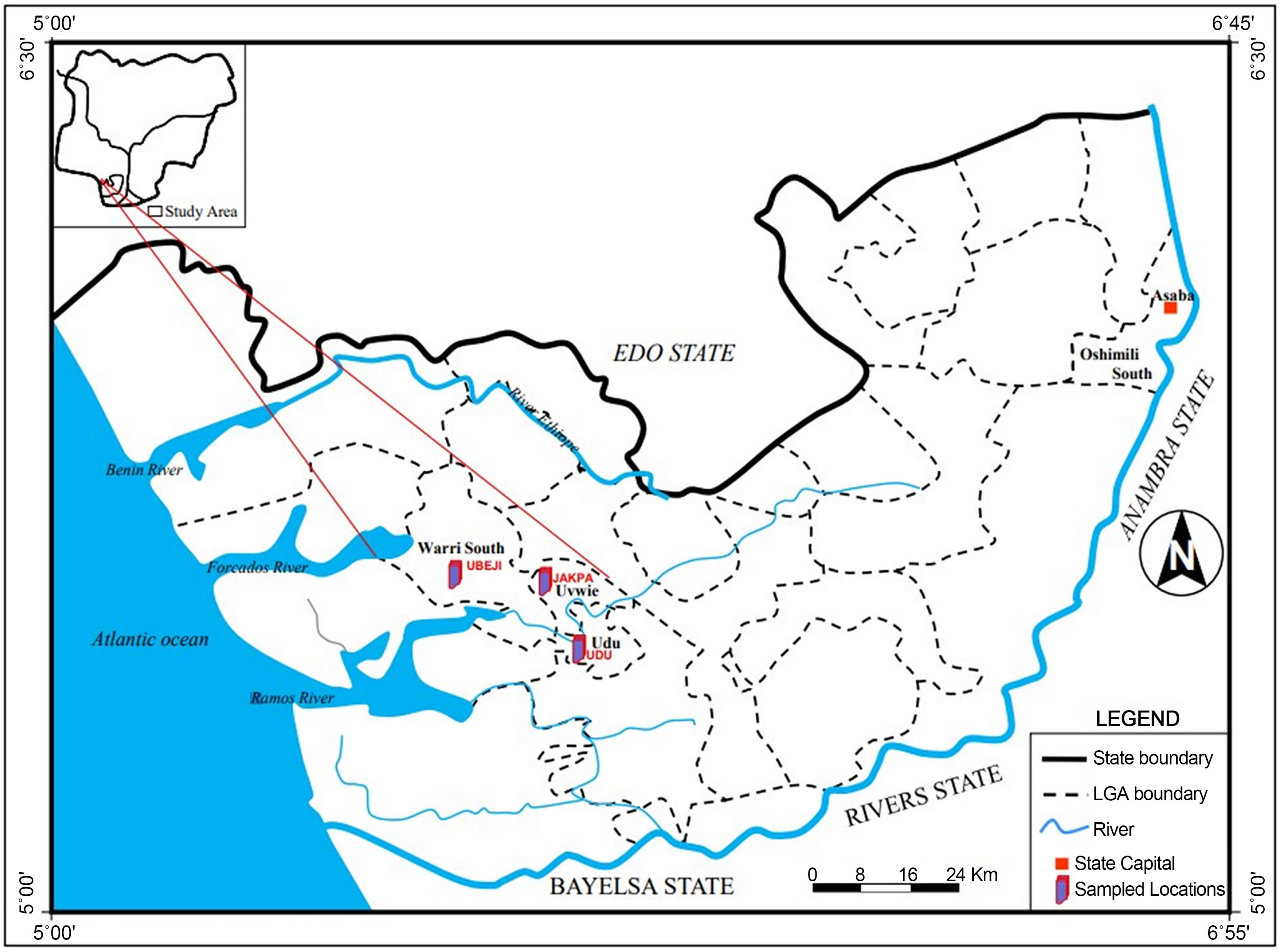

Figure 1. Map showing sampling locations.

2.2. Analyses of Heavy Metal Characteristics of Rainwater

The rainwater collected from (aluminum) roof and non-roof (open space that was devoid of any external interference); each at 1.5 m above the ground with stainless aluminum basins placed on the tripod stand. The collected rain samples were transferred to 100 ml polythene bottles. Bottles were soaked in 10% HNO_3 for 24 h and rinsed several times with deionised water, prior to sample collection. Bottles were also rinsed with aliquots of the sampled water at the time of collection to avoid carryover of contaminants that may compromise the quality of the results. Upon arrival at the laboratory, samples were stored in the refrigerator until the day of the analysis. 50 ml of water sample was digested using HNO_3 and HCl mixture, extract analyzed for metal content using atomic absorption spectrometer (AA320 model). Four heavy metals analyzed for chromium, lead, cadmium, copper, and zinc.

2.3. Analysis of Physicochemical Characteristics

The following tests were carried out on the water samples: pH value, calcium, hardness, chloride, hardness and total alkalinity.

2.3.1. Acidity

10 ml of water sample was placed in test tubes and 20 ml of bromothymol blue solution was added to each test tube, then a glass electrode was dipped into the solution then dipped into the pH meter to test the pH of the water sample.

2.3.2. Chloride Test

A 100 ml of water sample was measured into a conical flask and 1 ml of potassium chromate solution was added as an indicator. The mixed solution was then titrated against silver nitrate. The end point was indicated by the solution changing from yellow to red. The same procedure was carried out for distilled water as blank.

2.3.3. Alkalinity

100 m1 of water sample was poured into a conical flask and three (3) drops of methyl orange indicator was added. The resulting solution was titrated against sulphuric acid.

2.3.4. Total Hardness

100 ml of water sample was measured into a conical flask and two (2) drops of crichrome black-1 indicator were added and mixed properly. Then 2 ml of ammonium chloride (NH_4Cl) and ammonium hydroxide (NH_4OH) buffer solution were added and mixed properly. The resulting solution was titrated against standard ethylene-di amine tetra-acetic acid (EDTA) solution and the volume at the end point was recorded.

2.3.5. Calcium Hardness

A total of 100 m1 of sample and 2 ml of sodium hydroxide buffer solution was added while mixing so as to avoid excess of buffer solution. 0.4 g of murexide (ammonium purpate) indicator was added and the solution was titrated against sequestric acid.

2.3.6. Nitrate Test

A few drops of water sample were taken in an evaporating dish, followed by two drops of diphenyl amine were added to sulphuric acid in a conical flask. The content of the flask was poured into the evaporating dish and the solution was heated. Blue colour indicates the presence of nitrate. The absorbance of the mixture was read on a spectrophotometer at 520 nm.

3. Results and Discussion

Concentrations of Cr, Cd, Pb, Cu and Zn of rainwater samples collected from roof and non-roof sources

The results of the investigated heavy metals concentration in the harvested rainwater are presented in Figures 2-5. Out of the four tested heavy metals, Cr, Cd, Pb, Cu and Zn were detected in all samples. The results of the current study are compared against international and local studies on the occurrence of heavy metals in harvested rainwater. In context of Jakpa, Ubeji, and Udu, the pattern in the mean concentration of Chromium (Cr), Cadmium (Cd), and Lead (Pb) were assessed based on research objective one. The results revealed that pattern and concentration of Chromium for both the non-roof and roof sources were within the World Health Organization (2004) recommended standard of 0.05 mg/L, with exception of the Jakpa which the roof source result gave 0.085 mg/L during the month of April (**Figure 2**). The concentration of Cadmium indicated sudden increase in some localities and months well above the threshold limit of 0.03 mg/L WHO (2004). For instance, the results from the non-roof source in Jakpa gave 0.040 mg/L for the month of August and not available for other months. However, the results from roof source gave the values of 0.035 and 0.075 mg/L for the months of April and June, which were above WHO standard. The result suggested pollution with respect to Cadmium (**Figure 3**) especially during June (**Table 2** and **Table 3**).

Table 2. Standard for health risk assessment (US EPA, 2011; Omali & Snow, 2023).

Parameter	Adult	Children	Units
Ingestion Rate (Lw)	1.5	0.7	l/d
Average Body Weight (W_b)	70	15	kg
Average Height (H)	165	153	cm

Table 3. Parameters used for health risks assessment (US Environmental Protection Agency, 2011; Omali & Snow, 2023).

Metals	RfD oral (mg/kg/day)
Cr	3
Cd	0.5
Pb	1.4
Zn	300
Cu	40

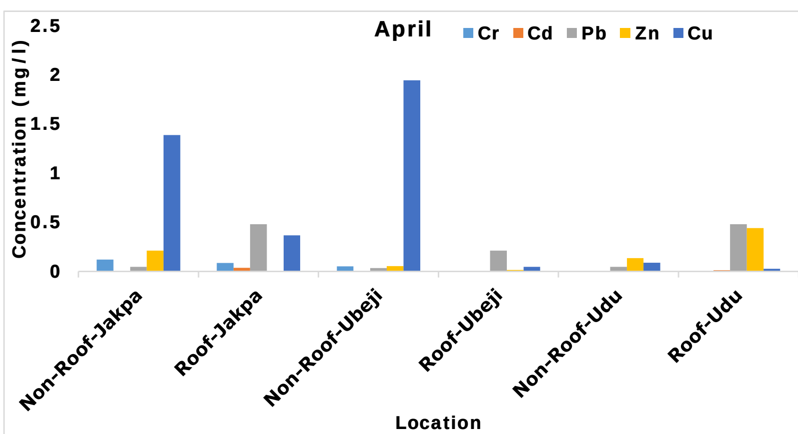

Figure 2. Mean concentration of metals in harvested rainwater sample during the month of April.

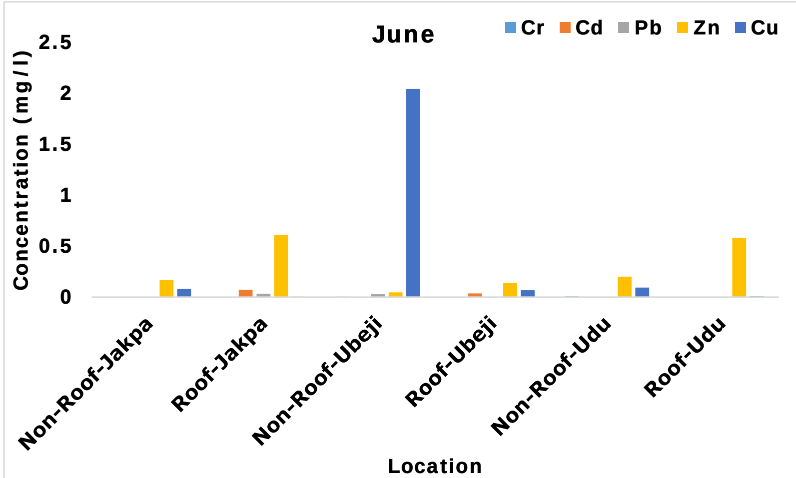

Figure 3. Mean concentration of metals in harvested rainwater sample during the month of June.

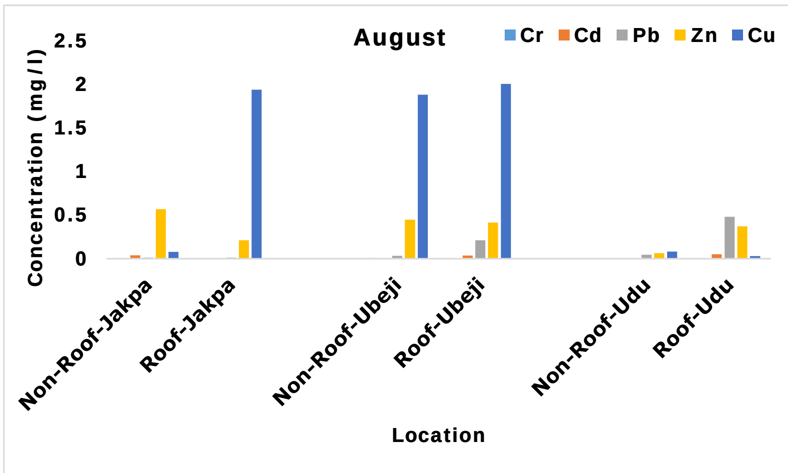

Figure 4. Mean concentration of metals in harvested rainwater sample during the month of August.

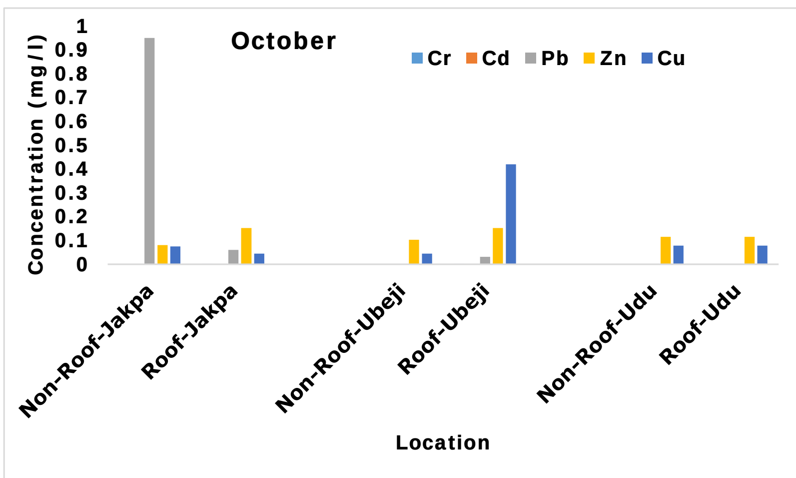

Figure 5. Mean concentration of metals in harvested rainwater sample during the month of October.

The concentration of Lead as indicated in **Figure 2**, **Figure 3** and **Figure 5** revealed that rainwater constituted serious pollution problem in Jakpa and Ubeji. The pattern of concentration in Jakpa at non-roof source (location) gave the values of 0.046 mg/L, 0.011 mg/L, and 0.081 mg/L for the months of April, August, and October 2022. The results from roof samples gave the mean concentration of 0.480 mg/L, 0.033 mg/L, 0.012 mg/L, and 0.006 mg/L for the months of April, June, August, and October which are higher than the WHO standard value of 0.01 mg/L. Thus, indicating high level of pollution. Similar perspective of Lead reflected in Ubeji roof source sample with an exception of the month of October.

The assessments of Zinc and Copper concentration in rainwater within selected locations were carried out and the results presented in **Figures 2-5**. The result of Zinc concentration in rainwater at non-roof Jakpa gave the value of 0.081 mg/L (**Figure 5**) for the month of October to a highest value of 0.567 mg/L (**Figure 4**) for the month of August. Similar patterns reflected in roof samples with the least value of 0.152 mg/L recorded during October and the highest value of 0.610 mg/L. In Ubeji, the concentration of Zinc within the non-roof source was the lowest during the month of April with a value of 0.052 mg/L (**Figure 2**) and the highest during the month of August with a value of 0.447 mg/L (**Figure 4**). The results of the values from roof source ranged between 0.014 and 0.413 mg/L.

In summary, the Pb, Cr and Cd concentration in rainwater samples especially from roof top collected from Jakpa were above the threshold value reported by WHO (2004). Other researchers such as Nicholas & Ukoha (2023) reported mean concentration of 0.07 mg/L for Pb in rainwater samples from asbestos roof. Also, Okudo et al. (2023) reported high values of 0.58 for Pb in analyzed rainwater samples from Enugu State, Nigeria. Similarly, Ayenimo et al. (2006) reported higher values of Pb from runoff water from roof which were above the set standard.

Non Roof and Roof Sources

The raw data (**Tables A1-4**) were statistically analyzed using SPSS (version 20) The results presented in **Table 4** revealed widespread differences with respect to the coefficient that range between 0.017 for Lead and 0.720 for chromium. However, only chromium (0.720), alkalinity (0.751), and total suspended solid (0.502), exhibited moderate coefficient that were significance at 95 percent interval. The results suggested that significance difference existed in the concentration of chromium, alkalinity, and total suspended solid in roof and non-roof rainwater samples in the study area, thereby implying point-source contaminations emanating from the influence of roof materials.

A test of significant difference in the mean concentration of physicochemical characteristics of rainwater quality at *p*-value of 0.05 gave a tabulated T-test is presented in **Table 5**. A comparison of the significant values reveals that there is no significance difference between the concentration of physicochemical parameters in rainwater from roof and non-roof sources in Warri and it environ of Delta State.

Table 4. Correlation analysis of rainwater quality from Roof and Non-roof Sources in Jakpa, Udu, and Ubeji.

Group	Parameter and source	Correlation
Pair 1	Cr Non roof & Cr roof	0.720
Pair 2	Cd Non roof & Cd roof	−0.185
Pair 3	Pb Non roof & Pb roof	−0.017
Pair 4	Zn Non roof & Zn roof	0.188
Pair 5	Cu Non roof & Cu roof	0.197
Pair 6	pH Non roof & pH roof	0.223
Pair 7	TSS Non roof & TSS roof	0.502
Pair 8	TDS Non roof & TDS roof	−0.175
Pair 9	Alkaline Non roof & Alkaline roof	0.571
Pair 10	Hardness Non roof & Hardness roof	0.351
Pair 11	Cl Non roof & Cl roof	−0.267
Pair 12	SO_3 Non roof & SO_3 roof	0.276
Pair 13	NO_3 Non roof & NO_3 roof	−0.239
Pair 14	Ca Non roof & Ca roof	−0.233

Values stared represent significant value less than 0.05.

Table 5. Paired sampled t-test of significant differences in the mean concentration of distinct parameters in rainwater from Roof and Non-roof sources.

Paired Group	Parameter Sources	Paired upper Difference at 95% Interval	T	df	Sig. (2-tailed)
Pair 1	Cr Non roof & Cr roof	0.007848	−0.931	11	0.372
Pair 2	Cd Non roof & Cd roof	0.007805	−1.283	11	0.226
Pair 3	Pb Non roof & Pb roof	2.100753	0.912	11	0.381
Pair 4	Zn Non roof & Zn roof	0.068458	−1.213	11	0.250
Pair 5	Cu Non roof & Cu roof	0.886283	0.801	11	0.440
Pair 6	pH Non roof & pH roof	0.488088	−0.698	11	0.500
Pair 7	TSS Non roof & TSS roof	3.200773	−0.971	11	0.352
Pair 8	TDS Non roof & TDS roof	0.909599	−1.854	11	0.091
Pair 9	Alkaline Non roof & Alkaline roof	0.430566	1.187	11	0.260
Pair 10	Hardness Non roof & Hardness roof	0.350033	−1.416	11	0.184
Pair 11	Cl Non roof & Cl roof	0.347233	−1.187	11	0.260
Pair 12	SO_3 Non roof & SO_3 roof	0.135578	−0.825	11	0.427
Pair 13	NO_3 Non roof & NO_3 roof	0.103559	1.010	11	0.334
Pair 14	Ca Non roof & Ca roof	0.359786	0.307	11	0.764

Table 6. Summary of the health risk index (HRI) calculations (children) Cd intake.

Location	April		June		August	
	Roof-top	Non-roof	Roof-top	Non-roof	Roof-top	Non-roof
Jakpa	3.2	0	6.8	0	0	3.8
Ubeji	0.18	0	0.2	0	4	0
Udu	1	0	0	0	4.8	0

Note: 0 concentrations represent samples were Cd was not detected.

Table 7. Summary of the health risk index (HRI) calculations (Adult) Cd intake.

Location	April		June		August	
	Roof-top	Non-roof	Roof-top	Non-roof	Roof-top	Non-roof
Jakpa	1.5	0	3.1	0	1.71	0
Ubeji	0.85	0	0.4	0	1.6	0
Udu	0.47	0	0	0	2.2	0

Note: 0 concentrations represent samples were Cd was not detected.

Human Health Risk Assessment as the harvested rainwater, in the study area, is use for drinking and other domestic purposes. Parameter in Table 2 and Table 3 is used for the estimation. It is important to make sure that this water is safe to be used by consumers. Two approaches were used to test the safety of the rainwater:

1) Chronic daily intakes of metals (CDI) is calculated as Anabtawi et al. (2022)

$$\text{CDI} = \frac{C_m}{W_b} \times I_w$$

2) Health risk indexes of metals (HRI). This is estimated as

$$\text{HRI} = \frac{\text{CDI}}{\text{RfD}}$$

The CDI and HRI values calculated for the meals exceeded the WHO standards.

The HRI values calculated for the intake of Cd from rainwater samples are presented in (Table 6 and Table 7). The highest value is recorded for roof-top at Jakpa (6.8) for children and (3.1) for adults from roof top (Table 7). Implying that the harvested rainwater is not safe for consumers as HRI is greater than 1. This makes sense, as the samples exceeded the limits. The results of this study show that heavy metals in the harvested rainwater in the study area is a big issue, as their concentrations were usually above the international limits.

4. Conclusion

Concerning heavy metals contamination, the results of this research showed that most of the water samples analyzed were not safe. For the metals, 67%, 25% and 4% representing Pb, Cd and Cr of the samples collected for different months had values above the WHO limits. None of the samples exceeded the WHO for Zn and Cu in all months. Statistical analysis showed that there was relationship between rainwater samples from roof and non-roof top. Health risk index estimated for Cd in samples is not within safe limit. This study only presents results for heavy metals. Therefore, it is hereby recommended that other important contaminants such as PAHs, OCPs and phthalate esters should be considered for further study for drinking water safety.

Declaration

All authors have read, understood, and have complied as applicable with the statement on Ethical responsibilities of Authors as found in the Instructions for Authors.

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Authors' Contributions

Iwekumo E. Agbozu designed the research, methodology and edited the manuscript. Tobore R. Maminor performed the experiments and collected samples, Uwem Bassey wrote the manuscript and analyzed the data.

Data Availability

All data generated or analyzed during this study are included in this published article.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

Table A1. The concentrations of pH, TSS and TDS in rainwater.

Parameter/ Month	JAKPA		UBEJI		UDU	
	Non Roof	**Roof Top**	**Non Roof**	**Roof top**	**Non Roof**	**Roof top**
pH April	7.83	11.54*	7.90	7.83	7.60	7.33
pH June	7.87	7.33	7.73	7.50	7.30	7.40
pH Aug.	7.83	7.83	7.90	7.70	7.27	7.49
pH Oct.	8.07	7.86	7.56	7.97	7.73	7.53
TSS April	10.42*	0.400	16.15*	35.47 *	1.373	11.74*
TSS June	0.817	9.270*	12.08*	0.989	0.750	10.32*
TSS Aug.	13.80*	10.42*	18.58*	16.20*	5.340*	14.63*
TSS Oct.	0.630	0.667	0.509	0.669	0.481	0.480
TDS April	14.64	10.33	14.27	11.73	0.786	14.14
TDS June	0.612	16.20	12.73	0.707	0.711	14.17
TDS Aug.	13.91	14.66	16.84	14.18	5.340	14.63
TDS Oct.	1.950	13.91	0.711	13.91	0.843	3.027

*Values greater than WHO standards.

Table A2. The concentrations of Alkalinity, Hardness, and Chloride in rainwater.

Parameter/ Month	JAKPA		UBEJI		UDU	
	Non Roof	**Roof Top**	**Non roof**	**Roof top**	**Non Roof**	**Roof top**
Alkal. April	0.467	0.400	0.427	0.517	0.440	0.210
Alkal. June	0.377	0.333	0.310	0.350	0.260	0.197
Alkal. Aug.	0.547	0.467	0.520	0.523	0.583	0.478
Alkal. Oct.	2.180	0.667	0.509	0.669	0.481	0.480
Ca/Mg April	3.143	4.067	4.067	3.633	1.633	1.067
Ca/Mg June	1.767	3.570	3.703	1.933	1.667	2.833
Ca/Mg Aug.	4.767	3.140	4.710	5.647	2.146	3.825
Ca/Mg Oct.	0.867	4.173	2.007	4.173	1.187	1.187
Cl April	0.503	1.100	1.613	1.197	0.303	0.186
Cl June	0.370	2.670	1.433	0.383	0.400	2.333
Cl Aug.	2.453	0.503	1.440	1.780	0.102	0.943
Cl Oct.	0.572	1.457	0.367	1.457	0.317	0.738

Table A3. The concentrations of Sulphide, Nitrate, and Calcium in rainwater.

Parameter/ Month	JAKPA		UBEJI		UDU	
	Non Roof	**Roof Top**	**Non roof**	**Roof Top**	**Non Roof**	**Roof top**
SO_3 April	0.056	0.193	0.029	0.016	0.070	0.013
SO_3 June	0.150	0.695	0.116	0.377	0.204	0.603
SO_3 Aug.	0.523	0.060	0.045	0.216	0.504	0.630
SO_3 Oct.	0.013	0.079	0.614	0.079	0.738	0.738
NO_3 April	0.014	0.053	0.076	0.016	0.070	0.013
NO_3 June	0.100	0.060	0.018	0.080	0.150	0.086
NO_3 Aug.	0.046	0.014	0.011	0.043	0.006	0.096
NO_3 Oct.	0.367	0.018	0.030	0.018	0.043	0.043
Ca April	0.845	0.810	0.823	0.138	0.417	0.510
Ca June	0.237	0.900	0.671	0.126	0.370	0.610
Ca Aug.	0.837	0.845	0.940	1. 080	0.300	0.706
Ca Oct.	0.403	0.973	0.377	0.073	0.214	0.214

Table A4. The patterns of Potassium and Electrical Conductivity in rainwater.

Parameter Month	JAKPA		UBEJI		UDU	
	Non roof	**Roof Top**	**Non roof**	**Roof top**	**Non Roof**	**Roof top**
K April	0.845	1.050	0.817	1.393	0.540	0.723
K June	0.303	0.813	1.301	0.197	0.357	1.034
K Aug.	1.007	0.861	0.870	1.684	0.575	0.639
K Oct.	0.416	1.253	0.386	1.253	0.215	0.215
EC April	11.40	24.64	14.14	7.17	5.49	13.17
EC June	3.500	29.70	54.45	20.50	29.10	28.86
EC Aug.	29.83	11.407	29.53	72.33	31.80	14.68
EC Oct.	4.593	9.223	22.60	9.230	6.444	6.512