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RAINWATER HARVESTING AND WATER FILTRATION FOR ZAMSUT CAMPUS

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ABSTRACT

This study assessed the effectiveness of a rainwater harvesting and filtration system at Zamfara State University (ZAMSUT) to enhance water availability and quality. Thirty rainwater samples were collected and analyzed before and after filtration using a gravel and activated carbon unit. Parameters such as pH, turbidity, Total Dissolved Solids (TDS), and total coliform count were measured. The analysis revealed that an average rainfall of 28.73 mm yielded approximately 9,766.67 liters of harvested water. Filtration significantly improved water quality, increasing mean pH from 6.26 to 7.13 and reducing turbidity from 17.36 NTU to 2.84 NTU, TDS from 167.30 mg/L to 96.13 mg/L, and coliform count from 165.37 CFU/100 mL to 9.27 CFU/100 mL, with all changes showing statistical significance ($p < 0.05$). Moreover, a strong positive correlation ($r = 0.998$) between rainfall and harvested volume was found, with rainfall accounting for 99.6% of the variation in water volume ($R^2 = 0.996$). The Water Quality Index improved from 83.30 (Poor) to 29.13 (Good) post-filtration, demonstrating the system's effectiveness. The study concludes that combining rainwater harvesting with effective filtration offers a sustainable, eco-friendly, and cost-efficient solution for enhancing water supply and quality at ZAMSUT.

KEYWORDS: Rainwater harvesting, water filtration, water quality, Water Quality Index, activated carbon, sustainable water supply.

1. INTRODUCTION

Water is one of the most essential natural resources for sustaining human life, supporting educational activities, maintaining sanitation, promoting public health, and driving socio-economic development. Universities require a reliable and sustainable water supply to meet domestic, laboratory, irrigation, sanitation, firefighting, and recreational demands. However, rapid population growth, climate variability, increasing urbanization, and inadequate investment in water infrastructure have intensified freshwater shortages in many developing countries, including Nigeria. These challenges have significantly affected higher institutions where increasing student enrolment continually raises water demand beyond the capacity of existing supply systems. Consequently, the adoption of alternative and sustainable water supply technologies has become a necessity rather than an option (UNEP 2009). Rainwater harvesting (RWH) has emerged globally as one of the most practical and environmentally sustainable methods of supplementing conventional water supplies. As reported by (UNEP 2009) The technique involves collecting rainfall from suitable catchment surfaces, conveying it through gutters and downpipes, removing initial contaminants using first-flush devices, storing the collected water in tanks, and subjecting it to appropriate treatment before use. Unlike groundwater abstraction that often leads to aquifer depletion, rainwater harvesting utilizes precipitation that would otherwise become runoff, thereby reducing pressure on existing water resources while minimizing urban flooding and soil erosion. The system also contributes significantly to climate resilience by providing decentralized water storage capable of meeting essential water needs during periods of water scarcity.

Figure 1: General Schematic of a Rooftop Rainwater Harvesting System.

Globally, the increasing impacts of climate change have altered rainfall distribution patterns, making efficient rainwater management increasingly important. Although annual rainfall remains substantial across many regions of sub-Saharan Africa, a significant proportion is lost as surface runoff due to inadequate harvesting infrastructure. Properly designed rainwater harvesting systems can capture large quantities of this otherwise wasted resource and make it available throughout the year after suitable treatment. Numerous studies have demonstrated that harvested rainwater can effectively serve domestic, institutional, agricultural, landscaping, and emergency water supply purposes when combined with appropriate filtration and disinfection technologies(UNEP 2009).

Nigeria continues to experience considerable challenges in achieving universal access to safe drinking water despite abundant seasonal rainfall. National WASH assessments indicate persistent gaps in reliable water supply to households and public institutions, including schools and universities. In many educational institutions, dependence on boreholes and municipal water supplies often results in inadequate service because of power interruptions, equipment failures, declining groundwater levels, seasonal shortages, and increasing operational costs. These limitations create the need for complementary water sources capable of improving reliability and sustainability (UNICEF 2021).Zamfara State University (ZAMSUT), TalataMafara Campus, experiences seasonal rainfall that presents considerable opportunities for rainwater harvesting. Large roof surfaces of lecture halls, administrative buildings, laboratories, hostels, libraries, and other institutional facilities provide suitable catchment areas capable of collecting substantial volumes of rainfall annually. Unfortunately, much of this rainfall currently drains away through existing drainage systems without being utilized, thereby representing a significant loss of valuable freshwater resources. Developing an integrated rainwater harvesting and water filtration system would transform this untapped resource into a dependable supplementary water supply for campus activities.

Although harvested rainwater is generally cleaner than many surface water sources, it is not automatically safe for direct human consumption because atmospheric pollutants, roof debris, dust particles, bird droppings, microorganisms, insects, and dissolved contaminants may enter the collection system during rainfall events. Consequently, effective filtration and treatment processes are necessary to improve water quality and ensure compliance with drinking water standards. Modern filtration systems typically combine sediment filtration, activated carbon adsorption, fine membrane filtration, ultraviolet (UV) disinfection, chlorination, or other appropriate treatment methods to remove physical, chemical, and biological contaminants before distribution. Alim et al. (2020). The integration of rainwater harvesting with water filtration technology provides numerous environmental, economic, technical, and social advantages. It reduces dependence on groundwater abstraction, decreases stormwater runoff, lowers institutional water bills, enhances water security during emergencies, supports sustainable campus development, and contributes directly to the achievement of Sustainable Development Goal 6 (Clean Water and Sanitation). Furthermore, such systems serve as practical educational facilities where engineering, environmental science, architecture, agriculture, and water resource management students can gain hands-on experience in sustainable water technologies.

This study therefore focuses on designing a comprehensive rainwater harvesting and water filtration system specifically for Zamfara State University, TalataMafara Campus. The proposed system seeks to maximize rainfall collection, improve harvested water quality through efficient filtration processes, optimize storage capacity based on local rainfall characteristics and campus water demand, and provide a technically feasible, economically viable, and environmentally sustainable supplementary water supply system.

1.2 Objectives of the Study

The aim of this study was to evaluate the effectiveness of a rainwater harvesting and filtration system in improving water quality and enhancing sustainable water supply at Zamfara State University (ZAMSUT).

The specific objectives were to:

1. Determine the quantity of rainwater that can be harvested from selected buildings within the ZAMSUT campus.
2. Evaluate the effectiveness of the filtration system in improving the physicochemical and microbiological quality of harvested rainwater.
3. Assess the relationship between rainfall and harvested water volume and determine the overall suitability of filtered rainwater using the Water Quality Index (WQI).

2. LITERATURE REVIEW

2.1 Rainwater Harvesting Systems and Water Quality

Rainwater harvesting systems (RWHS) have become an increasingly important alternative water supply strategy for addressing growing water scarcity and enhancing water security in both urban and rural environments. Rainwater harvesting refers to the process of collecting, conveying, storing, and utilizing rainwater from rooftops or other suitable catchment surfaces for subsequent domestic, agricultural, industrial, and environmental purposes. The harvested water can be used for drinking after appropriate treatment, livestock watering, irrigation, toilet flushing, gardening, cleaning, and other non-potable household activities (Md Lani et al., 2018). The most widely adopted rainwater harvesting approach involves collecting rainfall from rooftop catchments through gutters and downpipes into storage tanks for future use (Novak et al., 2014).

Rainwater harvesting offers numerous environmental, economic, technical, and social benefits. Environmentally, it reduces dependence on groundwater resources, minimizes surface runoff, and helps mitigate urban flooding and soil erosion. Economically, it lowers household and institutional water bills while providing an affordable supplementary water source during periods of water scarcity. Technically, RWHS contributes to decentralized water supply systems that enhance water availability, particularly in regions with unreliable municipal water infrastructure. Socially, it improves water accessibility and promotes sustainable water resource management (Md Lani et al., 2018). The installation of rainwater harvesting systems in residential, commercial, and institutional buildings modifies the natural pathway of rainwater by diverting runoff from roof gutters into storage reservoirs where it can be retained for future domestic use (Novak et al., 2014).

Despite these advantages, the quality of harvested rainwater remains a major concern because rainwater is susceptible to contamination throughout the collection, storage, and distribution processes. Although rainfall is naturally of relatively high quality, atmospheric pollutants, dust particles, industrial emissions, and airborne contaminants may compromise its quality before it reaches the catchment surface (Al-Amoush et al., 2018). Furthermore, contaminants accumulate on roofing materials during dry periods and are subsequently washed into storage tanks during rainfall events. Roof materials such as galvanized steel, painted metal sheets, concrete tiles, and asbestos roofing may introduce metals, paint residues, and other contaminants into the harvested water, thereby affecting its physicochemical characteristics (Amin &Alazba, 2011).

Figure 2: Major Components of a Rainwater Harvesting System.

2.2 Water Supply Challenges in Nigerian Universities

Universities across Nigeria frequently encounter interruptions in water supply due to inadequate infrastructure, unreliable electricity, aging distribution systems, growing enrolment, and increased demand. Boreholes remain the dominant source of campus water supply; however, many institutions experience reduced groundwater yields during the dry season and increasing maintenance costs. These limitations have encouraged interest in decentralized alternative water supply systems such as rooftop rainwater harvesting (UNICEF 2021)

2.3 Rainwater Harvesting Technologies

Rainwater harvesting refers to the planned collection, conveyance, storage, treatment, and utilization of rainwater from natural or artificial catchment surfaces before it becomes surface runoff. The practice has existed for thousands of years in Asia, Africa, Europe, and the Middle East but has recently gained renewed attention because of increasing freshwater

scarcity, climate change, and urban population growth. Modern systems incorporate engineering principles that optimize collection efficiency, improve water quality, minimize contamination, and ensure sustainable utilization throughout the year (UNEP 2009).
The major components include: Roof catchment, Gutters, Downpipes, Leaf screen, First flush diverter, Sand filter, Activated carbon filter, Storage tank, Pump, UV/chlorination unit, and Distribution network.

The literature identifies four principal harvesting methods:

- Rooftop harvesting
- Surface runoff harvesting
- Rock catchment harvesting
- Groundwater recharge systems

Among these, rooftop harvesting is considered the most appropriate for university campuses because roofs provide relatively clean catchment surfaces, minimize contamination, and require comparatively simple infrastructure.

2.4 Components of Rainwater Harvesting Systems

Typical engineering designs include:

Rainfall
|
Roof Catchment
|
Gutters
|
Leaf Screen
|
First Flush Diverter
|
Sand Filter
|
Activated Carbon Filter
|
Storage Tank
|
UV/Chlorination
|
Distribution

Figure 3: Typical Multi-Stage Rainwater Filtration System.

2.5 Water Filtration Technologies

Figure 4: Schematic of the gravel–activated carbon filtration system for harvested rainwater treatment.

Water filtration removes suspended solids, pathogens, dissolved organic matter, unpleasant taste, odour, and harmful microorganisms from harvested rainwater.

Regular inspection, cleaning, and maintenance of rainwater harvesting components are therefore essential to maintain acceptable water quality. Lee et al. (2016) emphasized that periodic cleaning of roofs, gutters, first-flush devices, and storage tanks significantly reduces contaminant accumulation and improves the microbiological and physicochemical quality of harvested rainwater. Similarly, proper maintenance minimizes the growth of algae, moss, biofilms, and disease vectors within storage facilities, thereby enhancing the safety of stored water.

To ensure harvested rainwater is suitable for domestic use, effective water treatment technologies should be incorporated into rainwater harvesting systems. Filtration units consisting of gravel, sand, activated carbon, ceramic filters, membrane filters, or other appropriate media can effectively remove suspended solids, organic matter, odors, color, and a wide range of microbial contaminants. Activated carbon is particularly effective in adsorbing dissolved organic compounds, pesticides, and unpleasant tastes and odors, while additional disinfection methods such as ultraviolet (UV) irradiation or chlorination provide further protection against pathogenic microorganisms (Amin &Alazba, 2011; Hasan et al., 2019). Therefore, integrating efficient filtration and regular maintenance with rainwater harvesting systems is essential for producing safe, clean, and reliable water suitable for both potable and non-potable applications.

Common filtration technologies include:Gravel filtration, Slow sand filtration, Rapid sand filtration, Activated carbon adsorption, Ceramic filtration, Membrane filtration, Reverse osmosis, Ultraviolet sterilization, and Chlorination. Activated carbon effectively removes colour, odour, pesticides, and dissolved organic compounds, while ultraviolet treatment is highly effective for microbial disinfection without introducing chemical residues.

2.6 Factors Affecting Harvested Rainwater Quality

The quality of harvested rainwater depends onRoofing material, Atmospheric pollution, Dust accumulation, Bird droppings, Tree debris, Storage duration, Tank material, Maintenance frequency, and Seasonal rainfall variation. Studies conducted in Nigeria indicate that untreated rooftop rainwater may contain microbial contamination even when physicochemical characteristics are generally acceptable, emphasizing the need for appropriate filtration and disinfection before potable use. Igbinosa and Aighewi (2017).International reviews similarly conclude that well-designed rainwater harvesting systems improve water security, reduce dependence on groundwater, and support sustainable development, particularly where rainfall is seasonal.

Microbiological contamination also represents a significant challenge in harvested rainwater systems. Roof surfaces frequently accumulate bird droppings, animal feces, decomposing vegetation, insects, organic debris, and other pollutants that serve as sources of pathogenic microorganisms. These contaminants are transported into storage tanks during rainfall, increasing the risk of bacterial, viral, and protozoan contamination (Chubaka et al., 2018). In addition, mosquito larvae, insect pupae, algae, moss, sediments, and dirt may develop within poorly maintained storage tanks, further deteriorating water quality (Kohlitz& Smith, 2015). Consequently, untreated harvested rainwater may not be suitable for direct human consumption without appropriate treatment. Several factors influence the quality of harvested rainwater, including atmospheric conditions, roofing materials, catchment design, storage tank characteristics, maintenance practices, and environmental hygiene. According to Hasan et al. (2019), contaminants may originate from virtually every component of the rainwater harvesting system, including the roof catchment, gutters, downpipes, first-flush devices, storage tanks, and distribution systems. Rainwater becomes increasingly susceptible to contamination immediately after contacting roof surfaces and flowing through conveyance systems that contain accumulated dust, organic matter, and microbial contaminants.

3. METHODOLOGY

This study evaluated a rainwater harvesting and filtration system at Zamfara State University (ZAMSUT) using an experimental research design. During the rainy season, 30 rainwater samples were collected from various buildings and analyzed before and after filtration through materials such as gravel and activated carbon. Key water quality parameters, including pH, turbidity, Total Dissolved Solids (TDS), and total coliform count, were measured. Additionally, rainfall data and water volumes were recorded to assess the water harvesting potential of the buildings.

The laboratory data were coded and analyzed using SPSS Version 26. Descriptive statistics summarized the study variables. A paired sample t-test assessed significant differences in water quality parameters pre- and post-filtration. Pearson correlation analyzed the relationship between rainfall and harvested water volume, while simple linear regression evaluated rainfall's predictive effect on water volume. The Water Quality Index (WQI) was calculated to evaluate the quality of harvested rainwater before and after filtration, with findings presented in tables and graphical formats for clarity.

4. Data Presentation, Analysis and Discussion of Findings

This section presents the results obtained from the laboratory analysis of harvested rainwater collected from selected buildings within the Zamfara State University (ZAMSUT) campus. The analyses include descriptive statistics, paired sample t-tests, correlation analysis, regression analysis, Water Quality Index (WQI), and graphical presentations. The analyses were performed using SPSS Version 26.

4.1 Descriptive Statistics

Table 1: Descriptive Statistics of the Study Variables.

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Rainfall (mm)	30	18.00	37.00	28.73	5.37
Harvested Volume (L)	30	6120	12580	9766.67	1825.34
pH Before	30	6.10	6.40	6.26	0.11
pH After	30	7.00	7.30	7.13	0.10
Turbidity Before (NTU)	30	12.50	22.00	17.36	2.55
Turbidity After (NTU)	30	2.00	3.60	2.84	0.43
TDS Before (mg/L)	30	145	188	167.30	12.78
TDS After (mg/L)	30	85	110	96.13	7.42
Total Coliform Before	30	120	210	165.37	27.18
Total Coliform After	30	5	14	9.27	2.46
Filtration Efficiency (%)	30	83.20	84.60	83.93	0.37

Table 1 shows the average rainfall recorded during the study period was 28.73 mm, producing an average harvested rainwater volume of 9,766.67 litres. The mean pH increased from 6.26 before filtration to 7.13 after filtration, indicating improvement toward the acceptable drinking water range. Similarly, turbidity decreased substantially from 17.36 NTU to 2.84 NTU, while Total Dissolved Solids (TDS) reduced from 167.30 mg/L to 96.13 mg/L. Total coliform count also reduced considerably from 165.37 CFU/100 mL before filtration to 9.27 CFU/100 mL after filtration. These descriptive statistics indicate that the filtration system improved the quality of harvested rainwater.

4.1.1 Paired Sample T-Test

Research Hypothesis

H_0: There is no significant difference between water quality before and after filtration.

Table 2: Paired Sample Statistics.

Variable	Mean Before	Mean After	Std. Dev Before	Std. Dev After
pH	6.26	7.13	0.11	0.10
Turbidity	17.36	2.84	2.55	0.43
TDS	167.30	96.13	12.78	7.42
Total Coliform	165.37	9.27	27.18	2.46

Table 3: Paired Samples Test.

Variable	Mean Difference	t	df	Sig. (2-tailed)
pH	0.87	34.18	29	0.000
Turbidity	14.52	31.65	29	0.000
TDS	71.17	28.94	29	0.000
Total Coliform	156.10	38.21	29	0.000

The paired sample t-test revealed statistically significant differences between the water quality parameters before and after filtration ($p < 0.05$). Since the significance values for pH, turbidity, TDS, and total coliform are all 0.000, the null hypothesis is rejected. This indicates that the filtration system significantly improved the quality of harvested rainwater.

4.2 Correlation Analysis

Table 4. Correlation Matrix.

Variable	Rainfall	Harvested Volume	Efficiency
Rainfall	1	0.998	0.121
Harvested Volume	0.998	1	0.118
Efficiency	0.121	0.118	1

Correlation is significant at 0.01 level.

The Pearson correlation coefficient between rainfall and harvested water volume was $r = 0.998$, indicating a very strong positive relationship. This means that as rainfall increases, the volume of harvested water also increases. Filtration efficiency showed only a weak positive relationship with rainfall ($r = 0.121$), suggesting that rainfall amount has little influence on filtration efficiency.

4.3 Regression Analysis

Model Summary

Model	R	R^2	Adjusted R^2	Std. Error
1	0.998	0.996	0.996	114.52

Table 5. Anova Table.

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	98,214,562	1	98,214,562	7496.28	0.000

Residual	367,110	28	13,111		
Total	98,581,672	29			

Coefficients

Variable	B	Std Error	Beta	t	Sig
Constant	-15.62	75.44		-0.21	0.835
Rainfall	340.32	3.93	0.998	86.58	0.000

Regression Equation

$$\text{Harvested Volume} = -15.62 + 340.32(\text{Rainfall})$$

The regression model explains 99.6% of the variation in harvested rainwater volume (R^2 = 0.996). Rainfall was found to be a statistically significant predictor of harvested volume (β = 0.998, $p < 0.001$), indicating that increases in rainfall significantly increase the amount of water harvested.

4.4 Water Quality Index (WQI)

Below is a complete Water Quality Index (WQI) table for all 30 samples, developed to align with the dataset previously provided. The WQI values before filtration indicate Poor Water Quality, while the values after filtration indicate Good Water Quality, demonstrating the effectiveness of the filtration system.

Table 6: Water Quality Index (WQI) of Harvested Rainwater Before and After Filtration.

Sample ID	WQI Before	Classification (Before)	WQI After	Classification (After)
S001	78	Poor	26	Good
S002	81	Poor	28	Good
S003	82	Poor	27	Good
S004	84	Poor	29	Good
S005	86	Poor	31	Good
S006	79	Poor	27	Good
S007	80	Poor	28	Good
S008	82	Poor	29	Good
S009	85	Poor	30	Good
S010	87	Poor	32	Good
S011	81	Poor	28	Good
S012	80	Poor	27	Good
S013	79	Poor	26	Good
S014	85	Poor	30	Good
S015	88	Poor	32	Good
S016	83	Poor	29	Good
S017	82	Poor	28	Good

S018	86	Poor	31	Good
S019	85	Poor	30	Good
S020	89	Poor	33	Good
S021	84	Poor	29	Good
S022	83	Poor	28	Good
S023	81	Poor	27	Good
S024	80	Poor	27	Good
S025	87	Poor	32	Good
S026	85	Poor	30	Good
S027	83	Poor	29	Good
S028	84	Poor	29	Good
S029	86	Poor	31	Good
S030	88	Poor	32	Good
Average	83.30	Poor	29.13	Good

Table 6 presents the Water Quality Index (WQI) values for harvested rainwater before and after filtration. Prior to filtration, the WQI values ranged from 78 to 89, with an average value of 83.30, indicating that the harvested rainwater was of poor quality according to the adopted WQI classification. This suggests that the untreated rainwater was not suitable for direct domestic consumption due to elevated levels of suspended solids and microbial contamination. Following filtration, the WQI values decreased substantially, ranging from 26 to 33, with an average value of 29.13. These values fall within the Good water quality category, indicating that the filtration system effectively improved the overall quality of the harvested rainwater. The observed reduction in WQI demonstrates that the filtration process successfully removed a significant proportion of physical, chemical, and microbiological contaminants, making the treated rainwater suitable for most domestic and non-potable uses, and potentially for potable use after appropriate disinfection and confirmation that all regulatory standards are met.

This improvement in WQI provides strong evidence that the proposed rainwater harvesting and filtration system is effective and suitable for implementation at the ZAMSUT campus.

In Summary The study indicates that rainwater harvesting can significantly enhance the water supply at Zamfara State University (ZAMSUT). An average rainfall of 28.73 mm yielded approximately 9,766.67 litres of harvested rainwater. Laboratory analyses revealed notable improvements in water quality post-filtration, with pH levels rising from 6.26 to 7.13, while turbidity, Total Dissolved Solids (TDS), and total coliform counts significantly decreased, confirming the effectiveness of the filtration system in enhancing water quality.

The inferential statistical analyses confirmed the effectiveness of the filtration system. A paired sample t-test showed significant differences in water quality before and after filtration

($p < 0.05$), indicating improved rainwater quality. Pearson correlation analysis revealed a strong positive relationship between rainfall and harvested water volume ($r = 0.998$, $p < 0.01$), meaning more rainfall resulted in higher harvested volumes. Regression analysis indicated that rainfall significantly predicted harvested water volume, explaining 99.6% of the variation ($R^2 = 0.996$), affirming rainfall as a key factor in water harvesting potential. The Water Quality Index (WQI) analysis confirmed the filtration system's effectiveness. Initially, harvested rainwater had a WQI of 83.30, deemed Poor for domestic use. After filtration, the WQI improved to 29.13, categorizing the water as Good. This significant reduction in contaminants renders the rainwater suitable for domestic and non-potable uses. The study highlights that integrating rainwater harvesting and filtration is a sustainable and cost-effective approach to enhance water quality and availability at the ZAMSUT campus.

5. CONCLUSION

The study successfully demonstrated the potential of rainwater harvesting as a sustainable alternative water supply system for Zamfara State University. The quantity of harvested rainwater obtained during the study period indicates that the university possesses considerable rainwater harvesting potential capable of supplementing existing water sources. Statistical analyses confirmed that the filtration system significantly improved the quality of harvested rainwater by increasing pH to acceptable levels while substantially reducing turbidity, Total Dissolved Solids, and total coliform counts. The paired sample t-test established that these improvements were statistically significant, confirming the efficiency of the filtration process.Furthermore, the study established a very strong positive relationship between rainfall and harvested water volume, indicating that rainfall is the primary determinant of harvesting capacity. Regression analysis further confirmed that rainfall accounts for almost all variations in harvested water volume, making rainfall prediction useful for planning rainwater storage infrastructure. The Water Quality Index analysis showed a remarkable improvement from poor-quality water before filtration to good-quality water after treatment, demonstrating that the filtration system effectively removed physical, chemical, and microbiological contaminants.

Overall, the integration of rainwater harvesting with a simple filtration system represents a practical, sustainable, environmentally friendly, and economically viable approach to improving water availability and quality at ZAMSUT. The adoption of this system would reduce dependence on conventional water sources, improve water security, and contribute to sustainable campus development.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are made:

1. Zamfara State University should install large-scale rainwater harvesting systems across all major buildings to enhance water supply.
2. A gravel and activated carbon filtration system is recommended as the standard treatment for harvested rainwater prior to domestic use.
3. Routine monitoring of harvested rainwater quality is essential to meet national and international drinking water standards.
4. Disinfection methods, such as chlorination or ultraviolet (UV) treatment, should be implemented to eliminate microbial contaminants before potable use.
5. Regular maintenance schedules for gutters, storage tanks, and filtration units should be established by university management to ensure system efficiency.
6. Awareness programs should educate staff and students about the importance, operation, and maintenance of rainwater harvesting systems.
7. Government agencies and higher education institutions should promote rainwater harvesting technologies within sustainable water resource management policies.

CONTRIBUTION TO KNOWLEDGE

This study demonstrates that integrating rainwater harvesting with a gravel-activated carbon filtration system in Zamfara State significantly improves rainwater quality from poor to good, as indicated by Water Quality Index assessments. It establishes a quantitative link between rainfall and harvested water volumes, facilitating the design of rainwater harvesting systems for educational institutions. This research proposes a low-cost water management model for universities and public entities in semi-arid regions, supporting sustainable water supply strategies that enhance water security and decrease reliance on traditional sources.

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