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Evaluation of Quality proxies of roof-harvested rainwater obtained from tertiary institutions in Orlu Zone, Imo State

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ABSTRACT

The quality of most roof-harvested rainwater obtained from most rural communities with poor access to potable water has become a major pitfall in the longevity of the populace. Five different clean catch of the rainwater were collected from three different tertiary institutions namely Hezekiah University, Umudi, Nkwerre, Kingsley Ozumba, Mbadiwe University, Ideato Imo State and College of Health Technology, Amaigbo, Imo State. In situ parameters were measured and the other batch was aseptically transported to the laboratory. Quality indices were determined using standard reagents and methodologies. The pH of the rainwater samples obtained from roofs at the College of Health Technology was 6.4 and 6.6 for the hostel and canteen respectively. The electrical conductivity of samples obtained from the Hezekiah University hostel section was 69.1 µS/cm and 110.56 µS/cm for the canteen. The rainwater samples obtained from Hezekiah University had a faecal composition of 3.0 MPN/100mL and 7.4 MPN/100mL for the hostel and canteen section respectively while the samples obtained from K.O. Mbadiwe University had a coliform concentration of 6.1 and 7.4 MPN/100ml for the hostel and canteen respectively. The bacterial isolates obtained from the HezUni female hostel harvested rainwater in March were *E. coli*, *Citrobacter* sp., *Staphylococcus* sp., *Shigella* sp. and *Aerobacter* sp. In contrast, the canteen-harvested rainwater had *Shigella* sp., *E. coli*, *Staphylococcus* sp. and *Micrococcus* sp. The presence of coliforms in most of the rainwater available to students in tertiary institutions in the Orlu zone further defeats the classification of these sources as potable. There is a need for the universities to intensify the call for the provision and monitoring of rural water supplies as a roadmap for stemming the tides of water-borne diseases.

Keywords: Rainwater; Potable water; Roof harvested; Tertiary institutions; Quality indices; Water-borne diseases; Quality proxies; Most probable number; Reagents; Coliform concentration.

1.0. Introduction

Water is an elixir to every living thing, the insatiable demand for water ranges from agricultural to industrial purposes [1]. Population explosion, industrialisation and rural-urban migration have also impacted the water budget and the need for potable and safe water supply [2]. Although most rural communities lack access to safe water, the increasing need to access alternative water for domestic purposes has remained a talking point in their day-to-day activities. According to Nwogu *et al*. [3] failure and lack of potable water supply in developing countries remains a persistent bottleneck to both governmental organizations and donor agencies. It is estimated that over 4 billion people lack access to safe, potable water all over the world today [4].

In Nigeria, rural water supply and maintenance of available or redundant facilities to ameliorate the sufferings of a huge population of these dwellers have not been given the needed attention as it concerns the effect and negligence that can have on the health and longevity of the old, hapless and indigent persons [5].

Sadly, geopolitical distribution has been identified to have taken centre stage in the provision of potable water supply to these fragile populations in the society; total ignorance of specific indices and equitable provision of water has plagued most rural communities in the southeastern part of Nigeria. This is because there is an obvious lack of accessible drinking water or potable water channels in most rural communities, although political and goodwill donations have been identified as a major reason for the presence or absence of these basic amenities [6]. Insecurity in most parts of the southeastern states has also worsened the delivery of dividends of democracy to the poor and needy in society.

The term harvested rainwater refers to the actual collection and storage for use in either agro-allied, domestic or industrial purposes when rain falls. According to Itodo *et al*. [7], roof harvesting has been the most widely used and oldest means of collecting rainwater in the world. The harvesting of rainwater for domestic use poses a significant risk to its patrons, as it is considered an important source of water where water supply is low and may serve as a source of both potable and non-potable sources to a wide population of consumers living in arid environs. The harvesting of rainwater has undergone a revolution as it can be done through the roofs, either zinc, aluminium or thatch from raffia; others may collect from branches or leaves of trees; concrete roofs, and corrugated sheets have been reported in some studies. Free collection has been reported by Aleruchi *et al*. [8], which is said to be used for potable sources, especially for religious purposes. Generally, the harvesting can be categorised into land and roof techniques. The quality and nature of roofing materials, age and duration of usage, seasonal variation, intensity of industrial activities and presence of faecal matter of animal origin. The report of Adeniyi & Olabanji [9] observed a high concentration of heavy metals in roof-harvested rainwater and free-fall rainwater in Ile Ife, Southwest Nigeria. The present study sought to evaluate the physicochemical and microbiological quality of roof-harvested rainwater from tertiary in Orlu Zone, Imo State, Nigeria.

1.1. Objectives of the Study

The following specific objectives were followed during the study:

a) Collection and transportation of the roof--harvested rainwater from the tertiary institutions in Orlu zone, Imo State.

b) Physicochemical and microbiological analysis of the roof harvested rainwater from the tertiary institutions in Orlu zone, Imo State.

c) Identification and characterization of bacterial isolates from the tertiary institutions in the Orlu zone, Imo State.

d) Determination of the frequency of occurrence of the bacterial isolates from the tertiary institutions in the Orlu zone, Imo State.

e) Distribution and seasonal occurrence of the bacterial isolates from the tertiary institutions in Orlu zone, Imo State.

2.0. Materials and Methods

2.1. Description of the Study Area

Nkwerre Local Government is in the southeastern zone of Imo state; it seats within an area of over 47 km^2. It is estimated that the population density of Nkwerre as reported by the Nation Population Census is 235273 as of 2006. The annual population projection of Nkwerre seats 111, 600 in 2022. The climate in Nkwerre is a tropical rainforest with a significant presence of tall trees and dense forests. The Nkwerre Local Government is situated in the Nkwerre town, as it enjoys two air masses which are the equatorial air masses associated with rainfalls southwestern and the second being the dusty harmattan winds from the Sahara Desert north. Geophysically, it can be said that the Nkwerre Local Government is in the Imo Drainage Basin and falls within the Ameki formation and the soil here is sandy clay, coarse and calcerous. This local government is hosting the first private university in Imo

State called Hezekiah University, Umudi. The town is a popular blacksmithing town known as 'Nkwerre Opia egbe' meaning the Gun manufacturers.

In 1991, the military government of General Ibrahim Babangida created the local government called Ideato with its headquarters located in Urualla, which made it the 27th Local Government in Imo State under the governorship of Commodore Amadi Ikwuecheeghi. This local Government sits on 172.4 Km^2 sharing boundaries north with Aguata Local Government of Anambra State while it's flanked by the two local governments namely Okigwe and Onuimo Local Government. The two big towns in Ideato are Mbanasa and Arondiizuogu with clans such as Umukegwu, Owere-Akokwa, Akwu, Osina, Obodoukwu, Akpulu, Isiokpo, Urualla, Uzii, Umuezeaga, Umuopia, Umualaoma, and Umuokwra. While the Arondizuogu clan is made up of five autonomous communities, viz., Awa-Izuogu, Akaeme-Izuogu, Ejezie-Izuogu, Iheme-Izuogu, and Ndiuche. It's a tropical rainforest with similar geophysical soil formation as the Nkwerre as previously described, it plays host to the K.O. Mbadiwe University, a State-owned and -managed institution.

2.2. Sample collection

A simple random sampling of the part of the roof for the harvest was employed, with interest in the clean catch of the sample into a sterile receptacle which was pre-washed with the sample. The samples were labelled and packed in a cooler laden with ice and transported to the laboratory of Hezekiah University, Umudi, while the samples for the physicochemical evaluation were collected using the appropriate sample bottles and transported to Austino Laboratory in Alakahia, off UPTH entrance Port Harcourt, Rivers State. Two sampling locations were evaluated with three samples obtained from each sampling location making a total of six (6) samples obtained from each institution. This is because 3 samples were obtained from the canteen location and then bulked into one container, while three samples were obtained from the female hostel area where the three samples were bulked into one container.

2.3. Determination of physicochemical composition of the roof-harvested rainwater

The physicochemical quality of the harvested rainwater was evaluated using the following parameters: Temperature, pH, electrical conductivity, total dissolved solids, colour, turbidity, total hardness, calcium hardness, chlorides, total acidity, alkalinity, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, exchangeable cations and metals, such as Mg, Ca, Fe, Pb, Cr, Ni, sulphates and carbonates were performed using standard procedures as reported by Standard Methods and Analytical Grade Reagents for the Examination of Water and Wastewater [10;11].

2.4. Determination of coliform composition of the roof-harvested rainwater

The MPN technique was employed in the determination of the coliform composition for both faecal and total coliforms as reported by the previous report of Asionye *et al*. [12].

2.5. Determination of culturable microbial population.

Total heterotrophic composition, *Salmonella Shigella* count, and fungal count were determined as reported by the modified report of Nwogu *et al*. [3].

2.6. Identification of bacterial isolates associated with the roof-harvested rainwater

The method reported by Aleruchi *et al*. [8] was employed in the identification of the bacterial isolates obtained from the study using the biochemical test approach. The isolates were preserved for further studies by refrigeration. The frequency of occurrence of the bacterial isolates was determined using the modified report of Nwachukwu *et al*. [13].

3.0. Results and Discussion

3.1. Culturable microbial population of the roof-harvested rainwater for March and July 2023

The total heterotrophic bacterial count of the rainwater sample obtained from HezUni was 6.75 Log_{10}CFU/mL and 5.5 Log_{10}CFU/mL for the hostel and canteen sourced or harvested samples for March as presented in Figure 1.0. The total Salmonella-Shigella count was 4.08 and 4.05 Log_{10}CFU/mL for the hostel and canteen harvested rainwater samples respectively. The total fungal count for the Hezekiah University sourced and harvested rainwater was 3.36 Log_{10}CFU/mL and 3.1 Log_{10}CFU/mL. The total heterotrophic bacterial count for roof-harvested rainwater from KOMU was 6.75 Log_{10}CFU/mL and 6.5 Log_{10}CFU/mL for the female hostel and canteen, respectively, for March.

The culturable microbial counts as presented in Figure 2 show the heterotrophic bacterial count of the roof-harvested rainwater obtained from the hostel section of Hezekiah University was 5.4 Log_{10}CFU/mL, while 3.4 Log_{10}CFU/mL and 2.8 Log_{10}CFU/mL were for Total Salmonella Shigella count and Total fungal counts respectively. The canteen section was observed to have 4.4 Log_{10}CFU/mL, 2.6 Log_{10}CFU/mL and 2.2 Log_{10}CFU/mL for the total heterotrophic bacterial count, Total Salmonella Shigella count and total fungal count, respectively.

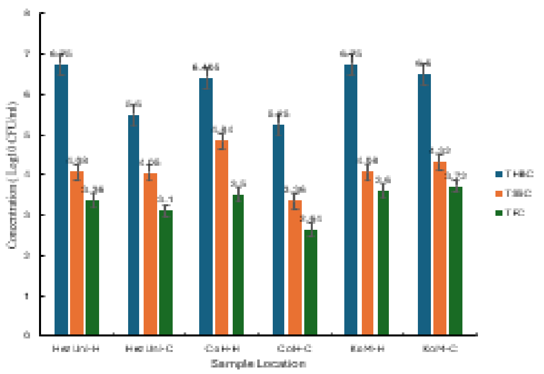

Figure 1: Microbial population of roof harvested rainwater obtained from tertiary institution in Orlu Zone of Imo state, Nigeria (March)

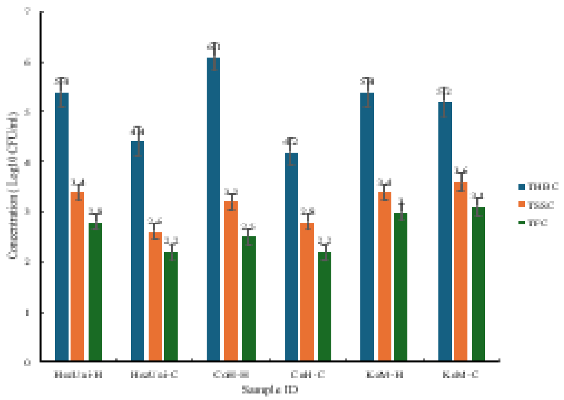

Fig. 2: Microbial population of roof harvested rainwater obtained from tertiary institution in Orlu Zone of Imo state, Nigeria (July)

Key= THBC- Total Heterotrophic Bacterial Count; TSSC- Total Salmonella Shigella Count; TFC- Total Fungal Count; C- Canteen; H- Hostel

3.2. Physicochemical composition of roof-harvested rainwater obtained from tertiary institutions in Orlu zone Imo State, Nigeria

The temperature of the roof-harvested rainwater obtained for the Hezkiah University was 22 ^{o}C and 20 ^{o}C for the hostel and canteen respectively, as presented in Table 1.0. The samples obtained from KOMU were 21 ^{o}C and 20

^{o}C. The NAFDAC/WHO limit of 20-32 ^{o}C was observed to comply and fell within the standard for potable water. The pH of the rainwater samples obtained from roofs at the College of Health Technology was 6.4 and 6.6 for the hostel and canteen respectively; the NAFDAC/WHO limits for potable water were 6.5-9.5. The electrical conductivity of the roof-harvested rainwater obtained from the Hezekiah University hostel section was 69.1 µS/cm and 110.56 µS/cm for the canteen. The electrical conductivity of the roof-harvested rainwater obtained from the canteen section of the College of Health was 120.34 µS/cm while that of the hostel was 110.7 µS/cm.

The samples obtained from KOMU had an electrical conductivity of 110.5 µS/cm while the samples obtained from the canteen section had 112.3 µS/cm; the NAFDAC/WHO limit for potable water was identified to range between 800 and 2500 µS/cm; the values obtained were within the limits for potable water. The turbidity of the roof-harvested rainwater obtained from the Hezekiah University female hostel was 0.12 NTU, while the samples obtained from the canteen section had 0.18 NTU. The total hardness of the rainwater samples from the canteen section of Hezekiah University was 13.49 mg/L while that of the hostel was 24.77 mg/L. Furthermore, the samples obtained from the College of Health were observed to have a total hardness of 25.41 mg/L and 31.2 mg/L for the samples obtained from the hostel and canteen respectively.

3.3. Fecal and Total coliform composition of roof harvested rainwater obtained from Orlu zone of Imo State

The results presented in Tables 2.0 and 3.0 show the total and faecal coliform content of the roof-harvested rainwater. The rainwater samples obtained from Hezekiah University had a faecal composition of 3.0 MPN/100 mL and 7.4 MPN/100 mL for the hostel and canteen sections, respectively. The samples obtained from K.O. Mbadiwe University had a 6.1 and 7.4 MPN/100 mL for the hostel and canteen respectively. The total coliform composition of the rainwater samples obtained from the Hezekiah University hostel section was 10 MPN/100 mL while that of the canteen section was 36 MPN/100 mL as presented in Table 2.0. Furthermore, the study identified that the rainwater sample obtained from the roofs at the College of Health was observed to have a total coliform content of 38 MPN/100 mL while that of the canteen section was 23 MPN/100 mL. The samples obtained from KOMU were observed to have a total coliform composition of 20 and 43 MPN/100 mL for the hostel and canteen harvested samples, respectively.

3.4. Microflora of the roof harvested rainwater

The results presented in Table 4 show the distribution of bacterial isolates associated with the roof-harvested rainwater. The bacterial isolates obtained from the HezUni female hostel harvested rainwater in March were *E. coli*, *Citrobacter* sp., *Staphylococcus* sp., *Shigella* sp. and *Aerobacter* sp. While the canteen harvested rainwater had *Shigella* sp., *E. coli*, *Staphylococcus* sp. and *Micrococcus* sp. while in July *Aerobacter* sp., *Citrobacter* sp. and *E. coli* were identified, while the canteen section had *Micrococcus* sp., *Shigella* sp. and *Proteus* sp. The sample obtained from the College of Health female hostel section was observed to have *Proteus* sp., *Staphylococcus* sp., *Moraxella* sp., *Klebsiella* sp. and *Streptococcus* sp. while in July, the predominant isolates were *Klebsiella* sp., *Proteus* sp. and *E. coli*. The samples obtained from the canteen section showed the presence of *E. coli*, *Klebsiella* sp., *Micrococcus* sp. and *Staphylococcus* sp., while in July, *Micrococcus* and *Staphylococcus* sp. were the predominant isolates.

3.5. Frequency of occurrence of the bacterial isolates associated with the roof-harvested rainwater

The occurrence of bacterial isolates in the roof-harvested rainwater was observed in both the canteen and hostel sections of the College of Health, as presented in Figure 4. The sample obtained in July in the hostel was observed to have *Micrococcus* sp. as its most predominant with a frequency of 56.25% while in March *Micrococcus* sp. had 33.33%, *Staphylococcus* sp. had 23.33%, *Klebsiella* sp. had 16%, and *E. coli* had 26.7%. The result presented in Figure 5 shows the frequency of bacterial isolates obtained from KOMU; it showed that the roof harvested rainwater from the hostel sections showed that during March, *Citrobacter* sp. was more frequent with a frequency of 65%, while in July, *Proteus* sp. was more frequent with 58.3% occurring in the samples with obtained during the study. The frequency of occurrence of the bacterial isolates in the roof-harvested rainwater from the canteen was *Proteus* sp. was 26.47%, *Staphylococcus* sp. was 29%, *Klebsiella* sp. was 23.53% while *Citrobacter* sp. had 20%.

Table 1. Physicochemical properties of roof harvested rainwater obtained from Tertiary Institutions in Orlu-Zone of Imo State, Nigeria

Parameters	HezUni		CoH		KOMU		
	H	C	H	C	H	C	NAFDAC/WHO limits for potable water
Temperature (^oC)	22	20	21	20	21	20	20 – 32
pH	6.5	6.9	6.4	6.6	6.8	6.7	6.5-9.5
E.C (µS/cm)	69.1	110.56	120.34	110.7	110.5	112.3	800-2500
TDS	8.53	11.97	12.33	14.11	9.4	9.6	50-150
Colour	8	6	8	9	6	6	5-35
Turbidity (NTU)	0.12	0.18	0.14	0.14	0.25	0.12	0.25
Total hardness (mg/L)	24.77	13.49	25.44	31.19	22.6	24.1	100-300
Calcium hardness (mg/L)	8.0	15.02	11.3	12.45	9.9	11.3	20-200
Chlorides (mg/L)	8.1	5.3	8.8	8.7	4.2	4.1	0.1-0.5
Total acidity (mg/L)	10.11	15	9.2	9.1	8.3	9.1	47-147
Total Alkalinity (mg/L)	20.4	31.9	17.56	16.2	18.6	15.2	30-50
Dissolved Oxygen (mg/L)	1.98	2.10	2.5	2.3	2.5	2.5	
Biochemical Oxygen Demand (mg/L)	1.01	1.16	1.15	1.21	1.09	1.10	
Chemical Oxygen Demand (mg/L)	13.45	16.45	20.34	22.01	15.12	19.33	
Mg^{2+} (mg/mL)	1.01	1.03	2.31	2.21	0.12	1.10	0
Ca^{2+} (mg/mL)	1.73	1.41	1.20	1.43	1.65	1.16	0
Fe (mg/mL)	2.43	2.44	1.30	1.10	2.08	2.20	0.3
Pb (mg/mL)	<0.001	0.004	<0.001	<0.001	0.002	0.009	0
Cr(mg/mL)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0
Ni (mg/mL)	<0.001	<0.001	<0.001	0.002	0.021	<0.001	0
Cd (mg/mL)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0
Sulphates (mg/kg)	0.95	1.12	0.51	0.55	2.4	2.5	<10
Carbonates (mg/kg)	5.12	6.51	2.97	3.02	3.3	3.21	<10

Table 2. Total coliform composition of Roof Harvested Rainwater obtained from the tertiary Universities in Orlu Zone, Imo State, Nigeria

Sample	3-DS 10 mL	3-SS 1.0 mL	3-SS 0.1mL	Confirmatory	Completed	CFU/100mL
HezUni-H	0	3	0	+	A/+	10
HezUni C	2	3	1	+	A/+	36
CoH-H	3	0	1	+	A/+	38
CoH-C	3	0	0	+	A/+	23
KOM-H	2	1	1	+	A/+	20
KOM-C	3	1	0	+	A/+	43

Confirmatory test (+) = Green Metallic Sheen.

Table 3. Fecal coliform composition of Roof Harvested Rainwater obtained from the tertiary Universities in Orlu Zone, Imo State, Nigeria

Sample	3-DS 10 mL	3-SS 1.0 mL	3-SS 0.1mL	Confirmatory	Completed	CFU/100mL
HezUni-H	0	0	1	+	A/+	3
HezUni C	1	1	0	+	A/+	7.4
CoH-H	1	2	1	+	A/+	15
CoH-C	2	0	0	+	A/+	9.2
KOM-H	0	1	1	+	A/+	6.1
KOM-C	1	1	0	+	A/+	7.4

Confirmatory test (+) = Green Metallic Sheen.

Table 4. Distribution of bacterial isolates obtained from the roof-harvested rainwater in tertiary institutions in Imo State, Nigeria

	HezUni-H	HezUni-C	CoH-H	CoH-C	KOMU-H	KOMU-C
March	*E. coli* *Citrobacter* sp. *Staphylococcus* sp. *Shigella* sp. *Aerobacter* sp.	*Shigella* sp. *E. coli* *Staphylococcus* sp. *Micrococcus* sp.	*Proteus* sp. *Staphylococcus* sp. *Moraxella* sp. *Klebsiella* sp. *Streptococcus* sp.	*E. coli* *Klebsiella* sp. *Micrococcus* sp. *Staphylococcus* sp.	*Proteus* sp. *Staphylococcus* sp. *Klebsiella* sp. *Citrobacter* sp.	*Proteus* sp. *Citrobacter* sp.
July	*Aerobacter* sp. *Citrobacter* sp. *E. coli*	*Micrococcus* sp. *Shigella* sp. *Proteus* sp.	*Klebsiella* sp. *Proteus* sp. *E. coli*	*Micrococcus* sp. *Staphylococcus* sp.	*Citrobacter* sp. *Klebsiella* sp. *E. coli*	*Klebsiella* sp. *Proteus* sp.

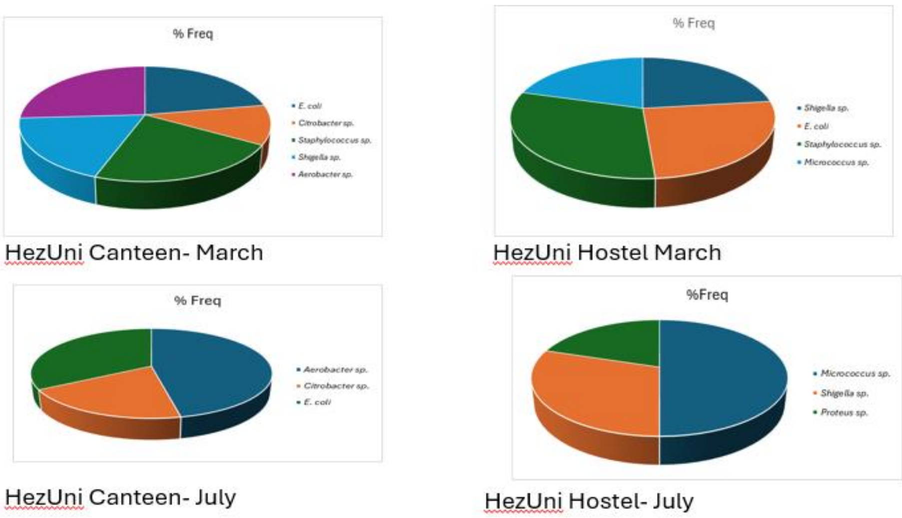

Figure 3. Frequency of occurrence of bacterial isolates in roof harvest rainwater in Hezekiah University

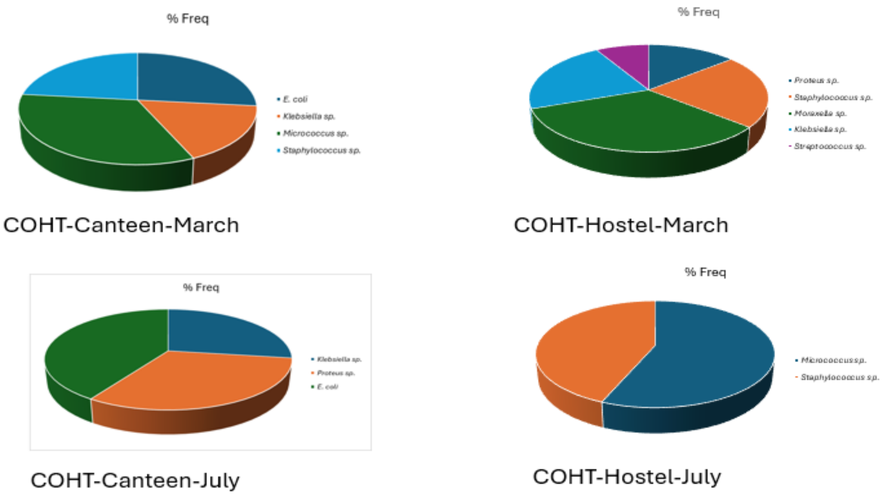

Figure 4. Frequency of occurrence of bacterial isolates in roof harvest rainwater in the College of Health Sciences

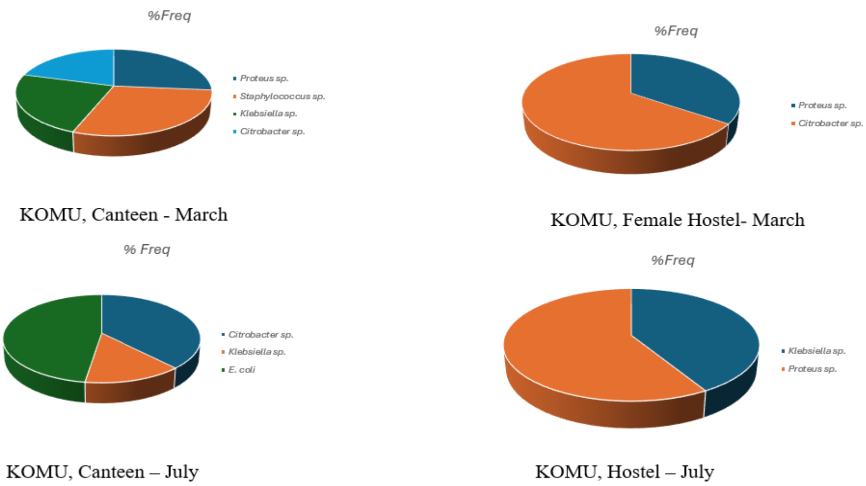

Figure 5. Frequency of occurrence of bacterial isolates in roof harvest rainwater in KOMU

4.0. Discussion of findings

The physicochemical composition of the roof-harvested rainwater obtained from the Hezekiah University hostel section was 6.9, while 6.5 was reported for the canteen section; the samples obtained from the Kingsley Ozurumba Mbadiwe University in Ideato had pH values of 6.8 and 6.7 for the hostel and canteen harvested samples. These findings corroborate with the previous report of Ezemonye *et al*. [14]; their study on the roof of houses in Esan-West Local Government in Edo State identified a pH range of 5.0-6.5 for galvanised roofs, and aluminium roof harvested rainwater had a concentration range of 5.16 to 6.5. Their study identified that the nature of the roofing material and the age of the usage of the roofing material were significant in the changes in the pH of the roof-harvested rainwater. Their study identified that the leaching of the roofing material was instrumental for the pH concentration values observed; this was because the acidic pH of the asbestos roof harvested rainwater was purely attributed to leaching. This can have both antimicrobial and carcinogenic potential.

The work of Selala *et al*. [15] identified a range of pH values between 6.4 and 6.9 while they strongly posited that their study on thatch roofs and corrugated steel was more aligned to meeting the WHO standards. They further identified that pH was the least sensitive parameter in their investigation. Ojo [16] reported a pH concentration value between 6.13 and 6.25 for the roof-harvested rainwater at the Federal University of Technology Akure, Nigeria; the roofs examined were asbestos, corrugated iron roofs and aluminium roofs. According to Nwachukwu *et al*. [13] The pH reported for rainwater in Owerri municipality ranged from 5.20 to 7.12, for which they reported that thatch roofs had a lower pH of 5.2; they attributed the dissolution of chemical pollutants as responsible for the acidic pH range of rainwater. Some aerodynamic effects of pollutants from the peri-urban communities like Nkwerre and Ideato were also responsible for the slightly acidic effects from the industrialisation and other anthropogenic effects; especially oxides of nitrogen, carbon and sulphur were notably associated with manufacturing, combustion of fossil fuels, degradation and decomposition. The report of Alvarez-Villa *et al*. [17] identified that carbon dioxide precipitation controls the pH of rainwater. Furthermore, Akubugwo and Duru [18] highlighted the benefits of consuming alkaline water from a reliable and safe source. Zdeb *et al*. [19] investigated the fluctuations of microbiological indices of tank-stored roof-harvested rainwater; the pH they obtained from their study was shown to vary between 6.0 and 7.3. They also affirmed that seasonal variations could affect the pH of the roof-harvested rainwater.

The electrical conductivity of the rainwater correlates with the presence of pollutants and ions both on the surface of the roof or washed down from the atmosphere. The electrical conductivity of the rainwater obtained from the College of Health Science female hostel section was 120.34 µS/cm canteen section had 110.7 µS/cm. The report of Mendez *et al*. [20] identified a high electrical conductivity and attributed it to the quality and nature of roofing materials, which they could associate with the leaching of the chemical component of the roofing sheets. These factors also agreed with the high concentration of the total dissolved solids which were 12.33 and 14.11 mg/L. Ezemonye *et al*. [14] reported a high concentration of total dissolved solids ranging from 10.8 to 26.45 mg/L while the thatch roofs harvested rainwater that had a high concentration of total dissolved solids. Particulates and residues of biochar may all be associated with the solids precipitate. Other studies like that of Itodo *et al*. [7] attributed it to organics and faecal matter from animals as a contributory factor. Aleruchi *et al*. [8] observed that the freely collected rain he sampled in Rivers State, Nigeria had a significantly higher total dissolved solids while having the opinion that the total suspended solids of the roof harvested rainwater were significantly higher than the freely collected ones. The study by Nwogu *et al*. [3] identified that the total dissolved solids and suspended solids correlated significantly. Their study reported a TDS of 7.0 to 37.05 mg/L while the freely collected atmospheric rainwater had a TDS of 7.0 mg/L. Keen observation of researchers like Mazurkiewic *et al*. [21] associated the high level of precipitation of the roofing materials with the acidic nature of the rainwater. Nwogu *et al*. [3] further underscored the seasonal fluctuations in physicochemical indices of the rainwater; however, they reported that in July the physicochemical compositions were significantly different, less than during the initiation of the rainfall.

The turbidity of the roof-harvested rainwater from the KOMU canteen was 0.15 and 0.25 mg/L for the study; this was slightly higher than the turbidity of the samples obtained from Hezekiah University, Umudi, which had a turbidity of 0.12 and 0.18 NTU for the hostel and canteen sections, respectively. The report of Itodo *et al*. [7] for the Warri refinery area and military formation areas; is 0.88 to 1.52 NTU. These concentration values were lower and fell within WHO limits for potable water. The presence of soot and heavy industrial activities has been identified to affect the turbidity of the rainwater [13]. Furthermore, Jongman and Korsten [22] have also reported that the objectionable quality of rainwater is also attributed to high turbidity and suspended particulates. This has not deterred the peasant farmers from using this water for the irrigation of crops and animal husbandry.

The total hardness of the rainwater harvested from the roof at the HezUni was 24.77 and 13.49mg/L for the canteen and hostel, respectively, while that of the samples obtained from KOMU was 22.6 and 24.1 although the samples were within the limit of 100-300 mg/L as given by WHO. There are concerns about the water not being economically fit to use for laundry purposes, as it can be economically effective since it may not form lather. These concentration values agreed with the report of Itodo *et al.* (2021) who reported that the rainwater obtained from the Warri refinery area had a total hardness of 22.0 mg/g while the military area sourced- rainwater had as high as 38 mg/L. However, it was reported that the hardness of the rainwater decreased as the rain flushed the roof. This also agreed with the report of Adeyeye *et al*. [1], whose study identified a high concentration value for total hardness.

The bacteriological quality of roof-harvested rainwater has been pivotal in the definition of the quality of this alternative source of domestic water as being potable or non-potable. The total heterotrophic bacterial count of the rainwater sample obtained from HezUni was 6.75 Log_{10}CFU/mL and 5.5 Log_{10}CFU/mL for the hostel and canteen harvested samples in March. These results agreed strongly with the earlier study of Aleruchi *et al*. [8], whose study identified that the bacterial load of the roof-harvested rainwater obtained from Rivers State had a concentration of 1.2×10^6 CFU/mL and 3.8×10^6 CFU/ml for direct free catch of the rainwater without the roof while residential roof harvested rainwater. Ahmed *et al*. [24] reported a similar concentration as our current investigation. A concentration of 6000/100mL, some citing the absence of *E. coli* in samples enumerated in Australia. Nwogu *et al*. (2024) also agreed by reporting that in July the microbial population was 1.02×10^5CFU/mL was observed for the samples obtained from corrugated pipes, while the aluminium roof-harvested samples had 6.6×10^4 CFU/mL. Sedimentation of particulates and organic or faecal matter is responsible for the high microbiota in the roof-harvested rainwater. Ezemonye *et al*. [14] reported that during the onset of the study, they observed a total bacterial count of 100-200 CFU/ml, but they reported that the asbestos-harvested rainwater had a higher microbial population than the other roofing sheets. The adsorption of the surface of the roofing sheets helps to trap infectious particles that may sediment on the roof.

The total coliform count of the roof-harvested rainwater is a crucial factor in the determination of the potability of the rainwater. Total coliform counts of the rainwater samples obtained from Hezekiah University had faecal matter content of 3.0 MPN/100mL and 7.4 MPN/100mL for the hostel and canteen section, respectively. The samples obtained from K.O. Mbadiwe University had a 6.1 and 7.4 MPN/100mL, for the hostel and canteen respectively. The total coliform composition of the rainwater samples obtained from the Hezekiah University hostel section was 10 MPN/100mL while that of the canteen section was 36 MPN/100mL. Ewelike *et al*. [21] reported a coliform content of 3 CFU/mL for roof-harvested rainwater. These findings corroborate the report of Mazuriewicz *et al*. [22] whose study identified 264,000 CFU/100mL in the roof harvested rainwater in a study conducted in Poland, thereby indicating that the quality of harvested rainwater might be a threat as they surpass the zero-coliform consideration for potable water as stipulated by WHO.

The bacterial isolates obtained from the study showed the bacterial isolates obtained from the HezUni female hostel harvested rainwater in March were *E. coli*, *Citrobacter* sp., *Staphylococcus* sp., *Shigella* sp. and *Aerobacter* sp. While the canteen harvested rainwater had *Shigella* sp., *E. coli*, *Staphylococcus* sp. and *Micrococcus* sp., while in July *Aerobacter* sp., *Citrobacter* sp. and *E. coli* were identified, while the canteen section had *Micrococcus* sp., *Shigella* sp. and *Proteus* sp. as presented in Table 4. The sample obtained from the College of Health female hostel section was observed to have *Proteus* sp., *Staphylococcus* sp., *Moraxella* sp., *Klebsiella* sp. and S*treptococcus* sp.; while in July, the predominant isolates were *Klebsiella* sp., *Proteus* sp. and *E. coli.*

The samples obtained from the canteen section showed the presence of *E. coli*, *Klebsiella* sp., *Micrococcus* sp. and *Staphylococcus* sp., while in July *Micrococcus* and *Staphylococcus* sp. were the predominant isolates. This corroborates the findings of Nwogu *et al*. [3] reported the presence of a wide array of bacterial isolates such as *Acinetobacter*, *Bordetella*, *Burkholderia*, *Legionella*, *Mycobacterium*, *Pseudomonas*, *Rickettsia*, and *Tatlockia* as previously reported by Ahmed *et al*. [24]. In a related study, Kaushik *et al*. [25] isolated the following categories of microbes from freshwater obtained from roofs of buildings *Betaproteobacteria*, *Alphaproteobacteria*, *Sphingobacteria*, *Actinobacteria*, *Gammaproteo- bacteria*, *Lentisphaerae*, CH21, *Phycisphaerae*, *Chlorbia*, and *Spirochaetes*. Jongman and Korsten [23] reported the presence of *Betaproteobacteria*. Most of these isolates have been reported to cause gastroenteritis or some form of food poisoning as this also aligns with the result of Nwachukwu *et al*. [3]. They further highlighted the ability of these microbes to possess resistance genes which are leading the cause of death in the world today. *Proteus* sp. has been identified to cause nosocomial infections and urinary tract infections.

5.0. Conclusion and Recommendation

The quality indices of rainwater obtained from the roof of the canteens and female hostels in the tertiary institution in the Orlu Zone of Imo State have shown that the safety of this alternative source of domestic water may pose a substantial risk to its patrons, as it contains both chemical and biological contaminants of concern which can cause harm to its consumers, as it failed to meet both domestic and international regulations. Tertiary institutions are citadels of quality education and learning must show and educate their students about the dangers of using roof-harvested rainwater for potable reasons. There is a need for mass campaigns for rural dwellers through radio jingles, as the government must be encouraged to provide safe and potable water for rural dwellers.

Declarations

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Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

Both the authors made an equal contribution to the conception and design of the work, data collection, experimental analysis, writing of the article and critical revision of the article. Both the authors have read and approved the final copy of the manuscript.

Availability of data and material

Authors are willing to share the data and materials according to relevant needs.

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