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Assessing the Impact of Sustainable Roof Designs on Rain Water Harvesting and Resource Conservation in Yunusari, Yobe State

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Abstract: ***This study investigates the effect of roof design on rainwater harvesting in rural Toshia, Yunusari Local Government, Yobe State. Using cluster sampling, 40 households were randomly selected from four streets (A-D). Field observations, questionnaires, and rainfall data analysis revealed that sustainable roof designs significantly impact rainwater harvesting potential. The study found that a household with a 72 square meter roof area (House 9, Street A) can harvest up to 19,440 liters of rainwater. The research highlights the importance of rainwater harvesting and conservation in areas with inadequate water infrastructure, contributing to the development of sustainable water management strategies in rural communities.***

Keywords: rainwater harvesting, sustainable water management,

1.0 Introduction

Water scarcity is a significant issue in Yunusari, Yobe State, with a high proportion of households experiencing acute water shortages (Baba-Adamu & Jajere, 2020). This is exacerbated by the use of unimproved water sources and the impact of geologic factors (Mohammed & Ibrahim, 2020). The COVID-19 pandemic has further highlighted the vulnerability of households to water scarcity, with geographic variables playing a significant role (*Pulitzer Center*, 2020). The scarcity has also led to conflicts between farmers and pastoralists, particularly in the context of competition for water resources (Audu, 2013). These findings underscore the urgent need for increased investment in the rural water supply sector and the integration of geologic factors into water policy formulation to address water scarcity in Yunusari, Yobe State.

Ali (2023) opined that due to problems of both ground and surface waters, and the overall increased demand for water resources due to population growth in Toshia, Yunusari Local Government Area of Yobe State, the community is overreaching the limits of their traditional water resources. Therefore, they have to turn to alternative or supplementary water resource. Thus, prompting intellectual discuss on how to tame the problem of scarcity of water in the area. The sixth goal of the Sustainable Development Goals (SDGs) is to ensure clean water and sanitation, highlighting the crucial need for sustainable water supplies in both urban and rural areas across Africa (United Nations, 2020)

2.0 Technical Description

A rainwater harvesting system is designed to collect, convey, and store rainwater for various uses, such as irrigation, domestic supply, and groundwater recharge. According to Khoury-Nolde (2011), such a system typically consists of three fundamental components namely collection area, conveyance system and the storage facilities.

Rainwater collection typically begins with the collection area, usually a building's roof. Effective roof area and construction materials, such as metal, clay tiles, or concrete,

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significantly impact the volume and quality of collected water. Non-toxic roof materials ensure the safety of the water for use (Nakin et al., 2022). The conveyance system, comprising gutters, pipes, or channels, transports water from the rain which runs downward from the rooftop to storage containers and preferably made of chemically inert materials like wood, plastic, aluminium, or fiberglass to prevent contamination (Nakin et al., 2022; Khoury-Nolde, 2011). Finally, storage facilities, including tanks or cisterns made from materials such as reinforced concrete, fiberglass, or stainless steel (Hlushchenko & Tkachenko, 2023), are used to store rainwater safely, either integrated into the building or positioned separately.

These components work together to ensure efficient rainwater harvesting and maintain water quality. Figure 1 illustrates a schematic of a rooftop catchment system in the Dominican Republic.

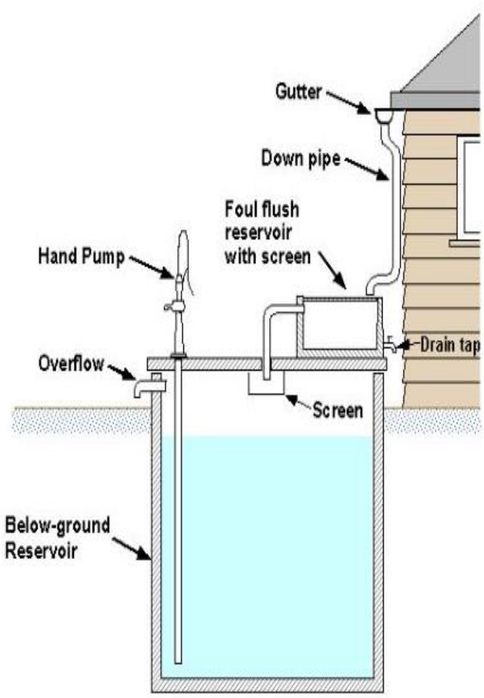

Figure 1: Diagrammatic representation of a harvesting system for rooftop rain-water Source: Norma Khoury-Nolde (2011)

2.1 Volume of Water Collection from Rooftop

Al-houri et al. (2014) and Nzelibe et al. (2022) both highlight the significant potential for rooftop rainwater harvesting. Then again, rainfall patterns in Nigeria show that annual variability of rainfall brings about differences in households' access to water (Ishaku & Majid, 2010). Faza & Suwartha (2021) further emphasize the impact of roof surface area on the amount and quality of rainwater runoff, with larger areas yielding higher volumes. These studies highlighted the potential of rooftop rainwater gathering as a maintainable and environmentally friendly water source.

While there is a 95% chance that the estimated amount can be expected, there is no guarantee that it will be achieved (National Poly, 2018). Nevertheless, the generally accepted basis is the mean/average ($\bar{x}$) rainfall per annum (RPA) – used to determine the size or capacity of the storage facilities.

The calculation for this can be done using the formula:

$$\text{Water Vol. (Ltrs)} = \text{Mean RPA (mm)} \times \text{Area (m}^2\text{)} \times \text{runoff factor}$$

Therefore: $450mm \times 120 \times 0.9 = 48{,}600\ litres$ of rainwater can be collected annually from this roof given a runoff factor of 0.9.

Wahyuningsih et al. (2020) further emphasized that material used for roofing and the slope significantly influence rainwater quality, with higher rainfall intensity and extended dry periods contributing to increased contamination levels. Villar-Navascués et al. (2020) explored the feasibility of rainwater harvesting in low-density urban settings, noting that the type of roof plays a significant role in determining the effectiveness of water collection. Hasse (1989) suggests that a single-pitch roof is particularly suitable for rainwater harvesting because it allows the entire roof surface to channel water into just one gutter, with one or two downpipes depending on the size of the roof. In contrast, a hip roof is less effective for this purpose, as it requires gutters around the entire perimeter of the building. While flat roofs are useable for rainwater collection if they have a raised edge to retain water until it drains through a gutter or downpipe, they are generally less efficient due to longer runoff times and higher evaporation rates (Rocha et al., 2023). One way to improve the catchment is to provide the slab with a sloping cement screed.

Example: a house with a roof measuring 9.00 meters by 6.50 meters, which is being equipped with rainwater collection and storage systems. With an average rainfall per annum of 450 mm, the bulk of rainwater that could be harvested can be estimated using the following formula: Vol. of Water (litres) = Average annual rainfall (mm) x roof area (m^2) x runoff factor. Thus, $450mm \times 9.00 \times 6.50 \times 0.9 = 23{,}895\ ltrs.$ This calculation indicates that approximately 23,895 liters of rainwater can be collected annually from this roof, assuming a runoff coefficient of 0.9.

3.0 Methodology

3.1 Study Area and Population

Toshia is located in Yunusari Local Government Area, Yobe State, Nigeria, with geographical coordinates of 13°06′15″N latitude and 12°04′20″E longitude. It shares a border to the north with Niger Republic and has an area of 3,790 km², with a projected population of 271,303 persons. The main monthly temperature in the study area varies between 26.2°C in February and 35.3°C in May. Usually, rainy season starts between April and July, characterised by the incidence of high winds, with heavy storms prevailing in July or early August. The study area is located in a semiarid zone/Sahel savannah; it experiences a total mean annual rainfall of 270 mm. The intensity of rainfall is low, and the subsequent rainwater harvesting by the community thus justifies the choice of Toshia community as a case study for this research.

3.2 Method of Data Collection

Cluster sampling was adopted, where four streets named A to D were sampled for this study in Toshia, Yunusari Local Government Area, Yobe State. A total of forty (40) households were randomly sampled, and responses were collected on water collection and storage practices, rainwater harvesting, and one-year rainfall data.

The methods of data collection adopted in this research included field observation of roof catchment areas of houses and a pre-designed questionnaire in Toshia, Yunusari Local Government Area, to determine the extent of rainwater harvesting and conservation. Data analysis was conducted using descriptive statistics. Common methods for sample size estimation include Krejcie and Morgan's table and Cohen's Statistical Power Analysis (Penyelidikan, 2006). The sample size for this research was determined using Krejcie and Morgan's table.

A total of 40 out of 45 households from the selected streets were randomly sampled and physically measured. The sampling was conducted in residential areas A, B, C, and D of Toshia town, specifically: Bakin Kasuwa (A), Layin Makaranta (B), Guro Bulama (C), and Fulari (D).

4.0 Findings

Out of the 40 houses studied, 26 were having flat roofs, 12 were having gable roof and 2 were having pitch roof. As flat roof being the dominant roof style in the study area, it has an increased surface area which offers a larger surface area, consequently it allows for greater rainwater collection potential. Table 1 highlights the comparative review of rain water catchment in relation to the roof area.

Table 1. Comparative review of rain water catchment in relation to the roof area

S/N	Street A (m^2)	Rain catchment capacity (liters)	Street B (m^2)	Rain catchment capacity (liters)	Street C (m^2)	Rain catchment capacity (liters)	Street D (m^2)	Rain catchment capacity (liters)
1	15.5	4185	32.8	8856	22.4	6048	19.2	5184
2	18.6	5022	24	6480	30.4	8208	26.3	7101
3	21.7	5859	27	7290	31.5	8505	33.6	9072
4	51.2	13824	56.5	15255	27.3	7371	54	14580
5	24.8	6696	22.5	6075	31.5	8505	21	5670
6	51	13770	26.6	7182	27.2	7344	30	8100
7	24.8	6696	24.8	6696	33.15	8951	22	5940
8	28.7	7749	43.5	11745	22.4	6048	22	5940
9	72	19440	25.2	6804	25.6	6912	24	6480
10	33	8910	19.8	5346	30.8	8316	27.2	7344

Based on this study, house number 9 in street A was rated the highest with 19,440 liters of rain water collection potential per annum while house number 1 in street A was rated lowest with 4,185 liters of rain water collection potential per annum.

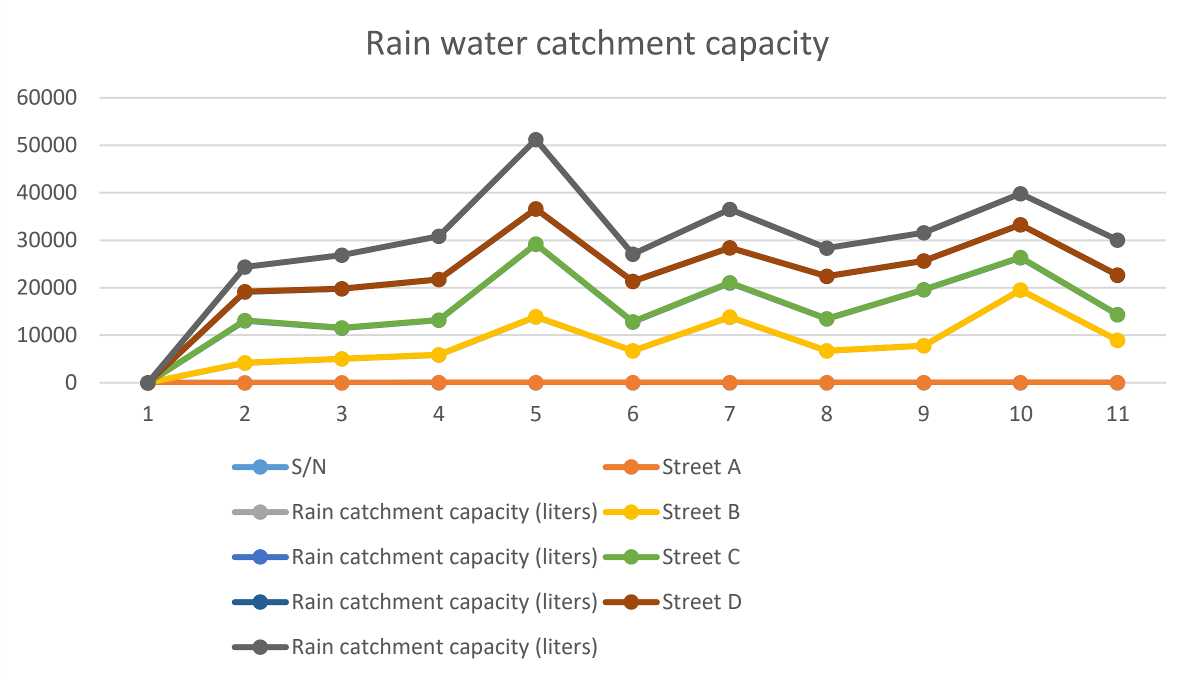

Figure 2. Rainwater catchment capacity

In order to account for the occupants' feedback on rain water collection and usage, 40 questionnaires were administered to the occupants of the studied houses. the occupants were of different backgrounds; 14 were farmers, 2 were civil servants, 11 were business men and 13 were house wives.

Table 2. Occupants 'rain water collection and conservation

	Occupants with rain water collection systems	Occupants without rain water collection systems	Occupants who conserve rain water for domestic uses	Occupants who reject rain water for domestic uses
	25	15	34	06
Percentage (%)	62.5	37.5	85	15

Table 2 shows that 62.5% of the occupants have rain water collection systems in their houses while 37.5% have not. Moreover, 85% of the occupants use rainwater for domestic purposes while 15% of the occupants rejected it.

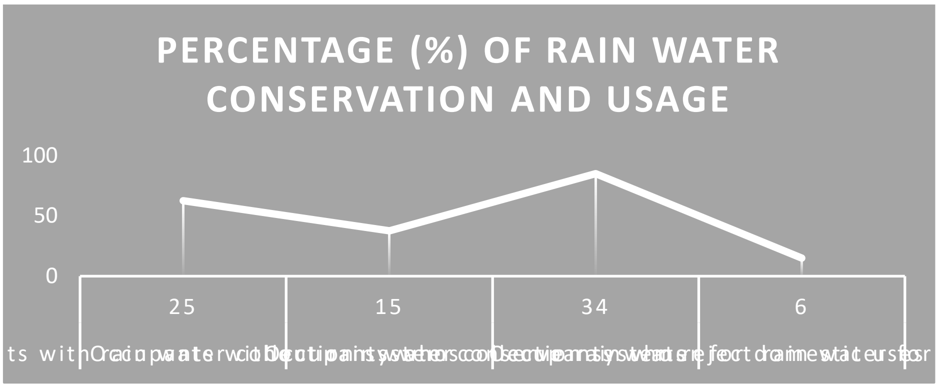

Figure 3. Percentage (%) of Rainwater Conservation and Usage

5.0 Conclusion

1. Out of the 40 houses studied, 26 were having flat roofs, 12 were having gable roof and 2 were having pitch roof. As flat roof being the dominant roof style in the study area, it has an increased surface area which offers a larger surface area, consequently it allows for greater rainwater collection potential.

2. Based on this study, house number 9 in street A was rated the highest with 19,440 liters of rain water collection potential per annum while house number 1 in street A was rated lowest with 4,185 liters of rain water collection potential per annum.

3. It is established by this study that 62.5% of the occupants have rain water collection systems in their houses while 37.5% have not. Moreover, 85% of the occupants use rainwater for domestic purposes while 15% of the occupants rejected it.

4. Slope and shape: Roofs with steeper slopes can channel rainwater more efficiently into gutters and downspouts, minimizing water loss. A well-designed roof shape can enhance rainwater runoff, directing it towards the collection system.

5. Materials: Different roofing materials can affect rainwater quality and collection efficiency. Non-toxic and non-porous materials are preferable to avoid contamination and water loss. Smooth surfaces with minimal texture are also advantageous as they minimize water retention and facilitate runoff.

6. Gutters and downspouts: Properly designed and installed gutters and downspouts can efficiently channel rainwater from the roof to the collection system. The size and placement of these components should be optimized to prevent clogging and maximize water flow.

7. Roof maintenance: Regular roof maintenance is crucial for rainwater collection systems. Keeping the roof clean and free from debris, leaves, and algae helps maintain water quality and ensures maximum water collection.

8. Rainwater filtration: Roof design can impact the need for additional filtration systems. For instance, roofs with a high potential for contamination, such as those with bird droppings or industrial pollutants, may require extra filtration to ensure the collected rainwater is safe for use.

9. Overflows and diversion: Roof design should consider mechanisms for managing excess rainfall through overflow or diversion systems. This prevents flooding, damage to the collection system, and loss of rainwater during heavy downpours.

6.0 Recommendations

1. Materials: Different roofing materials can affect rainwater quality and collection efficiency. Non-toxic and non-porous materials are preferable to avoid contamination and water loss. Smooth surfaces with minimal texture are also advantageous as they minimize water retention and facilitate runoff.
2. Gutters and downspouts: Properly designed gutters and downspouts can efficiently channel rainwater from the roof to the collection system. The size and placement of these components should be optimized to prevent clogging and maximize water flow.

3. Roof maintenance: Regular roof maintenance is crucial for rainwater collection systems. Keeping the roof clean and free from debris, leaves, and algae helps maintain water quality and ensures maximum water collection.
4. Rainwater filtration: Roof design can impact the need for additional filtration systems. For instance, roofs with a high potential for contamination, such as those with bird droppings or industrial pollutants, may require extra filtration to ensure the collected rainwater is safe for use.
5. Rural dwellers should be educated on the benefits and techniques of rainwater harvesting and conservation. This can be done through interactive sessions to educate them about techniques of hygiene water. Sharing success stories and providing technical support can encourage widespread adoption.

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