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EVALUATION OF THE POTABILITY OF HARVESTED RAINWATER IN GBARAIN AND EKPETIAMA COMMUNITIES: IMPLICATIONS FOR PUBLIC HEALTH NEW

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ABSTRACT

This investigation delves into the potability of rainwater collected by Gbarain and Ekpetiama communities, the areas which accommodate Shell Petroleum Development Company (SPDC) Central Processing Facility (CPF) in Obunagha, Bayelsa State, Nigeria, along with public health implications as a key factor. Though water from rainwater harvesting is mostly the only option and it is the most economical source in rural and peri-urban regions. During the wet and dry seasons, samples were taken from various households and then analyzed for physico-chemical parameters (pH, turbidity, TDS, conductivity, nitrates, sulphates, and heavy metals) and microbiological quality (total coliforms and other pathogens). The data indicated that the average values of most of the physico-chemical parameters were within the limits set by WHO (2017) and NSDWQ (2015), however, at times, there were heavy metal exceedances of lead and zinc. The microbiological testing showed contamination throughout the area and over the whole period of study but it was especially bad in the wet season with high fecal coliform count ringing direct consumption as unsafe. The results point out that communities are at risk of cholera, typhoid, and diarrhea epidemics. The authors recommend boiling, chlorination, and filtration as treatment methods at household level, clean collection roofs, and proper storage tanks as infrastructure improvements, and policy support and public health education as overall measures to secure using rainwater. Appropriately, untreated rainwater harvesting in these communities is non-potable, but with the right measures it can serve as a sustainable water source.

KEYWORDS: Rainwater harvesting, Potability, Public health, Gbarain, Ekpetiama, Waterborne diseases.

1.0 INTRODUCTION

1.1 Background

Safe and reliable drinking water access is still a big challenge for public health, particularly in the rural and peri-urban areas of developing countries. Approximately 2.2 billion people over the world do not have access to adequately managed drinking-water services [1]. In Nigeria, rural and peri-urban communities suffer the most from inadequate water infrastructure, poor distribution systems, and contamination of the available water resources despite the country's ample water resources [2], [3]. Thus, many households depend on other sources of water, and rainwater harvesting (RWH) is one of the most approachable and widely used among them. Rainwater harvesting is the activity of capturing and storing rainwater from roofs, land surfaces, or other catchment areas for household, agricultural, or industrial use [4]. The Gbarain and Ekpetiama communities are near the SPDC CPF facility in Obunagha, which raises concerns about the possible environmental impacts on water quality. In rural and peri-urban areas, the practice serves as a relatively inexpensive and sustainable method of supplying domestic water needs, particularly during the times of unreliable or no municipal supply [5]. It is even more important in regions where groundwater is polluted with iron, heavy metals, or germs and where surface waters are affected by industrial or oil-related activities, as in some parts of the Niger Delta [6].

Furthermore, collection of rainwater is of paramount importance in water security, lessening reliance on unsafe water sources and through that to waterborne diseases impacts [7]. For a large number of community people, it is an eco-friendly and climate-resilient adaptation strategy, which very much protects them from seasonal water scarcity and hinge of climate change impacts on the conventional water supplies (UNEP, 2010). In the area of Gbarain and Ekpetiama communities in the Bayelsa State where there is only little and non-functional piped water infrastructure, collection of rainwater is a major part of the household water supply strategy. More so, it is an important source of drinking water, but the certainty of the harvested rainwater potability is often in doubt due to contamination from roofing materials, storage tanks, and aerial settling of pollutants [9], [10]. This indicates that the water quality is an issue, and in fact, it raises serious concerns about the health of the public that may eventually require systematic evaluation of its quality.

1.2 Problem Statement

The worldwide need for safe drinking water has surpassed the available supply and this is especially the case in rural and peri-urban areas where there is no delivery of potable water supply infrastructures or they are inadequate. In the Sub-Saharan Africa region, up to 400 million people continue to be deprived of even basic water services [1]. Nigeria, despite its abundant water resources, has been unable to supply clean and safe drinking water to its people primarily because of poor infrastructure and pollution from oil, besides lack of investment in water treatment operations [9],[11]. As a result, some communities like those in Bayelsa State depend on rainwater harvesting as the main alternative for domestic water supply. Rainwater harvesting is a solution to water scarcity but its safety for human consumption is still a matter of debate. Rooftop rainwater that is gathered and stored in household tanks is usually vulnerable to various kinds of contamination risks, such as metals coming from roofing materials, airborne pollutant settling, and microbial contamination due to animals' faeces and litter [9],[10]. In the Niger Delta region, oil and gas extraction operations contribute significantly to the risks by discharging hydrocarbon pollutants and dust into the air, which may cover the roofs and contaminate the collected water [12].

Reliance on untreated rainwater has resulted in grave consequences for public health. It has been found that in Nigeria and some other underdeveloped areas the collected rainwater regularly does not comply with WHO and local drinking water quality standards, with microbial pollution being the main danger [2], [3]. The presence of waterborne microbes like Escherichia coli, Salmonella, and coliforms has been confirmed in the water tanks connected to the houses, which may lead to the spread of diseases like diarrhea, typhoid, and infections of the gastrointestinal tract [13].

1.3 Study Area Context

Gbarain and Ekpetiama are two clans that are very close to each other and situated in the Yenagoa Local Government Area of Bayelsa State, which is right in the center of the Niger Delta region of Nigeria. The Niger Delta is a low-lying area that is very prone to flooding and is characterized by vast areas of wetlands, rivers, and mangrove swamps. The communities are geographically located along the Nun River basin, which is one of the main distributaries of the River Niger. The climate is normally very humid tropical, with very high rainfall that averages between 2,500–4,000 mm annually, which is a characteristic that makes rainwater harvesting a very common household practice [6], [14]. Access to drinking water still poses a big problem in both communities. In the past, the people living there used to rely on streams, rivers, and hand-dug wells for their domestic water supply. However, over time, the use of these natural water bodies has been reduced because they became more contaminated with industrial effluents, oil spills, and poor sanitation, among others [2]. In the absence of reliable municipal water system, rainwater harvesting has become drinking, cooking, and household purposes' most viable alternative. Collecting rooftop rainwater, which is then stored in plastic or metal tanks, is common. Even though it is crucial to the potability of rainwater collected, there is still doubt about it, since water quality is subject to the influence of a number of factors including roofing materials, atmospheric deposition, and storage conditions [9], [10].

1.4 Research Objectives

Rural and peri-urban communities in Bayelsa State are getting more and more dependent on rainwater, which leads to the necessity of evaluating this water's quality for human use. When it is collected through rainfall, water is usually the case many times through processes that might alter its quality, thus exposing the public to health risks [9], [10]. Rainwater harvesting has very much been the family water supply method in Gbarain and Ekpetiama where good drinking water from the government is either a no-go area or very expensive. However, since no one has ever done a systematic study to prove its being potable, the residents are at risk of being infected with waterborne diseases. The primary aim of this research is thus to carry out an assessment of the water collected from the rain in Gbarain and Ekpetiama as potable water with specific mentioning of the following: to check the physico-chemical quality of the rainwater by evaluating several parameters like pH, turbidity, total dissolved solids (TDS), conductivity, and the concentrations of nitrates, sulphates, and heavy metals, and then comparing to [15] and [16]; to study microbiological quality, concentrating on the issue of total coliforms, Escherichia coli, and other possible pathogens that might indicate fecal contamination and be health hazards; to look at rainwater quality differences seasonally between wet and dry periods and thus alert the researchers to the times when contamination is most likely; to evaluate the public health aspects of rainwater use, especially health concerns created by waterborne diseases and long-term exposure to the contaminants within the scope of the health of rural and peri-urban communities, and to suggest both household-level and community-level interventions including low-cost treatment options, safe collection and storage practices, and policy support for rainwater management aimed at improving the safety of harvested rainwater.

The study aims to produce evidence-based insights regarding the safety of rainwater as domestic water and thus contribute to the improvement of public health in less privileged areas through its strategies.

1.5 Significance of the Study

The provision of safe drinking water is a fundamental requirement for public health, sustainable development, and the environment. In rural and peri-urban areas like Gbarain and Ekpetiama in Bayelsa State, the constant lack of reliable potable water infrastructure forces the locals to rely on harvested rainwater for their daily needs. The practice not only solves the immediate water shortage problem but the issue of its safety is still open to debate because of the risk of pollution from the surfaces where the water is collected, storage systems, and air. One of the vital reasons why this research is even done is the fact that it will provide scientific evidence of the potability of harvested rainwater while at the same time pointing out its environmental health, water management policies, and community well-being implications. The outcomes of this study will definitely be beneficial to the environmental health sector by clarifying the role of harvested rainwater in the transmission of waterborne diseases. The study will not only determine the main contaminants, whether chemical or microbial but also the pathways of exposure which in turn will be the basis for ineffective [3],[13] disease burden reduction in susceptible groups. As for the water management policy aspect, the study is anticipated to steer the local and state government officials towards more informed decisions regarding the promotion of rainwater harvesting as a supplementary water source. The proof from this research could be the basis for developing standards for the safe collection, treatment, and storage of rainwater. This practice would also be in line with the national water supply and sanitation policies of Nigeria. Besides, it complements global engagements like the United Nations Sustainable Development Goal 6 (SDG 6) which advocates for access to clean water and sanitation [17] for everyone.

Here the main output of the study at community well-being level, is that households in Gbarain and Ekpetiama can benefit from the research directly. The study by checking the rainwater quality that people drink, not only gives the community the information to change its behavior to the safer use of the water, like employing low-cost treatment methods or better storage or even teaching hygiene, etc. Also, social and economic resilience that comes with the population's good health is the main reason why water supply is a very powerful skill, as education, local development and other livelihood activities become the playground for healthy people.

2.0 MATERIALS AND METHODS

2.1 Study Area Description

The Gbarain and Ekpetiama communities are within the Yenagoa Local Government Area of Bayelsa State the central part of the Niger Delta, Nigeria. The Niger Delta is a low-lying alluvial plain where the River Niger and its distributaries have caused the deposition of sediments. The areas researched is between the latitudes of 4°30′ and 5°30′ N and the longitudes of 6°00′ and 6°45′ E, consisting mainly of wetlands, floodplains, and large creeks [6], [14]. The Nun River, which is one of the most important branches of the River Niger, flows through the region making water the main factor not only in the environment but also in people's daily activities and livelihood. Gbarain and Ekpetiama's climate is characterized by the tropical humid type, that is, the wet and the dry season are very well distinguished. Precipitation is plentiful, the amount is about 2,500 mm to 4,000 mm per year, with the wet season from April to October having maximum rainfall [18]. The high rainfall intensity together with the lack of a reliable municipal supply of water has resulted in the widespread use of rooftop rainwater harvesting for water supply in households. The average humidity is above 80%, and the annual temperature is between 25°C and 28°C, the factors that are responsible for both the large amount of water and the high microbial contamination of water being stored [19].

Gbarain and Ekpetiama are socio-economically Ijaw ethnic group. The main activities of the residents include fishing, subsistence farming, small trade, and crafts. The major crops grown in the area include cassava, plantain, yam, and vegetables, while fishing in Nun River and neighboring creeks is another source of food and money. On the other hand, the oil and gas exploration work in Bayelsa State have negatively affected the local communities socially and environmentally, resulting in river pollution, loss of fertile land, and decline of fish stock [12]. All these environmental pressures have led to the need to adopt rainwater harvesting as a safer option than the surface and groundwater sources that are becoming increasingly unsafe.

2.2 Sampling Strategy

A purposive sampling strategy was used to obtain representative data regarding the quality of rainwater harvested in Gbarain and Ekpetiama. The sampling strategy was set up in such a way that the different household water collecting and storage practices within the two clans were indicative of the diversity, and the roofing materials, tanks, and the storage conditions were the variation factors taken into consideration.

1. Rainwater Collection Points: The main storage units for harvested rainwater were sampled directly from household storage containers like plastic tanks, metal drums, and overhead reservoirs. The primary collection points were chosen to illustrate the case of both aluminum roofing sheets and galvanized iron roofing sheets since roofing material is considered one of the major factors that affect rainwater quality [9], [10]. To ensure that the samples were comparable, they were drawn from the tanks of first-use domestic storage rather than secondary containers to reduce the risk of external contamination.

2. Number of Households: Choosing a total of 13 households for sampling in both communities, Gbarain contributed 7 households and Ekpetiama 6. The sample size was influenced by the population size of each community, the accessibility of the households, and the need to keep all these factors in balance within the limits of logistical feasibility. The selection of households was done through a stratified random sampling method, which made sure that the differences in socio-economic status, roofing materials, and tank sizes were duly represented [20].

3. Sampling Duration: Over a period of 2 months, the sampling was performed, which included the rainy season and the transitional dry season, thus, potentially verifying the impact of seasons on the quality of rainwater harvested. Rainwater, in particular, was sampled in July-September 2024, which were the months in Bayelsa State when the rainfall was at its peak. The time was selected since it was when the rainwater harvesting was most intensive and also it gave information about the water quality dynamics in different seasons [2]. Sampling was done every month, producing a total of 26 water samples (13 households × 2 months).

Samples from all sites were taken in pre-sterilized polyethylene bottles, stored in ice-packed coolers, and sent to the lab for tests within 24 hours of being taken. By the adoption of such a sampling design, the dataset for evaluation of the potability of harvested rainwater in the area has been given reliability, comparability, and statistical robustness.

2.3 Physico-Chemical Analysis

Lighthouse Petroleum Engineering Co Ltd, Warri, Delta State, conducted physicochemical analyses to determine the quality of harvested rainwater samples collected from households in Gbarain and Ekpetiama communities regarding their drinking suitability. The choice of parameters was made in accordance with the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines, which specify allowable limits for safe water.

pH: The pH level in water is considered a major parameter in deciding if it is safe for human consumption or not since it has an effect on solubility, corrosion potential, and the effectiveness of disinfection. The measurement process involved the use of a digital pH meter (HANNA HI 98129), which was calibrated before the commencement of each analysis batch.

Turbidity: The turbidity measurement which indicates the water's clarity was made with the HACH 2100N turbidimeter. High turbidity might block the disinfection processes from reaching the microorganisms and simultaneously imply the presence of organic matter [21].

Total Dissolved Solids (TDS): The TDS levels, indicative of dissolved inorganic salts and organic matter, were determined with a portable TDS meter. Excessive amounts of TDS cause taste deterioration, low palatability, and thus, the reject of that water by the consumers.

Electrical Conductivity (EC): The ionic content of the rainwater collected was indirectly measured by a conductivity meter which determined the conductivity. Conductivity is frequently associated with TDS and salinity [22].

Nitrate (NO_3^-): The nitrate levels were measured using a UV-Visible spectrophotometer (APHA Method 4500-NO_3^-). Drinking water with high nitrate content can cause methemoglobinemia ("blue baby syndrome") in infants and present a threat to public health [23].

Sulphate (SO_4^{2-}): Sulphate levels were also determined using a spectrophotometric method, since high amounts can cause a bitter taste to water and, equally, may have a laxative effect [15].

Heavy Metals (Pb, Cd, Fe, Zn, Cu): Water samples were first acid-digested and then, through Atomic Absorption Spectrophotometry (AAS, PerkinElmer AAnalyst 400), heavy metals were analyzed. Lead (Pb) and cadmium (Cd) are of most concern because of their accumulation in the body and toxicity, while the monitoring of iron (Fe), zinc (Zn), and copper (Cu) was done as essential trace elements that may be harmful at high concentrations [9].

All analyses were performed according to standard methods [22] to guarantee that the findings would be reliable and reproducible. The data from these analyses were compared with [15] and [16] guideline values in order to determine compliance and assess the risk implications of the studied communities' health.

2.4 Microbiological Analysis

To carry out the microbiological analysis, the water treated with rain in the Gbarain and Ekpetiama communities was tested for the bacteriological quality. Microbial analysis, which is a very reliable way of measuring the quality of water, is necessary since rainwater may be contaminated during collection, conveyance, or storage. The analysis looked at total coliforms, and other pathogenic bacteria which were indicators of fecal contamination and health risks.

Sample Preparation and Handling:

Water samples were taken in sterile 500 mL glass bottles and placed in ice cooler and sent to the microbiology laboratory within 6 hours of collection. All the analyses were done within 24 hours following the standard protocols recommended by the [22].

Total Coliforms:

Total coliforms were counted by the Multiple Tube Fermentation (MTF) method and confirmed using the Most Probable Number (MPN) technique (APHA Method 9221B). Coliforms are regarded as the primary indicator organisms for water contamination as their presence signifies that the water had been exposed to unsanitary conditions and that pathogens could have been introduced [24], [25].

Other Pathogens:

To identify possible pathogens existing together with coliforms, the researchers employed selective media:

• The use of Salmonella-Shigella agar was for the identification of Salmonella and Shigella species. • And Pseudomonas aeruginosa was isolated on Cetrimide agar.

• MacConkey agar was for the identification of the lactose fermenting enteric bacteria.

Even though the study main focus was on indicator organisms, the screening of other potential pathogens was necessary because of the health consequences associated with waterborne diseases like diarrhea, typhoid fever, and gastroenteritis that are widespread in rural Nigerian communities [26].

Quality Control and Standards:

All the culture media were made in accordance with the specifications set by the manufacturers, and sterile controls were kept throughout the entire process. The microbiological results were matched with the standards set in [15], which mandates that drinking water are to be completely free from total coliforms. This meticulous microbiological evaluation guaranteed that not only the indicator but also the potential pathogens were followed, thus offering a thorough assessment of the microbiological safety of the rainwater collected at the research site.

2.5 Data Analysis

The Physico-chemical and microbiological analysis of rainwater samples collected in Gbarain and Ekpetiama communities has generated data that were processed and analyzed in a systematic manner to see the extent of compliance with the quality standards for drinking water.

Data Processing and Statistical Methods: The first step in data management was the use of Microsoft Excel for the logging of all raw data; after this, the data was transferred to SPSS (Version 26) where it was subjected to statistical processing. To give a better understanding of the data's central tendency and distribution, descriptive statistics like mean, standard deviation, minimum and maximum were calculated. Inferential statistics were employed to check for any significant differences regarding the quality of water between the sampling sites and the different sampling months as well.

Analysis of Variance (ANOVA): One-way ANOVA was utilized for the determination of seasonal variations for the parameters that include pH, turbidity, and microbial counts. For those cases where significant differences were found ($p < 0.05$), post-hoc tests (Tukey's HSD) were conducted to identify the exact differences among the groups.

Independent t-tests: Carried out for the purpose of comparing the average values of water quality parameters in the two localities (Gbarain vs. Ekpetiama).

Correlation Analysis (Pearson's r): Employed to discover the associations between the selected parameters (e.g., conductivity and TDS; turbidity and microbial counts).

Compliance with Standards:

The evaluation of the results was done by comparing them with the limits allowed by [15] and [16]. For example:

- **pH:** Recommended range by WHO is 6.5-8.5.
- **Turbidity:** Should not be more than 5 NTU.
- **Nitrate**: 50 mg/L is the upper limit.
- **Sulphate**: Maximum limit of 100 mg/L (NSDWQ) and 250 mg/L (WHO).
- **Heavy Metals**: Lead (Pb) < 0.01 mg/L, Cadmium (Cd) < 0.003 mg/L, Iron (Fe) < 0.3 mg/L, Zinc (Zn) < 3 mg/L, Copper (Cu) < 2 mg/L.
- **Microbiological Parameters**: WHO and NSDWQ allow no total coliforms in drinking water.

Interpretive Framework:

The parameters which were beyond the limits set by WHO/NSDWQ were identified as non-compliant and their impact on public health was pointed out. The context of environmental factors such as rainfall intensity, roofing materials, and storage practices was used to interpret the statistical significance in variations. The method of using both statistical analysis and guideline comparison ensured a thorough assessment of the safety of harvested rainwater.

This analytical framework not only provided quantitative insight but also made regulatory benchmarking possible, hence increasing the reliability of the study's findings regarding the potability of harvested rainwater in the two communities.

3.0 RESULTS AND DISCUSSIONS

3.1 Physico-Chemical Parameters

The physical and chemical parameter assessment of rainwater from Gbarain and Ekpetiama communities indicated different levels of compliance with the WHO and NSDWQ standards. The parameters that were analyzed include pH, turbidity, total dissolved solids (TDS), electrical conductivity (EC), nitrate, and sulfates together with chosen heavy metals (Pb, Cd, Fe, Zn, Cu).

pH: Acidic (5.8) and nearly neutral (7.2) were the two extremes in the pH of rainwater samples. The majority of the values were within the WHO and NSDWQ tolerance levels of 6.5-8.5, but samples that came from galvanized roofs were more acidic. This could mean that there is leaching of the metallic ions or the atmospheric deposition effects [9]. Corrosion of the storage tanks and the possible mobilization of toxic metals are the risks associated with acidic pH.

Turbidity: Variation of turbidity values was from 1.2 to 7.8 NTU. Many of the samples met the WHO guideline of ≤5 NTU, but a large number exceeded this limit mostly in the peak rainfall months. The presence of high turbidity could be a sign of contamination with dust, roofing debris, or the existence of microorganisms and their growth within storage containers [21].

TDS and Conductivity: The range of total dissolved solids was from 25 to 220 mg/L and conductivity values were mostly below 300 µS/cm, thus both were well within WHO (≤1000 mg/L TDS) and NSDWQ standards. These values indicate low mineralization, which is the main characteristic of rainwater. However, extremely low mineral content might have a negative impact on taste and palatability.

Nitrate and Sulphate: Nitrate levels fluctuated from 0.2 to 12.5 mg/L, while sulphate levels were between 2.0 and 35.0 mg/L. The two parameters were below the WHO (50 mg/L nitrate; 250 mg/L sulphate) and NSDWQ (50 mg/L nitrate; 100 mg/L sulphate) standards. The relatively clean conditions indicate that contamination through agricultural runoff is small, and the main source of pollution is atmospheric deposition.

Heavy Metals:

• **Lead (Pb):** The amounts in some of the samples were found to be over the limit set by the WHO at 0.01 mg/L particularly in households where galvanized roofing sheets were used, which shows that there is leaching from roofing or plumbing materials.

• **Cadmium (Cd):** Found in very small quantities in a few samples, but some surpassed the limit of 0.003 mg/L, which is a matter of concern for health due to its toxicity as it is a cumulative poison.

• **Iron (Fe):** The measurements went from 0.05 to 0.65 mg/L. A number of samples went over the NSDWQ limit of 0.3 mg/L, and this might result in discoloration, metallic taste, and staining of containers.

• **Zinc (Zn)** and **Copper (Cu):** Usually, they ranged in the limits specified (Zn ≤3 mg/L; Cu ≤2 mg/L) as they are the result of very little corrosion or leaching effects.

3.2 Microbial Quality

The quality assessment of microbiological rainwater collected in Gbarain and Ekpetiama showed big differences in the microbial quality and already pointed to possible public health risks through their results. The tests primarily looked at total coliforms, Escherichia coli (E. coli), and some pathogens as indicators of contamination and safety.

1. Total Coliforms: Total coliform counts varied from 0 to >100 MPN/100 mL in different sampling locations. Although certain samples met the requirement of [15] and [16] of zero coliforms per 100 mL, most samples went beyond this standard. Coliforms' presence is a sign of environmental pollution that probably got in through various ways like rooftops, tanks, and practices of [24].

2. Other Pathogens: The screening for different microbial contaminants showed the rare finding of Salmonella spp., Shigella spp., and Pseudomonas aeruginosa in a few households mainly during the rainy season. This kind of rare pathogens is threatening for their links with enteric fever, dysentery, and infections of the immune system. The sporadic detection, however, suggests that harvested rainwater could be a potential means for outbreaks if the household hygiene is poor.

3. Associated Health Risks: Rainwater harvested with microbial contaminants poses a major health risk to public especially in the groups of children, the elderly, and the immunocompromised. The situation is worsened by the fact that in some places rainwater is the only water source for the community. Drinking water that has been contaminated with rainwater has been a cause of diarrheal diseases, cholera, typhoid, and parasitic infections in rural areas in Nigeria and sub-Saharan Africa [26], [27].

4. Compliance with Standards: The majority of rainwater samples from both communities did not meet the microbiological safety requirements and the WHO and NSDWQ guidelines that stipulated no tolerance for total coliforms in drinking water. This suggests that the harvested rainwater without treatment is not safe for human consumption directly.

5. Implications: The findings highlight the necessity of household-level interventions that include disinfection (boiling, chlorination, solar treatment), installation of first-flush diverters, and regular cleaning of storage tanks. Besides, community education on sanitary practices around rainwater harvesting systems is also very important as it will help reduce microbial contamination and hence, safeguard public health.

3.3 Seasonal Variations

Rainwater quality in Gbarain and Ekpetiama communities exhibited marked seasonal changes, demonstrating the shifting pattern of rainfall through intensity, frequency and environmental conditions which were wet and dry. These variations had a major impact on the physico-chemical and microbiological characteristics of the rainwater that was stored.

1. Physico-Chemical Variations:

The rainy season saw the upsurge of water quality indicators like turbidity, total dissolved solids (TDS), and conductivity as they were considerably higher than during dry season. A major reason for this was the initial "first flush effect" that took place during the rainy season, where the rainwater washed away dust, debris, bird droppings, and organic matter from the roofs that had been accumulating during the long dry periods [28]. Nitrogen and sulphur compounds were contributed to the soil during the rain through the air along with nitrate and sulfate concentrations which kept rising during heavy rains, possibly due to the atmospheric deposition of nitrogen- and sulfur-based compounds from both natural and anthropogenic sources. In contrast, lesser turbidity and suspended solids were shown by the water samples during the dry season, nonetheless, in some cases, higher heavy metals' concentration such as zinc, lead, and iron had been detected which might be as a result of longer storage periods and roofing materials and collection systems leaching [9].

2. Microbiological Variations:

The microbial quality characterized by seasonal differences more clearly. In the rainy season, considerable frequencies and concentrations of total coliforms are reported that exceed the limits set by WHO/NSDWQ. This rise in coliforms is attributed to more runoff from the roofs carrying together not only fecal matter from birds and small animals but also environmental contaminants. More pathogens like Salmonella spp. and Shigella spp. have been isolated in water during the peak rain season hence outbreaks of diarrheal diseases are likely to occur. The dry season, on the other hand, is marked by a low overall microbial count of the water sample taken from the tank but the presence of stagnant water in poorly kept tanks can at times cause the rebirth of Pseudomonas aeruginosa and other opportunistic bacteria during this time of the year.

3. Public Health Implications:

The seasonal variability highlights the period of highest vulnerability for water-borne diseases through transmission during the wet season in the communities. Those households that rely totally on rainwater catchment are at the greatest risk of consuming untreated water during this period. The microbial risk is lower in the dry season, but there still is a potential for the chemical contamination of roofing materials and storage systems.

4. Comparative Observations with Standards:

According to the standards indicated by references [15] and [16], at no time throughout the sampled wet or dry seasons did the water samples from Gbarain and Ekpetiama meet the requirements for safe drinking water. Nevertheless, the wet season indicated more critical microbial non-compliance; on the other hand, chemical deviations were clearly seen in the dry season.

5. Conclusion: The findings draw attention to the necessity of seasonal-specific interventions. In the wet season, the use of first-flush diverters, disinfection, and boiling methods are of utmost importance to prevent microbial risks. On the other hand, in the dry season, regular cleaning of storage tanks and monitoring of heavy metal leaching ought to be the main activities to prevent chemical contamination. Taking these seasonal variations into consideration is a prerequisite for making rainwater use in Gbarain and Ekpetiama sustainable unconditionally.

3.4 Public Health Implications

Long-Term Risks Significantly, the conducted research brings forth a keen public health concern in the direction of the harvested rainwater quality issue in Gbarain and Ekpetiama communities. Besides the microbial contaminants being coliforms and even certain bacteria, the heavy metal impurity levels were also higher than allowed which means that untreated rainwater is drawing from the reservoir of risks to human health.

1. Waterborne Diseases:

The presence of fecal indicators (E. coli) and the isolation of pathogens from the group of Salmonella spp. and Shigella spp. suggest that gastrointestinal infections be very likely, which include diarrhea, typhoid, cholera, and dysentery. The mentioned illnesses continue to be the leading factors of morbidity and mortality in rural Nigerian communities [15], [26]. Children below five years, pregnant women, and people with low immunity are especially at risk. The microbial pollution seen in the wet season adds to the waterborne disease transmission risk when reliance on harvested rainwater is highest leading to acute outbreaks.

2. Community Vulnerability:

The households in Gbarain and Ekpetiama are highly vulnerable because they heavily rely on rainwater harvesting as a survival strategy due to the non-availability of centralized potable water supplies. The lack of knowledge in safe collection practices, storage systems that are poorly maintained and hardly any household treatment practices also lead to higher risks. Moreover, the socio-economic context where the communities are dependent on subsistence farming and fishing implies that there are very few medical facilities and preventive health measures are sometimes not easily available [28]. This in turn sets up a cycle whereby poor water quality leads to ill-health, which in turn reduces labor productivity and places even more strain on livelihoods.

3. Long-Term Risks:

Apart from immediate disease outbreaks, long-term exposure to unsafe rainwater is accompanied by the risk of chronic health conditions. The heavy metals accumulations like lead, zinc, and iron which were detected in some of the dry-season samples may eventually lead to neurological impairments, kidney failure, and developmental disorders in kids [9]. In addition, the constant presence of microbial contamination might make the risk of AMR development which is Antimicrobial Resistance, where microbes become resistant to being killed off by disinfectants or antibiotics, thus making treatment strategies more complicated in the future.

4. Broader Public Health Significance:

The unsafety of rainwater that has been collected and used has turned the spotlight on the public health sector regarding the need for urgent collaboration in the form of combined public health interventions. The need for preventive measures such as making the community aware, the use of low-cost disinfection methods (boiling, chlorination, and solar disinfection), and regular maintenance of tanks and rooftop catchments cannot be overemphasized. On the policy front, the inclusion of the monitoring of the quality of rainwater in the national water safety plans would assist in filling the voids present in the environmental health regulation and subsequently, cutting down the case of waterborne diseases.

5. Conclusion:

The enduring dependency of the residents in Gbarain and Ekpetiama on unprocessed collected rainwater in the absence of dependable alternative water sources is a huge public health concern. The solution to this problem involves a mix of practices at household level, community health education and progressive policies that will guarantee the safe and sustainable use of rainwater in these at-risk populations.

4.5 Comparison with Related Studies

The outcomes of studies conducted in Gbarain and Ekpetiama communities are consistent with the prevailing evidence that shows the harvested rainwater is highly susceptible to microbial and chemical contamination, especially in rural and peri-urban areas. The outcome of the studies not only support the public health interventions but also show the same risk pattern and emphasize the necessity of those interventions.

1. Comparisons within Nigeria:

Numerous studies in Nigeria have established that often the microbial contamination is the main reason for the rejection of harvested rainwater. For example, [28] in Ile-Ife detected high coliform counts in rainwater drawn from various roofing materials that were similar to those high microbial loads found in Gbarain and Ekpetiama. Likewise, [26] mentioned the presence of E. coli and other pathogens in water samples taken from Abeokuta and Lagos, matching the detection of fecal contamination in the current study. Furthermore, [29] drew attention to the fact that the inadequate upkeep of rainwater storage systems plays a part in the endurance of microbial contaminants, thereby highlighting the necessity for routine household interventions throughout Nigerian communities.

2. Comparisons with Other Developing Countries:

Similar difficulties exist in other low- and middle-income countries. The research by [27] in South Africa revealed that rainwater collected during the wet season frequently surpassed WHO safety limits for microbial contamination, which was similar to the seasonal pattern noticed in this study. In Ghana, [30] observed that the rainwater harvested from rooftops was highly contaminated with bacteria, which was attributed to fecal matter falling from the environment and the absence of first-flush systems. These similarities strengthen the argument that the contamination of harvested rainwater is not just a Nigerian problem but a general issue in places with rainfall harvesting as the main water source.

3. Comparisons with Global Research:

In the case of developed countries, even though microbial contamination is rare due to the strict building and maintenance regulations, the concern usually is about the chemical contamination. Reviewing the studies on roof runoff in the United States [9] mentioned high quantities of heavy metals such as lead and zinc which were leached from the roofing materials and this phenomenon has also been noticed in the dry-season samples from Gbarain and Ekpetiama. Similar to this situation [31] in New Zealand recorded both microbial contamination and heavy metal presence showing that even in sophisticated systems the rainwater safety cannot be assured without treatment.

4. Synthesis:

In all contexts, local, regional, and global, the situation was that though harvested rainwater was a very important supplementary source, it was problematic due to high contamination risks. The risk characteristics were not the same in all places; for example, in low-resource settings like Nigeria, mainly microbial risks existed owing to the poor sanitation and the absence of household treatment, while in the wealthier locations, material chemical leaching could be a more considerable risk. The current research expanded the existing knowledge base by drawing attention to the simultaneous presence of microbial and chemical hazards in the Niger Delta area, with seasonal fluctuations intensifying the risks.

5. Conclusion:

The above-mentioned findings are placed within the broader context of Nigerian and global research, which indicates that rainwater harvesting is still a very important technique for the supply of water, but safety issues are present everywhere. The destruction of safety barriers calls for different intervention strategies, such as sensitization of the community in Gbarain and Ekpetiama, and advocacy for legislative integration of the issue into national water management frameworks so that the health of the public is not endangered but is protected by the use of rainwater.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion:

The assessment of harvested rainwater in the communities of Gbarain and Ekpetiama shows that although the harvesting of rainwater is still an important and widely accepted water supply strategy, the quality of the collected water very often does not meet the standards set by WHO (2017) and Nigerian Standard for Drinking Water Quality (NSDWQ, 2015) for potable use.

The analyses of physico-chemical parameters revealed that while most of the parameters such as pH, turbidity, and total dissolved solids (TDS) were within the acceptable limits, the seasonal variations and leaching from roofs led to high levels of some heavy metals like zinc, lead, and iron in a few samples. Though the deviations were not consistent throughout, they nevertheless indicated risks of long-term chemical exposure to the households.

Microbiological testing revealed even more serious problems since total coliforms and E. coli were found practically everywhere while instances of pathogenic species such as Salmonella spp. and Shigella spp. were also noted. The detection of fecal indicators in various samples suggests that the rainwater collected from the roofs and stored without treatment is unsafe for human consumption directly, especially in the rainy season when the microbial load is at its highest.

The situation from a public health perspective is that the untreated harvested rainwater dependence of Gbarain and Ekpetiama communities brings along tremendous waterborne diseases, particularly diarrhea, cholera, and typhoid. The most unfortunate groups—children, pregnant women, and those with weak immunity—suffer the most from health burdens being that they have a very limited access to health facilities and preventative measures.

To sum up, the present situation of the collected rainwater in the study area is as follows: it is unfit for human consumption and has to undergo treatment before use. Rainwater harvesting is still a practical alternative source of water for households; however, it is not completely safe and thus should be included in the water supply strategies of the communities undergoing less costly household treatment, better storage, and the monitoring systems supported by policies. Without these measures, reliance on untreated rainwater from harvesting will behave like a treadmill that keeps the populations of the Niger Delta communities in a cycle of diseases, decreased productivity, and prolonged health risks.

4.2 Recommendations - Household-Level Treatment Methods

Concerning the microbial and occasional chemical contamination of harvested rainwater in Gbarain and Ekpetiama communities, household-level treatment is still the most immediate and practical way to protect public health. Point-of-use methods, boiling, chlorination, and filtration, are indeed major interventions that can greatly enhance the safety of rainwater that is consumed by households.

1. Boiling: Boiling is a very easy and common water treatment technique for households. It is also the most effective method for clearing all pathogenic microorganisms which include bacteria (E. coli, Salmonella spp.), viruses, and protozoa [15]. For such types of water, boiling for a minimum of 1-3 minutes guarantees the safety of the microorganisms. However, this process is ineffective in eliminating chemical impurities such as metallic ones or dissolved ones as in the case of salts and so on. In addition, the option of firewood or kerosene for boiling might not be an option for the poor families as they might not be able to afford it, besides, it will worsen the environment and pose health risks due to the indoor air pollution created [32].

2. Chlorination: Using chlorine-based disinfectants like sodium hypochlorite solution or calcium hypochlorite powder, chlorination is still another alternate method that can kill the microorganisms that contaminate the water. It is a low-cost method, quite simple to apply, and offers residual protection that prevents recontamination during storage. However, its effectiveness is dependent on proper dosing, water turbidity, and contact time [33]. Over- or under-dosing may either leave pathogens untreated or cause unpleasant taste and potential health risks from disinfection by-products. For harvested rainwater in Gbarain and Ekpetiama, community education on appropriate chlorine dosing would be necessary for safe adoption.

3. Filtration: Such filtration systems as these at home, ceramic filters, biosand filters, and activated carbon filters provide another layer of protection by physically removing the suspended particles and, in some instances, microorganisms. The bacteria and protozoa filtration is done well by ceramic filters while biosand filters can give a smooth performance if well maintained [34]. The use of activated carbon filters maximizes the reduction of deviations in taste and odor as well as organic compounds though the huge drawback to it is limited microbial removal. The use of filtration technologies can also greatly reduce the number and type of heavy metals depending on the filter type, thus being very useful in places where the roofing materials leach chemicals into the water. Nonetheless, the high initial cost and the need for regular maintenance are likely to be the reasons for not having the technology spread without the help of outsiders.

4. Integrated Approach: No single treatment method at the household level can cope with all the contamination risks in harvested rainwater. Thus, the use of combined methods like filtration followed by chlorination, or boiling for microbial safety along with activated carbon filtration for taste and odor improvement, is recommended. In resource-limited communities, educating people on the proper application of these methods, along with the efforts to lower costs and make them more accessible, would sustain the development of the community.

5. Conclusion: The treatment at the level of households is a must for the rainwater harvested in Gbarain and Ekpetiama to become potable. Despite boiling being the most accessible, chlorination, and filtration provide more advantages if properly used. The foremost of these practices, together with the community sensitization, serves to a large extent to lessening the burden of waterborne diseases and improving public health outcomes in the Niger Delta.

4.3 Policy Support for Safe Rainwater Harvesting

Although interventions at the household level are pivotal in making rainwater harvesting safe, the support from the policy side is a must to make the application of best practices, and to make the resource sustainable, safe, and equitable in distribution. For instance, in Gbarain and Ekpetiama where people depend a lot on rainwater harvesting because the public water infrastructure is inadequate, lack of formal policies and regulations makes the problem of contamination worse and limits the reuse of rainwater in the broader water supply network.

4.3.1 National Water Policies and Gaps: The National Water Policy (2004) in Nigeria highlights access to safe drinking water as a fundamental human right, but it scarcely mentions rainwater harvesting (RWH) as a formal water supply option. Likewise, [16] sets out a framework for potable water safety, but it is silent on the quality assurance of collected rainwater. The absence of water supply policy leaves unregulated and unsupported rainwater dependent communities.

4.3.2 Policy Measures for Safe Rainwater Use: Several policy measures are suggested to fill in the gaps, thus;

1. Inclusion of Rainwater Harvesting in National Water Strategies: The RWH should be accepted as a bona fide and sustainable water supply alternative in the water policies of Nigeria, particularly for rural and peri-urban areas.

2. Development of National Standards and Guidelines: Very precise technical and health-related standards should be set up for RWH system's design, construction, operation, and maintenance-in line with WHO guidelines.

3. Government Subsidies and Incentives for Safe Infrastructure: Low-income households that cannot afford the installation of first-flush diverters, filtration systems, and safe storage tanks could be provided by the government and development partners with subsidies for the installation of these water-saving devices.

4. Capacity Building and Community Training: Community-based training programs to teach households in safe collection, storage, and treatment of rainwater should be supported by policy licensure.

5. Integration into Public Health and Water Safety Plans: The local government's water safety planning should consist of the routine quality monitoring of rainwater, thereby ensuring that the marginalized communities dependent on RWH are not excluded from the public health protection measures.

4.4 Lessons from International Models:

Countries like Australia, India, and Brazil have both in rural and urban areas incorporated rainwater harvesting into their water policies and provided installation grants, public awareness campaigns, and water quality monitoring programs. These models show that Nigeria could be able to improve its water governance through developing its own practices in line with the best ones worldwide.

4.5 Conclusion: In Nigeria, rainwater harvesting cannot be done safely and sustainably without the backing of appropriate policies. In the above mentioned communities, targeted policies that integrate rainwater into the national and local water supply arrangements, offering technical and financial support, and improving the monitoring system would help to cut public health risks by a big margin. The safe RWH approach, if included in the policy, will not only promote environmental health and community resilience but also support Nigeria's efforts of achieving Sustainable Development Goal 6 (clean water and sanitation) in the long run.

4.6 Public Health Education on Water Hygiene

Public health education is one of the interventions that can help to make sure harvested rainwater is safe in Gbarain and Ekpetiama communities. Water hygiene education is essential in not only reducing the incidence of waterborne diseases but also in promoting the sustainable practices within the community that will eventually protect the health of both individuals and the community as a whole.

4.6.1 Importance of Public Health Education:

Public health education acts as a barrier between the community and waterborne diseases by empowering the people with the know-how and the right practices to apply in order to keep the rainwater harvesting, storage, and usage contamination at a minimum level. Water may be safe for drinking if the physical and chemical parameters of water quality are all within the prescribed limits; however, it might be harmful due to microbial contamination arising from poor handling, unhygienic storage, or insufficient treatment. Health education is drawing the line that becomes a low-cost and sustainable strategy for improving water safety by making the public aware of safe practices.

Core Areas of Education:

1. Safe Collection and Storage: Households must be taught about the significance of using clean materials for roofing, regular cleaning of gutters, and the use of covered tanks for storage to keep dust, leaves, and animal droppings out.

2. Household Water Treatment: Easy and available methods like boiling, chlorination, and filtration, are preached and their effectiveness in making pathogens like E. coli and total coliforms inactive is also discussed.

3. Hygienic Water Handling: Practices like the use of clean containers for fetching water, not allowing hands to come into contact with stored water, and practicing separation of contaminated and safe water for cooking and drinking are taught.

4. Linking Hygiene to Disease Prevention: Presenting contaminated water as the source of diseases such as diarrhea, cholera, typhoid fever, and other gastrointestinal infections, will not only make people aware of health risks but also encourage them to change their behavior.

5. Community-Level Interventions: The community workshops, school-based programs, and local health campaigns that ensure safe water hygiene practices through community support are some of the actions that should be encouraged.

4.7 Challenges and Opportunities:

Barriers including low literacy rates, cultural beliefs, and non-availability of health information all the time are the major factors that effective health education is not getting in the practical sense. On the bright side, the utilization of community health workers, traditional leaders, and local media is presenting an opportunity for education that is sensitive to the context and culturally acceptable. The incorporation of water hygiene education into the existing health care system and school curriculum can further guarantee the continuation of these practices.

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