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Water Quality Analysis: The Influence of Rooftops on Microbial Properties of Harvested Rainwater from Communities in Delta State, Nigeria

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ABSTRACT

A significant issue in using untreated harvested rainwater for drinking or other uses, is the potential public health risks associated with microbial pathogens. This research focuses on microbial activities associated with the harvested rainwater. In this study, sixty samples of harvested rainwater were collected from different roofing materials (zinc roofing sheets, aluminium roofing sheets, asbestos roofing materials and thatch roofing materials) in three communities: Ughelli, Agbarho and Opete, in Delta State, Nigeria. Microbiological analyses of the samples were carried out using USEPA standard methods. The harvested rainwater samples were analyzed using Multiple –Tube fermentation technique for total coliforms, faecal coliform, *E. coli*, total heterotrophic bacteria (THB) and total heterotrophic fungi (THF). Results obtained were compared with each other and with the water quality standards of the World Health Organization (WHO) to evaluate its suitability for potable and domestic uses. The results showed that rainwater collected from rooftops proved to be microbial contaminated above the World Health Organization stipulation for drinkable water. Also, the study revealed that harvested rainwater may not be suitable for direct drinking due to the presence of pathogens, but could be used for other domestic purposes after water treatment.

Keywords: Harvested Rainwater, Microbial, rooftops, Agbarho, Opete, Ughelli.

INTRODUCTION

The process of gathering water from surfaces that receive rainfall and storing it for later use is known as rainwater harvesting [1]. One of the biggest obstacles to growth in many parts of the world is a lack of water of sufficient quality and quantity [2, 3]. Health, agricultural productivity, food security, technological advancement, and state economies are all impacted. Problems with water quality and scarcity are especially problematic in tropical regions of the world, where many developing nations are located [4].

Because rainfall varies, certain rainwater harvesting techniques have been tried recently in the northern region of Nigeria, as well as in other water-stressed countries like Kenya and the Niger Republic, in an effort to alleviate drought and water shortages. The simplicity and ease of adoption of rainwater collection techniques at the individual or community level are its main selling points. Rainwater collection methods can be used in any agroclimatic zone [5]. Since prehistoric times, societies in most regions of the world have collected rainwater for residential and agricultural purposes. Rain is the earth's main source of freshwater [6, 7]. However, a move toward more centralized engineering approaches to water delivery using surface and groundwater sources, which are unable to fulfill the always growing gap between supply and demand, has resulted in a fall in the widespread usage of rainwater in the past. According to Li and Lee [8], there are three primary categories of rainwater harvesting (RWH) technologies: (1) Rooftop Rainwater Harvesting (RRWH), which involves producing small amounts of water for domestic use from rooftops; (2) Micro-catchment water harvesting, which collects surface runoff from a small catchment area and stores it in the root zone of an adjacent infiltration basin; and (3) Macro-catchment water harvesting, which transfers runoff from hill-slope catchments to the cropping area situated at the foothill on level ground.

Among the different methods used for rainwater harvesting, roof catchment is the most widely utilized. In rural regions, it often remains the primary source of safe drinking water for households, while in urban settings, it typically serves as a secondary supply due to the shortcomings of municipal water [1, 9, 10]. This method is favoured because residents can make use of the roofs of their existing homes, helping them avoid extra expenses [1]. The volume and quality of water collected are influenced by both the size and type of roofing material used [11, 12]. Roofs serve as effective surfaces for collecting rainwater, provided they are kept clean. They are constructed from various materials, and most are suitable for rainwater harvesting, except for those made from grass, such as thatched roofs [13-15]. Common roofing materials include corrugated iron and plastic sheets, asbestos-cement sheets, concrete, tiles, galvanized iron, metal sheets, anodized aluminum, and clay [16]. In Nigeria, particularly in the areas studied, galvanized iron, aluminum, zinc, and asbestos are the most frequently used [1]. Roofing materials can be either non-porous, like iron, aluminum, and zinc, or porous [17, 18]. The amount of rainwater that can be harvested depends largely on the size of the roof, while the type and condition of the roofing material influence the water's quality [19-21].

Rainwater can become contaminated with chemical pollutants from various sources it contacts, beginning with atmospheric exposure [22, 23]. As rain falls, it can absorb gases and pick up chemicals from dust and roofing materials [24]. Some chemical components in rainwater pose immediate health risks due to undesirable taste, smell, and appearance [25]. For instance, nitrate can become toxic in the human body when converted into nitrite—a process that occurs in human saliva and in infants' digestive systems during their first three months of life [26, 27].

The World Health Organization has established guideline values for various chemical elements in drinking water, including provisional limits based on practical treatment capabilities and testing accuracy [11]. The quality of rainwater depends on several factors [28], such as the type and condition of the roof surface, local weather, proximity to pollution sources, the nature of the storage tank, and how the water is handled and maintained [29-31]. In some cases, rooftop-harvested rainwater meets international quality standards for domestic use [33,34], while in others, chemical and microbial contaminant levels exceed safe drinking water limits [35]. Ensuring high water quality requires well-designed systems along with regular operation and maintenance, including cleaning of the collection and storage components [36, 37].

The main microbial threats to safe drinking water come from pathogens such as bacteria, viruses, protozoa, and parasitic worms. Diseases like typhoid, cholera, and dysentery are caused by some of these microorganisms [38]. Although coliform bacteria are commonly found in the environment and are generally harmless, their presence can signal potential contamination. Specifically, *Escherichia coli* (*E. coli*) indicates the possible presence of harmful pathogens originating from human or animal waste [35]. The WHO sets a standard of zero *E. coli* or thermotolerant coliforms per 100 mL in drinking water [11]. Brouqui [5] proposed alternate water quality standards for rainwater in tropical and developing regions.

E. coli contamination in rainwater is common, especially in samples taken soon after rainfall begins. The initial runoff often carries higher microbial loads, which tend to decrease as rainfall continues [40, 41]. Though total coliforms, fecal coliforms, and *E. coli* themselves may not always be dangerous, they are used as indicators for the possible presence of more harmful microbes [42-44].

The purpose of this study is to assess how roofing materials and microbial factors influence the quality of rainwater harvested in three communities—Ughelli, Agbarho, and Opete in Delta State, Nigeria.

MATERIALS AND METHODS

Study area

This research was conducted in three neighbouring communities—Ughelli, Agbarho, and Opete, located in Delta State, in the southern region of Nigeria [1]. The area falls between longitudes 3°E to 9°E and latitudes 4°30'N to 5°21'N. These communities experience high annual rainfall, typically ranging from 3,000 to 4,500 mm. The climate in Ughelli, Agbarho, and Opete is tropical, with a lengthy rainy season lasting approximately eight to ten months. Rainfall generally begins in February, pauses briefly in March, resumes from April through mid-November, and includes a short dry spell in August known locally as the "August break," lasting one to two weeks. The dry season extends from late November to January, although occasional rainfall may still occur in December and January. The inhabitants of these areas belong to the Urhobo ethnic group, the fifth largest in Nigeria, and are predominantly Christians [1]. Rainwater harvesting is widely practiced in these communities during the rainy season, as it is considered a free, readily available, and culturally accepted source of safe water for drinking and other domestic uses.

Chemicals

All reagents and chemicals used were of analytical grades and distilled water was sued in all preparations and analysis as described by USEPA [8, 39] and APHA [27].

Sample collection

Sixty plastic buckets were thoroughly cleaned and treated by soaking in a solution of 10% nitric acid (HNO_3) and a 1:1 mixture of hydrochloric acid (HCl) for 24 hours. Afterward, the buckets were thoroughly rinsed with distilled water and stored properly. Each sample container was labeled to ensure accurate tracking and record keeping. Rainwater samples collected from Ughelli were labeled as ugh1 through ugh5; those from Agbarho as agb1 through agb5; and samples from Opete as opt1 through opt5, corresponding to the first, through fifth rainfall collections in each community.

Water samples were collected in accordance with established guidelines [45, 46]. A random sampling method was used to select participating households. Four types of roofing materials were identified: asbestos, aluminum, zinc, and thatch. From each roofing category, four households were randomly chosen, and rainwater samples were collected at the start of each month. A total of sixty (60) samples were obtained from these selected homes, representing the first through fifth rainfall events of 2019, and covering rooftops made of asbestos, zinc, aluminum, and thatch.

To prevent contamination from soil and surface runoff, plastic buckets were placed on tables raised 3 m above ground level. All water samples were treated on-site based on the type of analysis planned before being transported to the laboratory for further examination [47-49].

Microbiological analysis

The presence of pathogenic organisms in water presents significant health risks. To assess this, several bacteriological parameters were tested, including total coliforms (TC), fecal coliforms (FC), *Escherichia coli* (EC), total heterotrophic bacteria (THB), and total heterotrophic fungi (THF). These tests were performed using the Multiple Tube fermentation technique (MPN method). Lauryl tryptose broth was used during the presumptive stage to detect total and fecal coliforms, while Brilliant Green Lactose bile broth and EC Medium were used in the confirmation stage for both total and fecal coliforms. The water quality testing followed the procedures outlined in the APHA's Standard Methods for the Examination of Water and Wastewater [27].

RESULTS AND DISCUSSION

The bacteriological results are displayed in Tables 1-6.

Table 1: Results of the microbial analyses from aluminium and zinc rooftops from first to fifth annual rainfall in Agbarho community

Sample	T.Coliform (MPN/100mL)	F.Coliform (MPN/100mL)	E.Coli (MPN/100mL)	THB (cfu/L)	THF (cfu/L)
Al-s 1	110.00	ND	ND	2.46	1.15
Al-s 2	70.00	ND	ND	1.89	0.90
Al-s 3	60.00	ND	ND	1.71	0.69
Al-s 4	40.00	ND	ND	1.65	0.47
Al-s 5	40.00	ND	ND	1.43	0.30
Zn-s 1	90.00	ND	ND	2.33	1.08
Zn-s 2	40.00	ND	ND	1.67	0.61
Zn-s 3	40.00	ND	ND	1.47	0.53
Zn-s 4	40.00	ND	ND	1.36	0.32
Zn-s 5	20.00	ND	ND	1.26	0.20
WHO	0	0	0	0	0

Al-s: aluminium-roofing sheet, Zn-s: zinc roofing sheet, THB: total heterotrophic bacterial, THF: total heterotrophic fungi. 1, 2, 3, 4, 5: first, second, third, fourth and fifth rain fall.

Table 2: Results of the microbial analyses from asbestos and thatch rooftops from first to fifth annual rainfall in Agbarho community

Sample	T.Coliform (MPN/100mL)	F.Coliform (MPN/100mL)	E.Coli (MPN/100mL)	THB (cfu/L)	THF (cfu/L)
Asb 1	310.00	70.00	20	2.89	1.56
Asb 2	140.00	20	10	2.27	103
Asb 3	90.00	10	ND	2.12	0.86
Asb 4	80.00	ND	ND	2.03	0.74
Asb 5	70.00	ND	ND	1.97	0.68
Tha 1	560.00	110	40	3.10	1.62
Tha 2	190.00	40	20	2.49	1.19
Tha 3	110.00	20	10	2.28	1.11
Tha 4	90.00	10	ND	2.14	0.87
Tha 5	60.00	ND	ND	1.76	0.52
WHO	0	0	0	0	0

Asb: asbestos roof, Tha: thatch roof, THB: total heterotrophic bacterial, THF: total heterotrophic fungi. 1, 2, 3, 4, 5: first, second, third, fourth and fifth rain fall.

Table 3: Results of the microbial analyses from aluminium and zinc rooftops from first to fifth annual rainfall in Ughelli community

Sample	T.Coliform (MPN/100mL)	F.Coliform (MPN/100mL)	E.Coli (MPN/100mL)	THB (cfu/L)	THF (cfu/L)
Al-s 1	90.00	ND	ND	2.27	0.95
Al-s 2	20.00	ND	ND	1.58	0.53
Al-s 3	40.00	ND	ND	1.53	0.49
Al-s 4	40.00	ND	ND	1.38	0.21
Al-s 5	40.00	ND	ND	1.17	0.15
Zn-s 1	110.00	10.00	ND	2.49	1.11
Zn-s 2	40.00	ND	ND	1.92	0.74
Zn-s 3	40.00	ND	ND	1.68	0.54
Zn-s 4	40.00	ND	ND	1.47	0.50
Zn-s 5	40.00	ND	ND	1.30	0.24
WHO	0	0	0	0	0

Al-s: aluminium-roofing sheet, Zn-s: zinc roofing sheet, THB: total heterotrophic bacterial, THF: total heterotrophic fungi. 1, 2, 3, 4, 5: first, second, third, fourth and fifth rain fall.

Table 4: Results of the microbial analyses from asbestos and thatch rooftops from first to fifth annual rainfall in Ughelli community

Sample	T.Coliform (MPN/100mL)	F.Coliform (MPN/100mL)	E.Coli (MPN/100mL)	THB (cfu/L)	THF (cfu/L)
Asb 1	170.00	40.00	ND	2.61	1.45
Asb 2	60.00	20	ND	2.12	0.98
Asb 3	70.00	10	ND	1.92	0.92
Asb 4	70.00	ND	ND	1.74	0.72
Asb 5	60.00	ND	ND	1.48	0.33
Tha 1	290.00	70	10.00	2.72	1.52
Tha 2	90.00	40	ND	2.30	1.04
Tha 3	70.00	20	ND	2.13	1.00
Tha 4	40.00	10	ND	1.62	0.46
Tha 5	40.00	ND	ND	1.51	0.36
WHO	0	0	0	0	0

Asb: asbestos roof, Tha: thatch roof, THB: total heterotrophic bacterial, THF: total heterotrophic fungi. 1, 2, 3, 4, 5: first, second, third, fourth and fifth rain fall.

Table 5: Results of the microbial analyses from aluminium and zinc rooftops from first to fifth annual rainfall in Opete community

Sample	T.Coliform (MPN/100mL)	F.Coliform (MPN/100mL)	E.Coli (MPN/100mL)	THB (cfu/L)	THF (cfu/L)
Al-s 1	90.00	ND	ND	2.43	1.15
Al-s 2	40.00	ND	ND	1.87	0.68
Al-s 3	40.00	ND	ND	1.41	0.58
Al-s 4	40.00	ND	ND	1.31	0.28
Al-s 5	20.00	ND	ND	1.19	ND
Zn-s 1	70.00	ND	ND	2.21	0.98
Zn-s 2	40.00	ND	ND	1.64	0.52
Zn-s 3	20.00	ND	ND	1.22	0.31
Zn-s 4	20.00	ND	ND	1.17	0.11
Zn-s 5	20.00	ND	ND	1.04s	ND
WHO	0	0	0	0	0

Al-s: aluminium-roofing sheet, Zn-s: zinc roofing sheet, THB: total heterotrophic bacterial, THF: total heterotrophic fungi. 1, 2, 3, 4, 5: first, second, third, fourth and fifth rain fall.

Table 6: Results of the microbial analyses from asbestos and thatch rooftops from first to fifth annual rainfall in Opete community

Sample	T.Coliform (MPN/100mL)	F.Coliform (MPN/100mL)	E.Coli (MPN/100mL)	THB (cfu/L)	THF (cfu/L)
Asb 1	210.00	40.00	ND	2.74	1.51
Asb 2	70.00	10	ND	2.23	0.89
Asb 3	40.00	ND	ND	1.73	0.62
Asb 4	20.00	ND	ND	1.09	0.24
Asb 5	20.00	ND	ND	0.87	ND
Tha 1	390.00	90	40.00	2.95	1.58
Tha 2	90.00	50	20.00	2.41	1.04
Tha 3	70.00	30	10.00	2.09	0.82
Tha 4	40.00	10	ND	1.66	0.51
Tha 5	20.00	ND	ND	1.38	0.29
WHO	0	0	0	0	0

Asb: asbestos roof, Tha: thatch roof, THB: total heterotrophic bacterial, THF: total heterotrophic fungi. 1, 2, 3, 4, 5: first, second, third, fourth and fifth rain fall.

The results presented in Tables 1–6 show that microbial parameters—including total coliforms, fecal coliforms, *E. coli*, total heterotrophic bacteria, and total heterotrophic fungi—were found in varying levels across the four types of roofing materials. These values were consistent with findings reported by Montgomery and Elimelech [38]. Coliforms, THF, and THB were present from the first to the fifth rain event on all roof types, likely due to contamination from human activity, as well as feces from birds and small animals (e.g., rodents) deposited on the roofs.

According to Forster [19], total coliform counts suggest potential sewage contamination, while fecal coliforms indicate contamination from human or animal waste. The concentration of these microorganisms reflects the extent of pollution. The World Health Organization [11, 46] recommends that drinking water should be completely free of coliform bacteria. High coliform counts were recorded in rainwater collected from thatch (560 MPN/100 mL) and asbestos (310 MPN/100mL) roofs in Agbarho (Table 2). This elevated presence of bacteria is likely due to the porous nature of these materials, surface runoff, and poor hygiene practices around the collection areas. Higher microbial contamination levels were observed in water collected from thatch and asbestos roofs across all three communities, suggesting that these materials tend to retain more contaminants [23], which in turn compromises the quality of the harvested water.

In contrast, rainwater collected from aluminum and zinc roofs showed the lowest microbial contamination in all communities (Tables 1–6). This is likely because these materials have smooth surfaces and high thermal conductivity, which helps dry off and remove contaminants via wind before rain begins.

The variations in microbial content across different roofing types—even within the same community—highlight the significant role that roofing materials play in determining the quality of harvested rainwater. For instance, in Table 2, Agbarho recorded the highest total coliform levels in rainwater from thatch (560 MPN/100 mL) and asbestos roofs (310 MPN/100 mL), whereas in Table 6, Opete also showed elevated coliform levels from thatch roofs (390 MPN/100 mL). In contrast, aluminum roofs had much lower coliform counts, such as 90 MPN/100 mL in Table 3 during the first rainfall.

Additionally, Agbarho and Opete recorded the highest total heterotrophic bacteria levels—3.10 cfu/L from thatch and 2.89 cfu/L from asbestos in Agbarho (Table 2), and 2.95 cfu/L and 2.74 cfu/L respectively in Opete (Table 6).

A significant decrease in microbial contamination was observed with subsequent rainfall events. By the fifth rainfall, *E. coli* and fecal coliforms were completely absent from samples collected from all roofing types in the three communities, indicating effective flushing. However, even after the fifth flush, total coliforms, THB, and THF remained present, indicating that the rainwater would still require treatment before it can be considered safe for either potable or non-potable use.

CONCLUSION

The findings from this study indicated that the quality of rainwater collected from various roofing materials across different rainfall events and communities is influenced by both the type of roofing material and environmental conditions. However, the microbial levels in the collected water samples generally exceeded the WHO's recommended limits for safe drinking water, except for *E. coli* and fecal coliforms, which were not detected after the fifth rainfall event. According to WHO guidelines, potable water must be entirely free of coliform bacteria. Among the roofing materials, thatch and asbestos showed the highest levels of contamination, followed by zinc, whereas aluminum roofs consistently produced the cleanest water samples. Rainwater harvested from aluminum roofing appeared to be the most suitable for use. Nevertheless, all harvested rainwater should undergo at least basic treatment before being used for domestic purposes such as washing clothes, bathing, toilet flushing, or general cleaning.

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