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An Assessment of the Potential of Rainwater Harvesting as a Sustainable Water Supply Method in Ekpoma, Nigeria

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Abstract

*Many rural areas lack access to reliable sources of clean water. This is the case in Ekpoma where available surface water is a distant river and water abstraction from a borehole is not viable because of the low water table. Rainwater harvesting can provide a sustainable and decentralized solution to this problem. By assessing the potential for rainwater harvesting, we can better understand how to leverage this natural resource to meet their water needs. This study examined Rainwater Harvesting as a Sustainable water supply method in Ekpoma with distant rivers and a low water table. Rainwater Samples harvested from different roof types were analysed for physical, biological, and chemical characteristics. The results were compared with the World Health Organisation (WHO) and the Federal Ministry of Environment (FMenv) values. Available water quantity was estimated from the roof area using rainfall data from the Nigerian Metrological Agency (NiMeT). Water demand for an average household of seven (7) over four (4) months of no rainfall was estimated. Ground reservoir storage capacity that will be sufficient was estimated to be 80.64*m^3*. The results showed that the samples for all roof types- asbestos, normal zinc, and aluminum had higher iron, lead, and turbidity than the acceptable values of FMenv. An aluminum roofing sheet, having a Water Quality Index of 7.832, was recommended alongside some suitable treatments such as reversed osmosis and chlorination, as the cost of treatment is low. The significance of assessing rainwater harvesting lies in its potential to address water scarcity, mitigate environmental impact, support socioeconomic development, and empower the community.*

1.0.Introduction

Life requires a sufficient supply of clean drinking water. Millions of people worldwide still lack access to this fundamental need. This is the case in Ekpoma where available surface water is a distant river and water abstraction from a borehole is not viable because of the low water table. Rainwater harvesting can provide a sustainable and decentralized solution to this problem. In homes, schools, and medical institutions, access to clean, safe drinking water and basic hygiene practices is restricted due to water scarcity. Water scarcity has led to sewage system failures and an increase in the risk of getting diseases such as cholera. The technique of gathering and storing rainwater for future use is known as rainwater harvesting. It involves capturing rain runoff from rooftops, paved surfaces, and other impermeable surfaces before it reaches the ground and storing it in tanks or underground reservoirs. This method helps increase the availability of water in areas that receive regular rainfall like Ekpoma, but do not have access to freshwater resources from surface and underground sources. Similar research was carried out by[1] who designed a rainwater harvesting (RWH) system incorporated with a treatment facility for a household of six inhabitants at Borokiri town in Port Harcourt city.

This study aims to assess the potential of rainwater harvesting as a sustainable source of water supply in Ekpoma, Nigeria. The objectives of this study are to: i. Study the layout of the selected area & collection of rainfall data .ii assess the rainfall pattern and estimate the potential volume of rainwater that can be harvested iii assess the quality of harvested rainwater from different roof covers iv determine the preferred roof cover for rainwater harvesting based on water quality index analysis v determines adequate storage capacity for a household, and vi recommend water treatment methods that would be needed based on water quality parameters Assessing rainwater harvesting in rural communities is significant for several reasons. It addresses the critical issue of water scarcity in ths community. By capturing and storing rainwater, rural communities can reduce their dependence on groundwater sources, which are often overexploited. This, in turn, helps to preserve local aquifers and ecosystems that depend on groundwater. Additionally, rainwater harvesting will reduce the risk of erosion and flooding in rural areas by capturing and utilizing rainwater that would otherwise run off the land. The assessment of rainwater harvesting in this community will contribute to improved livelihoods and economic development.

As climate change leads to more erratic rainfall patterns, rainwater harvesting provides a buffer against water scarcity and droughts, making rural communities more resilient. Access to clean water improves hygiene practices and reduces waterborne diseases, leading to better health outcomes in rural areas. Rainwater harvesting can lead to cost savings for households and communities by reducing the need to purchase water or invest in expensive infrastructure. Access to reliable water sources is essential for agriculture, livestock, and household needs. By harnessing rainwater, a community can enhance its resilience to droughts and other water-related challenges, thereby supporting food security and economic stability. By involving local community members in the assessment process, they will gain valuable knowledge and skills related to water management, infrastructure development, and environmental stewardship. This, in turn, will foster a sense of ownership and sustainability of the rainwater harvesting systems implemented.

1.1 Review of Related Previous Studies

[2] evaluated the suitability of different rainwater harvesting facilities for domestic use in Esanland of Edo state. The study found that the most suitable facility was the use of a Ferro-cement tank, followed by a plastic tank and a concrete tank. The study also highlighted the importance of proper maintenance of the rainwater harvesting system to ensure the quality of the harvested water.

[3] assessed the potential for rainwater harvesting in Ekpoma,. The study used rainfall data collected over ten years to estimate the amount of rainwater that could be harvested in the town. The study found that the potential for rainwaterharvesting was high, with an estimated annual rainfall of 1,556 mm and a potential harvestable volume of 19.4 million liters.

[4] also evaluated the quality of rainwater harvested in the town. The study collected rainwater samples from different households and analyzed them for physicochemical and

microbiological parameters. They found that the harvested rainwater was generally of good quality but recommended proper storage and treatment practices to ensure its safety for drinking purposes.

1.2 Research Gap Identified from Related Previous Studies Reviewed

While some studies have examined the initial implementation of rainwater harvesting systems, there exists a gap in understanding the long-term sustainability of these practices Some studies have focused on the technical aspects of rainwater harvesting systems in Ekpoma, such as design, installation, and water quality. However, there exists a gap in understanding the broader impact of these systems on the environment, water availability, and community livelihoods. Given the potential impacts of climate change on water resources, there exists a research gap in understanding how rainwater harvesting can contribute to climate resilience in Ekpoma. There is a need to investigate the role of these systems in mitigating the effects of changing rainfall patterns and increasing water scarcity.

2.0) Materials and Methods

2.1 Study Area

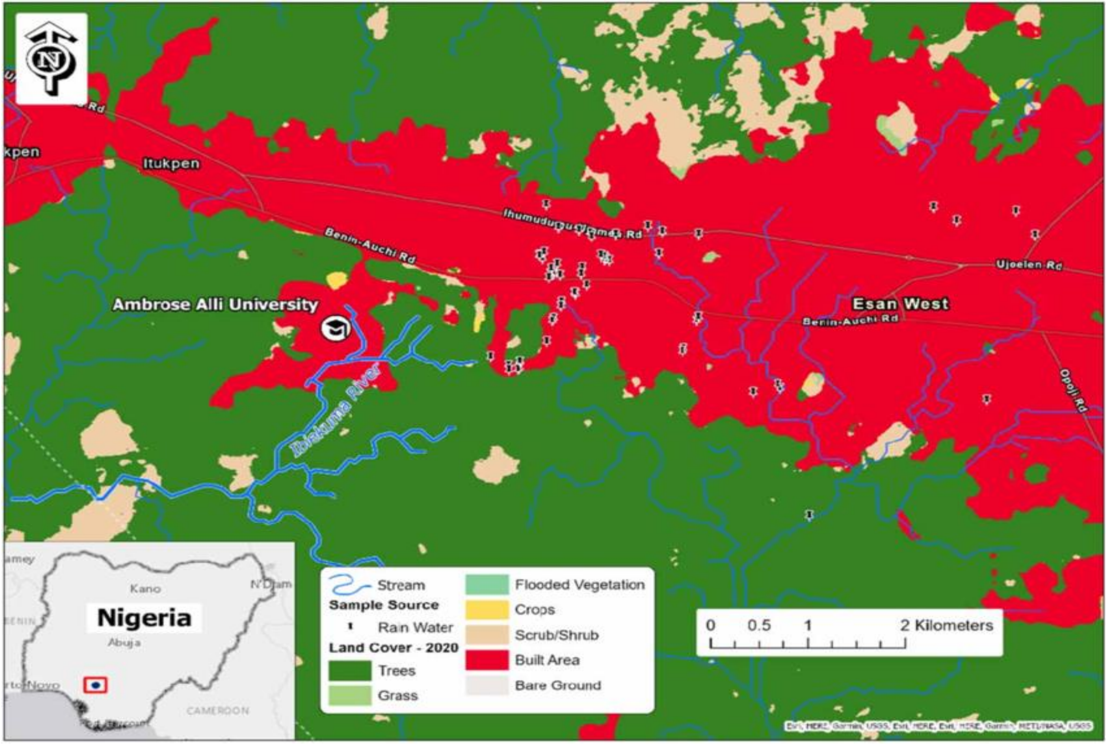

Figure 1:Map of the study Area (Source: [4])

Ekpoma is a town in Edo state, Nigeria. It is the administrative headquarters of the Esan West Local Government Area and it lies on the geographical coordinate of Latitude 6°45’N and Longitude 6°08’E.

2.2 Methodology

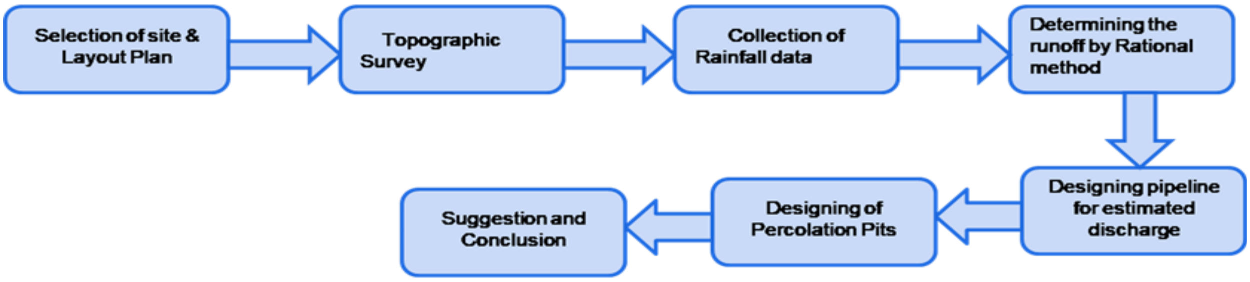

Figure. 1. Flowchart of the Methodology (Adapted from [5])

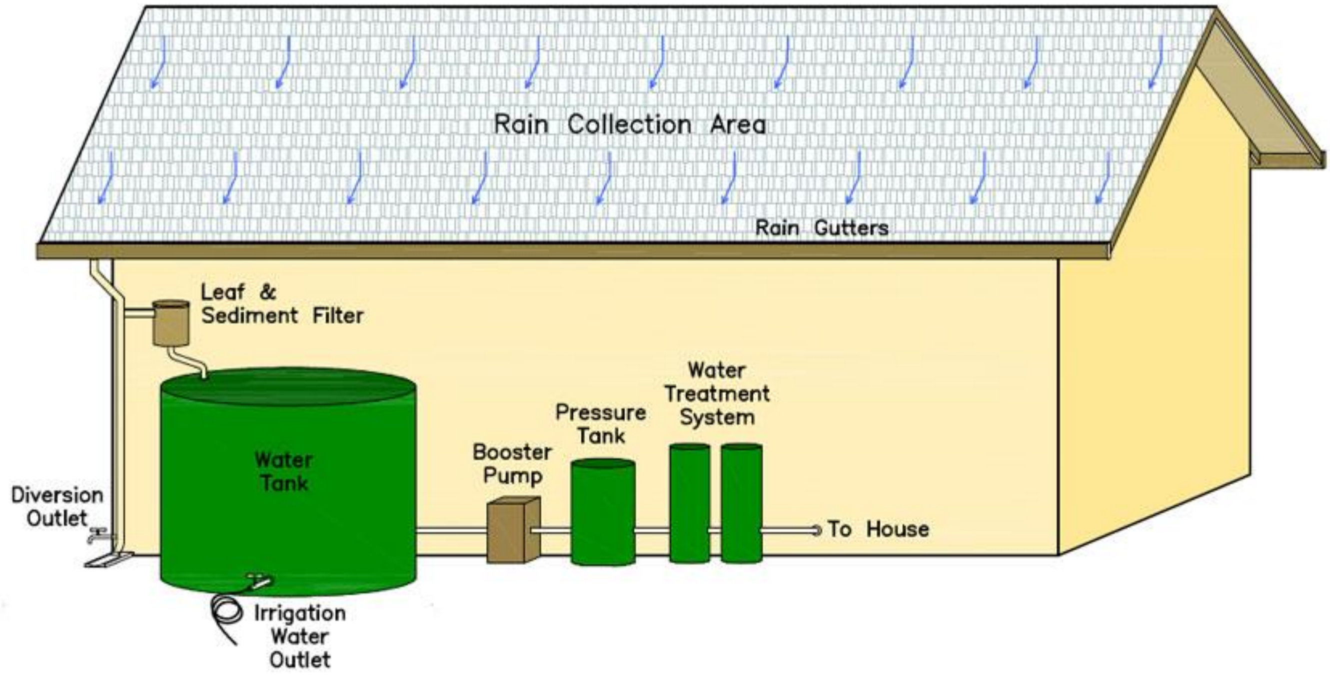

Figure 2: Representative image of rain water harvesting (Source :[6])

Figures 1&2 are the flow chart of methodology and the image of the set-up.After identifying the three homes that were suggested for the RWH system's design, the per capita water demand was calculated. After factoring in safety, the estimated value was used to calculate the amount of water required by the complete household. For the past 30 years, from January 1992 to December 2021, the monthly rainfall data of the catchment (study area) were acquired from the Nigerian Meteorological Agency's (NIMET) Abuja headquarters. The average monthly rainfall was then calculated. Equation (1) was used to determine the amount of rainfall that could be efficiently collected from the rooftop, also known as the rooftop's rainwater harvesting potentials.

$$Rainfwater\ harvesting\ potential\ (m^3) = R \times A_r \times C \qquad (1)$$

where R is the depth of rainfall in meters (m), Ar is the entire rooftop area that collects rainfall, and C is the material of the roof's runoff coefficient. (given in Table 1).

Table 1 Standard runoff coefficients for rooftop materials (Source: [7])

Roof Type	Galvanised iron sheets	Asbestos	Aluminum	Concrete
Runoff Coefficient (C)	0.90	0.80	0.80-0.90	0.70

3.0 Results and Discussion

3.1 Water Demand

According to [8] between 50 and 100 litres of water per person per day are needed to ensure that most basic needs are met and few health concerns arise. The water supply and sanitation facility for each person must be continuous and sufficient for personal and domestic uses. These uses ordinarily include drinking, personal sanitation, washing of clothes, food preparation and personal and household hygiene. The proposed building for the design of the Rainwater Harvesting (RWH) system was a 5-bedroom bungalow and the water demand for the 7 inhabitants of the apartment at an average daily per capital water demand of 80 L was estimated as follows,

To account for varying water demands, the per capita water demand is often raised by 20–25%; consequently, a 20% increase was assumed, resulting in a factor of safety of 1.20.

Daily per capital water demand=1.2 x 80 L=96L

Total Annual Water Demand = Water Use × Household Members × 365 days (2)

=96x7x365=**245,280 litres /year**

Number of liters consumed in a household per day = 96 x 7 = 672

Number of liters consumed in a household per month = 672 x 30 = 20,160

Number of liters to be consumed in 4 months = 20,160 x 4 = 80,640

Therefore, the storage capacity to be considered when constructing a storage reservoir that will last a household of seven (7) persons for a period of four (4) months when there will be no rainfall is a minimum of **80,640 liters** (80.64m$^{3)}$ i.e. a cylindrical well of 3.2m diameter and depth of 10 m

3.2 Rainwater Harvesting (RWH) Potential

The mean monthly rainfall of the study area for the past 22 years (January 1980 to December 2021) based on the records obtained from NIMET. Aluminum sheets were used to roof the five-bedroom bungalow, and the house plan showed that the roof's area was 247.34. Stated differently, the parameters and in Equation (1) were replaced with 247.34 and 0.8, respectively, and the mean monthly rainfall depths expressed in Volume of water that may be delivered from the roof was substituted for parameter.

S= R x A x Cr, (1)

S = mean rainwater supply in cubic meters (m^3). R = mean annual rainfall in millimeters (mm/a) A = catchment area in square meters (m^2), Cr =runoff coefficient R = 172.4049mm/Yr.

For A=247,34m^2, Cr=0.8

S = 0.1724049 x 247.34 x0.8,

= 34.11 m^3/year=34,110L/year

S = 34110/365 = 93.5L/d

3.3 Analyses of the harvested rainwater quality

The laboratory test results carried out on the harvested rainwater to obtain the quality of the samples are all shown in Table 2, in comparison with the published standards of WHO and FMenv.

Table 2: Results obtained from the laboratory tests (against WHO and FMenv standards)[9]

Parameters	Asbestos	Zinc	Alum	Atm.	WHO	Fmenv
pH	6.5*	6.9*	7.1*	7.3*	6.5-8.5	6.5-8.5
Conductivity (*µS/cm*)	32*	14*	6*	50*	250	1000
Turbidity (*NTU*)	11	9	6	10	10	5
Suspended Solid (*mg/l*)	8	7	2*	8	5	3
Phosphate (*mg/l*)	2.16*	0.12*	0.07*	0.07*	0.05	5
Nitrate (*mg/l*)	2.7*	2.1*	2.3*	3.0*	50	10
Alkalinity (*mg/l*)	12*	10*	8*	6*	200	100
Hardness (*mg/l*)	16*	10*	6*	10*	500	60
Calcium (*mg/l*)	4.81*	2.41*	1.60*	4.01*	200	40
Magnesium (*mg/l*)	0.97*	0.97*	0.49*	0.49*	150	20
Zinc (*mg/l*)	0.14*	0.12*	0.11*	0.13*	5	5
Iron (*mg/l*)	3.55	3.75	3.26	2.87	0.1	0.3
Lead (*mg/l*)	0.08	0.10	0.08	0.08	0.01	0.01
Total Coliform (*Cfu/100ml*)	1	0*	2	1	0	0
E.Coli (*Cfu/100ml*)	0*	0*	0*	0*	0	0

***** *parameters that meet the F.Menv published standard* All obtained results from the tests conducted in the laboratory

3.3.0 Comment On The Above Test Result:

3.3.1 Iron Content

The presence of iron in this collected water sample from asbestos exceeded the acceptable limitsof both WHO and FMenv (3.55);

Normal Zinc roof water sample had the highest amount of iron (3.75 *mg/l*) among other collected water samples and exceeded the approved standards as well;

Aluminum: the result obtained (3.26 *mg/l*) showed that there is a heavy presence of iron elements which exceeded the approved limits;

The atmospheric water sample had the lowest amount of iron (2.87 *mg/l*) but also exceeded the standard.

Consequently, the rainwater harvested would need to be treated for iron for all the types ofroofing materials tested for

3.3.2 Lead Analysis

The presence of lead elements in asbestos roof water sample was high in the collected water sample(0.08), exceeding the allowable limits;

Normal Zinc roof water sample had the lowest presence of lead among other collected water samples (0.10)but still exceeded the allowable limits of WHO and FMenv;

Aluminum roof water sample also had a high presence of lead elements in it (0.08); Also, atmosphere: water sample results showed that there is an unacceptable amount of lead in the collectedwater sample (0.08).

Consequently, the rainwater harvested would need to be treated for lead for all roofing materials tested.

3.3.3 Total coliform analysis

The presence of animal and human waste in the collected samples is analyzed below:

There was a trace of some waste in the asbestos roof water sample collected (1 *Cfu/100ml*), though little, but it was still more than the limits approved by WHO and FMenv;

There was no trace of wastes or by-products in the collected water sample (0);Aluminum: this has the highest amount of waste among all collected normal zinc water samples (2 *Cfu/100ml*); There was a trace of some waste in the atmosphere water sample collected here as well (1 *Cfu/100ml*).

Consequently, the rainwater harvested would need to be treated for total coliform for asbestosand aluminum roofing materials.

3,4 Water Quality Index analyses (WQI)

The water quality index, or WQI, is a rating that reflects the combined influence of various water quality parameters that are taken into account for the computation of WQI. It indicates the quality of water in terms of index number, which represents the overall quality of water for any intended use.

$$Z = \frac{\sum(Wn*Qn)}{\sum Wn} \qquad (3)$$

$$WQI = (Z - 100\%) \qquad (4)$$

Where: Wn = unit weight for nth parameter Qn = standard permissible value for nth parameter

Z = water quality rating by parameter [10]. Substituting values into equations 2 and 3 we have

$$Z = \frac{\varepsilon(\mathrm{Wn} * \mathrm{Qn})}{\varepsilon \mathrm{Wn}} = \frac{115417.2}{130.697} = 883.23\text{, and}$$

$$WQI = (Z - 100)\% = 7.832$$

The computed water quality index for the various roofing sheets are presented in Tables 3 - 4.

Table 3: Water quality index table (Aluminum)

PARAMETERS	WHO	Aluminum	WN	QN	WN x QN
pH	7.5	7.1	0.15385	20	2.667
Conductivity (*µS/cm*)	250	6	0.004	2.4	0.009
Turbidity (*NTU*)	10	6	0.1	60	6
Suspended Solid (*mg/l*)	5	2	0.2	40	8
Phosphate (*mg/l*)	0.05	0.07	20	140	2800
Nitrate (*mg/l*)	50	2.3	0.02	4.6	0.092
Alkalinity (*mg/l*)	200	8	0.005	4	0.02
Hardness (*mg/l*)	500	6	0.002	1.2	0.0024
Calcium (*mg/l*)	200	1.60	0.005	0.8	0.004
Magnesium (*mg/l*)	150	0.49	0.007	0.327	0.002
Zinc (*mg/l*)	5	0.11	0.2	2.2	0.44
Iron (*mg/l*)	0.1	3.26	10	3260	32600
Lead (*mg/l*)	0.01	0.08	100	800	80,000
Total Coliform(*Cfu/100ml*)	0	2	0	0	0
E.Coli (*Cfu/100ml*)	0	0	0	0	0
TOTAL			**130.697**		**115417.2**

Table 4.: Water quality index table (Asbestos)

PARAMETERS	WHO	Asbestos	WN	QN	WN x QN
pH	6.5	6.5	0.15385	100	15.384615

					38
Conductivity (*µS/cm*)	250	32	0.004	12.8	0.0512
Turbidity (*NTU*)	10	11	0.1	110	11
Suspended Solid (*mg/l*)	5	8	0.2	160	32
Phosphate (*mg/l*)	0.05	2.16	20	4320	86400
Nitrate (*mg/l*)	50	2.7	0.02	5.4	0.108
Alkalinity (*mg/l*)	200	12	0.005	6	0.03
Hardness (*mg/l*)	500	16	0.002	3.2	0.0064
Calcium (*mg/l*)	200	4.81	0.005	2.405	0.012025
Magnesium (*mg/l*)	150	0.97	0.00667	0.646666667	0.004311111
Zinc (*mg/l*)	5	0.14	0.2	2.8	0.56
Iron (*mg/l*)	0.1	3.55	10	3550	35500
Lead (*mg/l*)	0.01	0.08	100	800	80000
Total Coliform(*Cfu/100ml*)	0	1	0	0	0
E.Coli (*Cfu/100ml*)	0	0	0	0	0
TOTAL			**130.697**		**201959.2**

$$Z = \frac{\varepsilon(Wn - Qn)}{\varepsilon Wn} = \frac{201959.2}{130.697} = 1545.253$$

$$WQI = (Z - 100)\% = 14.45$$

Table 5: Water quality index table (Normal Zinc)

PARAMETERS	WHO	Normal Zinc	WN	QN	WN x QN
pH	6.5	6.9	0.1538	20	3.077
Conductivity (*µS/cm*)	250	14	0.004	5.6	0.0224
Turbidity (*NTU*)	10	9	0.1	90	9
Suspended Solid (*mg/l*)	5	7	0.2	140	28
Phosphate (*mg/l*)	0.05	0.12	20	240	4800
Nitrate (*mg/l*)	50	2.1	0.02	4.2	0.084
Alkalinity (*mg/l*)	200	10	0.005	5	0.025
Hardness (*mg/l*)	500	10	0.002	2	0.004

Calcium (*mg/l*)	200	2.41	0.005	1.205	0.006025
Magnesium (*mg/l*)	150	0.97	0.0067	0.647	0.00431
Zinc (*mg/l*)	5	0.12	0.2	2.4	0.48
Iron (*mg/l*)	0.1	3.75	10	3750	37500
Lead (*mg/l*)	0.01	0.10	100	1000	100000
Total Coliform(*Cfu/100ml*)	0	0	0	0	0
E.Coli (*Cfu/100ml*)	0	0	0	0	0
TOTAL			**130.697**		**142340.7**

$$Z = \frac{\varepsilon(Wn - Qn)}{\varepsilon Wn} = \frac{142340.7}{130.697} = 1089.0$$

$$WQI = (Z - 100)\% = 9.8909$$

The computed water quality index for the various roofing sheets is presented in Table3

The findings of all water samples are compiled into a hundred-point scale known as the water quality index.

The parameters that were being tested for, such were pH, turbidity, alkalinity, lead, iron, etc.

Table 6: Water quality index and its status [11]

Water qualityindex level	Water quality status	Grading	Possible usage
0-25	Excellent water quality	A	Drinking, irrigation, industrial
26-50	Good water quality	B	Domestic, irrigation, industrial
51-75	Moderate water quality or poor water quality	C	Irrigation, industrial
76-100	Poor water quality or very poor water quality	D	Irrigation
Above 100	Unsuitable for drinking	E	Proper treatment required before use

Hence, the results obtained from each roof type is as follow: Asbestos:14.45, Normal zinc 9.89 and Aluminum :7.83. These values being less than 25 (Grade A) in Table 6 is indicative that water quality is Excellent for drinking. The preference is still aluminum roofing sheets giving the lowest water quality index of 7.83.

3.5 Analysis for the Storage capacity for a household

Total Annual Water Demand = Water Use × Household Members × 365 days=96x7x365=**245,280 litres /year**

Number of liters consumed in a household per day = 96 x 7 = 672

Number of liters consumed in a household per month = 672 x 30 = 20,160

Number of liters to be consumed in 4 months = 20,160 x 4 = 80,640

Therefore, the storage capacity to be considered when constructing a storage reservoir that will last a household of seven (7) persons for a period of four (4) months when there will be no rainfall is a minimum of **80,640 liters** (80.64m$^{3)}$ i.e. a cylindrical well of 3.2m diameter and depth of 10 m

3.6 Suggested water treatment methods -Reverse Osmosis Water System

The harvested rainwater was generally of good quality but there is a need for proper storage and treatment practices to ensure its safety for drinking purposes.

Reverse osmosis water systems are water filtration processes for separating iron and numerous other molecules from drinking water. These are the most common water filters found in households and commercial facilities. They are capable of removing large particles and harmful chemicals from water. It is a simple and economical way to protect your household from lead contamination in water. Reverse Osmosis can remove 99.1% of lead in water and can remove dozens of other contaminants**.** Distillation is a very slow process and requires a lot of energy from a heat source, so it's not the optimal process.

During the reverse osmosis water treatment process, household water pressure pushes water through a series of filters. The membrane in the reverse osmosis system will filter out contaminants, including removing lead from water. Through the RO filtration process, impurities flush away, leaving you with filtered, clean drinking water. Reverse Osmosis is a highly effective purification process, has a low production cost (only pennies per gallon), consumes no energy, and is easy to clean and maintain

3.7 Community Participation and Awareness:

The result of this study is to stimulate the full exploration of the role of community engagement and awareness in the success of rainwater harvesting initiatives. There is the need to effectively engage and educate Ekpoma community about the benefits and best practices of rainwater harvesting

4.0 Conclusion

The results from this study have proven that great potential for exploitation of rainwater harvesting from rooftops is possible in Ekpoma. Aluminum roofing sheets, having the lower Water Quality Index, were recommended. Water quality parameters obtained from tests were compared with the recommended limits prescribed by the Nigerian Standard for Drinking Water Quality (NSDWQ), and the World Health Organization (WHO) guidelines for drinking water quality and observed to be within acceptable limits. The significance of assessing rainwater harvesting in rural communities lies in its potential to address water scarcity, mitigate environmental impact, support socioeconomic development, and empower local communities. With the understanding of specific context and potential for rainwater harvesting in this area, we can tailor solutions that are sustainable, effective, and beneficial for the communities involved.

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