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Qualitative and Quantitative Assessment of Rainwater Harvesting from Rooftop Catchments: Case Study of Oke-Lantoro Community in Abeokuta, Southwest Nigeria

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Abstract: Quantitative and qualitative assessment of Rainwater harvesting system from rooftop runoff from a catchment at Oke-Lantoro Community in Abeokuta, Southwest Nigeria was determined using eight roof design in respect to slope and six selected roofing sheet materials respectively. The result showed that the steeper the roof slope the more the rainwater harvested irrespective of rainfall amount and duration. Roof pattern with a large and steep slope designed with gutter tends to harvest more water and at a higher rate. Physico-chemical analysis of the harvested water samples gave results which varied from various drinking water quality regulatory standards. Sample from galvanized roofing sheet was influenced by zinc and lead in quantity beyond human consumption level, while the asbestos roofing sheet water sample gave higher calcium and magnesium content which reflects in the total hardness value. Sample from the aluminum roofing sheet gave the best result but it was also affected by the influence of atmospheric dust particles and feacal materials of birds, lizards and other small organisms. Considering the results of the physico-chemical tests, the harvested water samples could be put to other domestic uses, as they cannot be consumed directly.

Key words: rainwater, roof patterns, harvesting, water quality, potable.

1. INTRODUCTION

Rainwater harvesting system in Africa is becoming essential owing to the temporal and spatial variability of rainfall (FAO, 2007). It appears to be the most popular method among the several strategies for mitigating the growing urban water crisis and the supplementary source of water supply to already existing public water supply scheme, particularly in area with dispersed population and hilly terrain (Ayoade et al 1998, Fatokun 2004). Of all the rainwater harvesting methods, the rainwater runoff from household roofs is the most common form of rainwater harvesting. Apart from being cost effective and ease of maintenance for effective long-term system operation, the roof top runoff also has less contamination of rainwater runoff as compared with ground catchments system. Furthermore, roof catchments provide a water supply at the point of consumption (Gould and Nissen-Petersen 1999).

Despite having some clear advantages over other sources, rainwater use has frequently been rejected on the grounds of its limited capacity or due to water quality concerns. This is unfortunate as in many cases some simple upgrading and the integrated use of rainwater collection with other technologies is all that is required to obtain a cost effective and reliable water supply solution (Ragab et al., 2003). It therefore becomes important to qualitatively and quantitatively assess rainwater harvesting from rooftop catchments at Okelantoro Community in Abeokuta, Southwest Nigeria. This when achieved will contribute to the management of the water resources of the area and Nigeria in general.

2. STUDY AREA

The study area, Okelantoro community is situated within Abeokuta (7^o 15'N, 3^{o}25'E) South Local Government Area of Ogun State, South-Western Nigeria (Fig. 1a & 1b). It is situated in the tropics and covers an area extent of 1256km^2. It is 100km north of Lagos and 80km south-west of Ibadan. To the west of Ogun State is the Republic of Benin (Dahomey), Lagos state lies to the south, Ondo State to the east and Oyo State to the North. The Oke-Lantoro community is predominantly residential in outlook with houses of different structure hence water is mostly required for domestic purpose. Public water supply is either from community boreholes (mini water scheme) or surface water source. There are very few or scanty shallow wells for majority of the area where government water is not assessable (Ayeni 1994).

Fig. 1a. Map of Nigeria showing the position of Abeokuta.

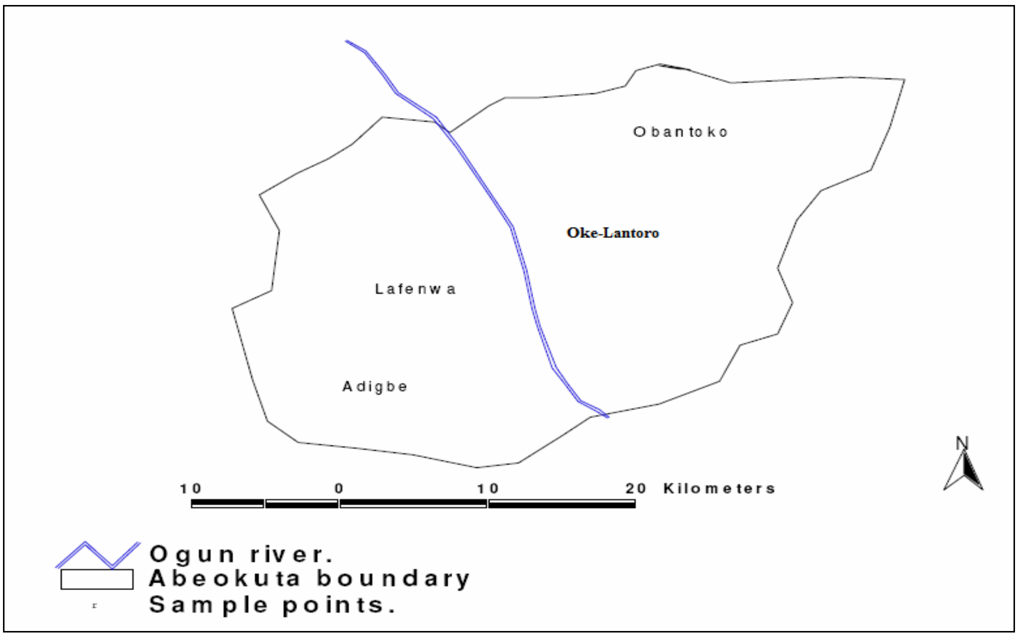


Fig. 1b. Abeokuta showing Oke-Lantoro

3. MATERIALS AND METHODS

The experiment for quantitative and qualitative analysis of water from rainwater harvesting through roof-top runoff from eight roof patterns and six selected roofing sheet materials were assessed as follow:

Table 1: Description of selected roof pattern and harvesting properties

Roofs	Dimension(m)	Surface Area(m^2)	Slope	Design pattern
1	11.2 by 25.2	282.24	0.24	Rain water harvesting is possible from two sides of the roof catchments.
2	10.68 by 14.68	156.78	0.20	Rain water harvesting is possible from two sides of the roof catchments.
3	18.9 by 41.47	783.78	0.24	Rain water harvesting is possible from two sides of the roof catchments.
4	10.97 by 10.9	218.30	0.21	Rain water harvesting is possible from three sides of the roof catchments.
5	11.6 by 24.2	280.72	0.24	Rain water harvesting is possible from all sides of the roof catchments.
6	11.27 by 16.2	182.57	0.21	Rain water harvesting is possible from all sides of the roof catchments.
7	19 by 9.1	172.90	0.46	Rain water harvesting is possible from all sides of the roof catchments.
8	21.85 by 15.2	332.12	0.59	Rain water harvesting is possible from all sides of the roof catchments.
9	CONTROL	1.0	0.00	Rain water was harvested directly from the atmosphere without any interception

3.1 Quantitative Analysis

Eight roof patterns were analyzed for quantitative study as shown in Table 1. The slopes and surface area extent of each roof catchments was determined using measuring tape. The height and length of truss carrying the roof was measured and the slope determined mathematically. Water vessels having 0.5m diameter were placed at the end of the roof catchments attached with collection gutter to harvest rainwater. Total volume of harvested was collected and measured at the end of a particular rainstorm in order to determine the actual harvest volume per the equivalent length of such roof. This volume was multiplied by the entire roof length in order to determine the total amount of harvest possible on such catchments considering the surface area. Also the volume of harvest per rainfall duration was monitored to determine the harvest intensity owing to variations in the slope of catchments. A control experiment was also set up to stand as comparison to other set-ups; in which a water vessel was placed to harvest rainwater directly from the atmosphere without any interception (Gould 1999). Harvest intensity was also monitored and likewise the total volume of harvest with respect to the surface area of the water vessel which represent the area of catchments. A rain-gauge was installed at the location for rainfall measurement.

3.2 Qualitative Analysis

Harvested rainwater samples were collected via roof-top run off made of six selected roofing sheet materials were analyzed for physical, chemical and bacteriological content using standard method for the examination of water. The roofing materials include new galvanized iron (A), old galvanized iron (B), new corrugated asbestos (C), old corrugated asbestos (D), blue aluminum (E) , red aluminum (F) roofing sheets and a control sample (G) which is the water collected directly from rain drop without contact with any roof material. The sampling periods are the months of May (1), which taken has the onset of rainfall in the area for the experimental year; July (2), the first peak period of rainfall and September (3) the rising period of rainfall after the August break.

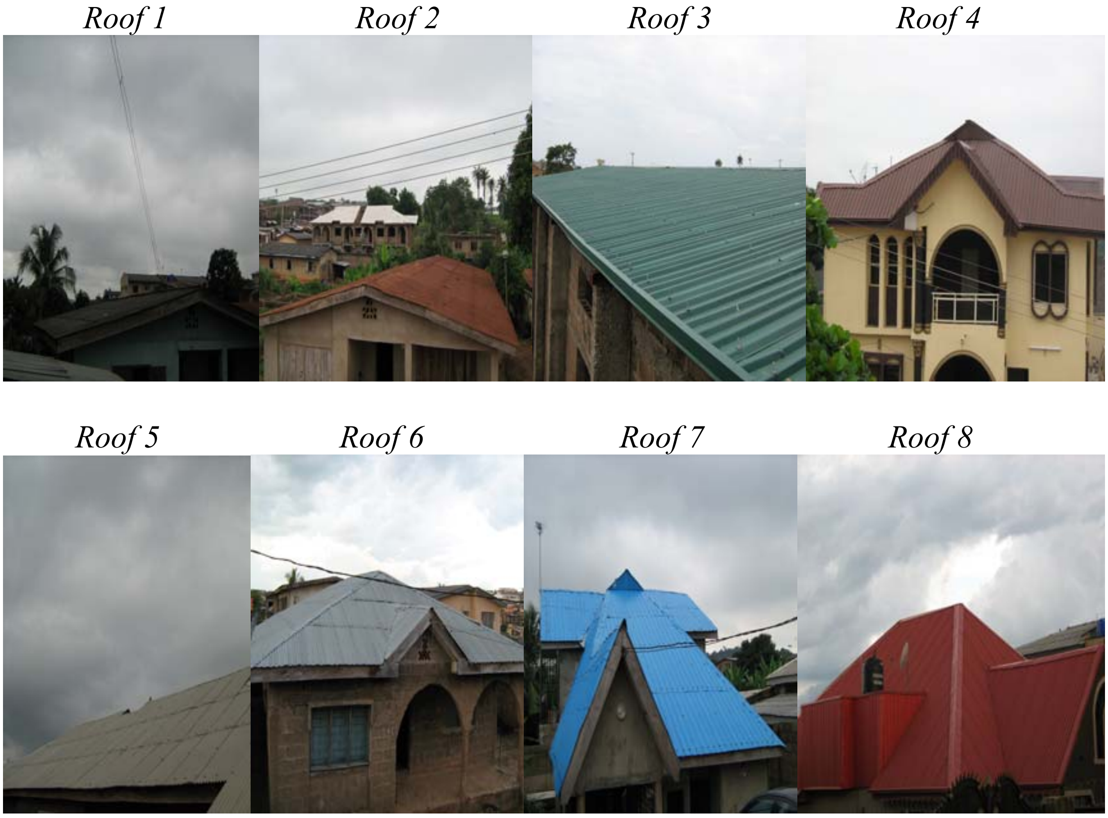


Fig. 1c: Selected roofs tops

4. RESULTS AND DISCUSSION

4.1 Quantitative assessment

Table 2 and Figures 2-4 showed the relationship between the slope and the intensity of water harvested for rainfall of different amount and duration for all the roof patterns. It was obvious from the result that the steeper the roof slope the more rainwater harvested irrespective of rainfall amount and duration.

Table 2: Relationship between harvested volume and Roof slope for selected roof pattern at different duration of rainfall

Roof Pattern	Slope of roof	Harvested volume of 20min. duration (l/min)	Harvested volume of 20min. duration (l/min)	Harvested volume of 20min. duration (l/min)
1	0.24	0.60	0.25	0.19
2	0.20	0.50	0.21	0.16
3	0.24	0.60	0.25	0.19
4	0.21	0.53	0.22	0.17
5	0.24	0.60	0.25	0.19
6	0.21	0.53	0.22	0.17
7	0.46	1.15	0.48	0.36
8	0.59	1.48	0.62	0.49
Control	0.00	0.06	0.21	0.02

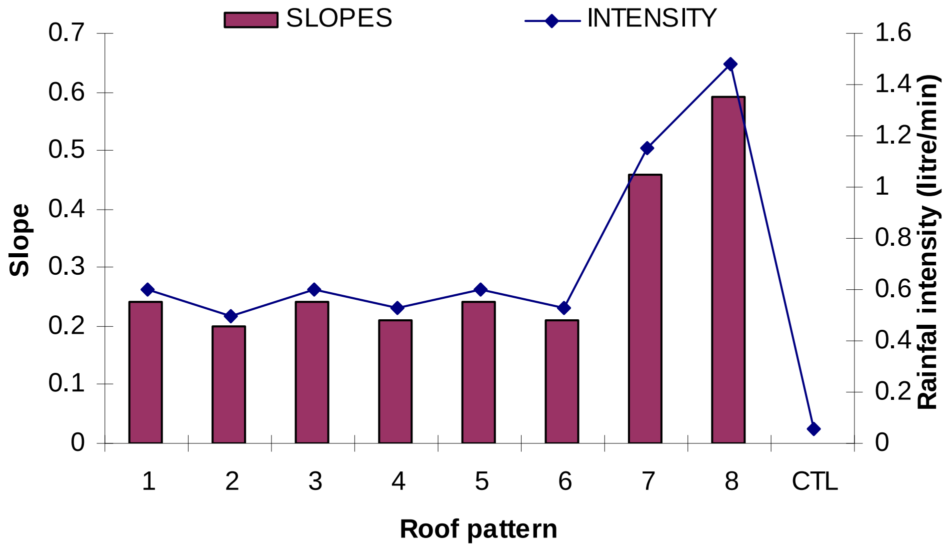


Fig. 2: Relationship between harvested volume and Roof slope for selected roof pattern at 2.1mm rainfall amount and 20 minute duration (24th May, 2008)

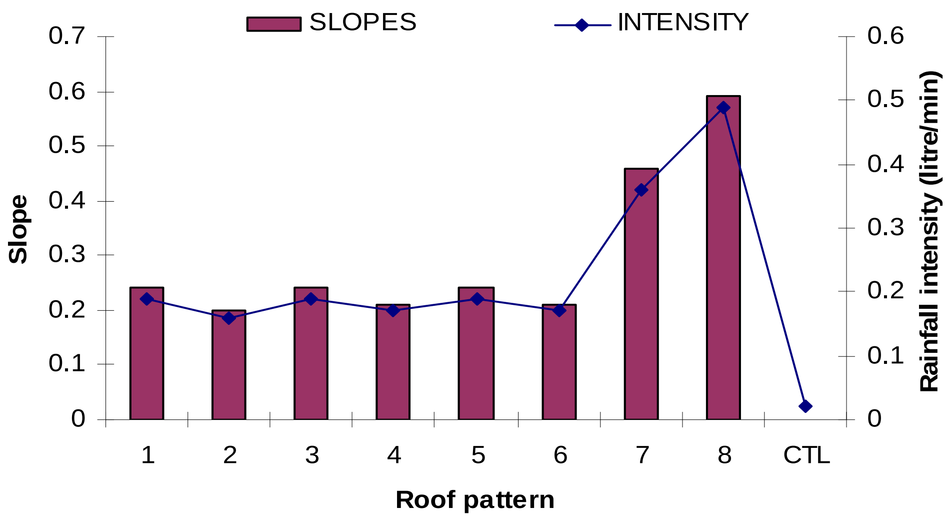


Fig. 3: Relationship between harvested volume and Roof slope for selected roof pattern at 1.7mm rainfall amount and 30 minute duration (8th July, 2008)

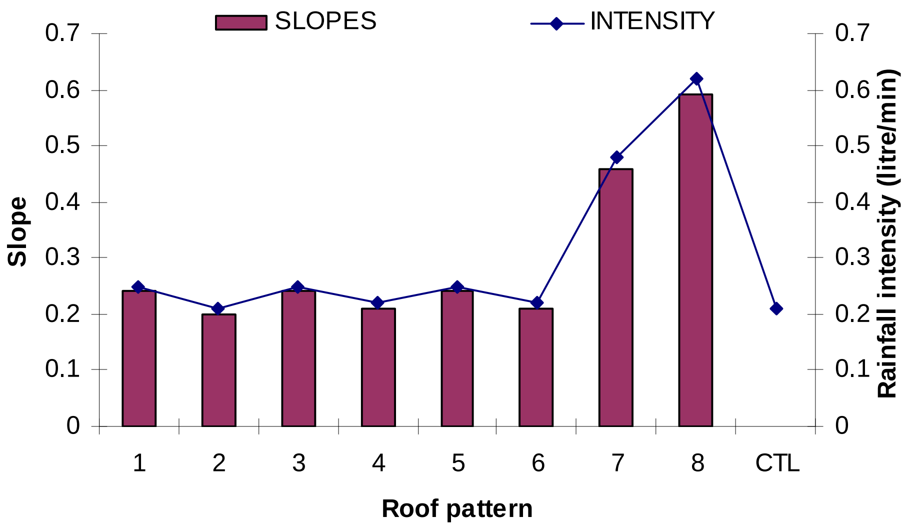


Fig. 4: Relationship between harvested volume and Roof slope for selected roof pattern at 12.5mm rainfall amount and 40 minute duration (3rd September, 2008)

The control set-up has the least harvesting capacity since the rainfall water was harvested directly from the rain drop, hence a zero slope (Koenig 1998). The effect of roof slope was obvious in this study as Roof slope influences the intensity of harvested via different roof. Roof 8 with highest slope of 0.59 has the highest rate of rainwater harvest irrespective of rainfall amount and duration, while Roof 2 with less of slope of 0.2 on the other hand has the lowest rate.

4.2 Qualitative assessment

Table 3 showed the result of physical, chemical and bacteriological analysis carried out on the water sample collected as related the standard limit of WHO and result was further expressed graphically for clear interpretation.

Table 3: Physical and chemical analysis of harvested roof top water sample

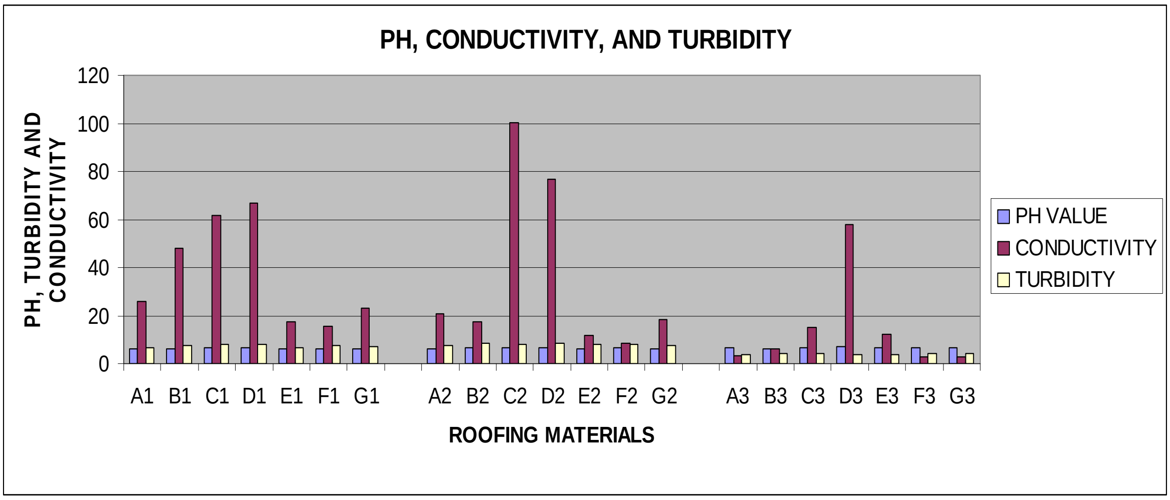
SAMPLE	pH	Conductivity (µsi/cm)	Turbidity (NTU)	Colour (Hu)	DO (mg/l)	BOD (mg/l)	Total Solid (mg/l)	TDS (mg/l)	TSS (mg/l)	Total Hardness (mg/l)	Ca ion Hardness (mg/l)	Mg ion Hardness (mg/l)	Chloride (mg/l)	Carbonate (mg/l)
A1	6.0	25.8	6.52	5	2.31	0.4	35	11.4	23.6	5	4	1	29	24.4
B1	6.0	48	7.43	5	1.53	0.45	35	21.4	13.6	9	9	0	25	48.8
C1	6.8	61.5	8.04	5	1.85	1.2	50	28.3	21.7	17	16	1	31	24.4
D1	6.8	66.9	8.1	5	2.02	1.01	50	30.3	19.7	17	15	2	26	24.4
E1	6.2	17.42	6.77	5	3.39	1.2	20	7.6	12.4	1	1	0	21	24.4
F1	6.2	15.61	7.43	5	2.76	0.67	25	6.7	18.3	5	1	4	23	24.4
G1	6.2	23.1	7.23	5	3.8	1.61	28.4	10.2	18.2	6	3	3	22	24.4
A2	6.2	20.5	7.31	5	2.43	0.31	25	9	16	5	5	0	30	24.4
B2	6.6	17.61	8.24	5	1.74	0.48	25	7.6	17.4	4	3	1	23	24.4
C2	6.8	100.1	7.91	5	3.35	1.25	60.5	45.6	14.9	30	21	9	28	24.4
D2	6.8	76.8	8.31	5	3.06	0.96	60.5	34.8	25.7	19	18	1	26	24.4
E2	6.2	11.94	7.91	5	3.28	0.8	22.5	5	17.5	2	1	1	26	24.4
F2	6.4	8.63	7.86	5	3.85	1.51	10	3.4	6.6	1	1	0	28	24.4
G2	6.2	18.18	7.47	5	3.23	0.83	50	7.9	42.1	6	4	2	26	24.4
A3	6.8	3.14	3.68	5	3.13	0.54	17.5	0.9	16.6	1	1	0	35	24.4
B3	6.2	6.06	4.2	5	3.29	0.4	20	2.3	17.7	7	6	1	26	24.4
C3	6.8	14.99	4.35	5	3.75	1.24	20	6.3	13.7	2	2	0	20	24.4
D3	7.0	57.8	3.72	5	3.71	1.33	37.5	25.8	11.7	23	18	5	30	24.4
E3	6.6	12.03	3.8	5	2.85	0.47	25	5	20	4	2	2	28	24.4
F3	6.6	2.74	4.02	5	3.88	1.1	17.5	0.7	16.8	0	0	0	25	24.4
G3	6.6	2.78	4.15	5	2.3	0.47	17.5	0.8	16.7	3	2	1	24	24.4
WHO LIMIT	7.0-8.9	900	5.0	NS	NS	NS	500	NS	NS	100	NS	20	200	NS

NS: Not specified

Figure 5 showed pH, Conductivity, Turbidity comparative assessment of different roofing materials during various rainfall periods in the study area. The conductivity value obtained from all the samples ranges from 2.74 to 66.9µs/cm. It is observed that conductivity was highest in the water collected from roof top with corrugated asbestos roofing sheets irrespective of the period of collection. This was followed by the galvanized iron roofing sheet, and then the water collected directly from the raindrop and the red aluminum roofing sheet samples having the lowest conductivity value. However, all the values were less than 900µs/cm which falls below the WHO drinking water standard. Furthermore, the graph also showed that the pH and Turbidity are uniform irrespective of the material used and the time of collection. However, from table 3, it was observed that the pH value ranged between 6.0 to 7.0 which in most sample does not conform with WHO standard except the water sample collected in September from old corrugated asbestos (D3) with marginal value of 7. Furthermore, the turbidity values were higher than the 5µsi/cm WHO standard for most of the water collected from the different roofing materials and the control. This implies therefore that high pH and turbidity of rainwater harvest is not only as a result of rooftop material particularly when sample collected directly showed similar results.

Figure 6 showed Total solids, Total dissolved solids and Total suspended solids comparative assessment of different roofing materials during various rainfall periods in the study area. It was observed that the total solids, total dissolved solids and total suspended solids were highest in the water collected from roof top with corrugated asbestos roofing sheets irrespective of the period of collection. This was followed by the galvanized iron roofing sheet, and then the water collected directly from the raindrop. However, all the values were less than 60mg/l which falls below the

WHO 500mg/l drinking water standard particularly for the total solid. It was observed that the values of total solids, total dissolved solids and total suspended solids was highest in the peak periods of rainfall in July, followed by the onset of rainfall in May, then the period after the August break in September. This may be as a result of higher sediments available in the environment prior to the beginning of rainfall as in the case of May and the high volume of runoff during the peak of rainfall in July.



A1 to G1 = rainwater samples collected in May for the selected roofing materials
A2 to G2 = rainwater samples collected in July for the selected roofing materials
A3 to G3 = rainwater samples collected in September for the selected roofing materials

Fig. 5: Assessment of pH, Conductivity and Turbidity of water harvested from different roofing materials at various rainfall periods.

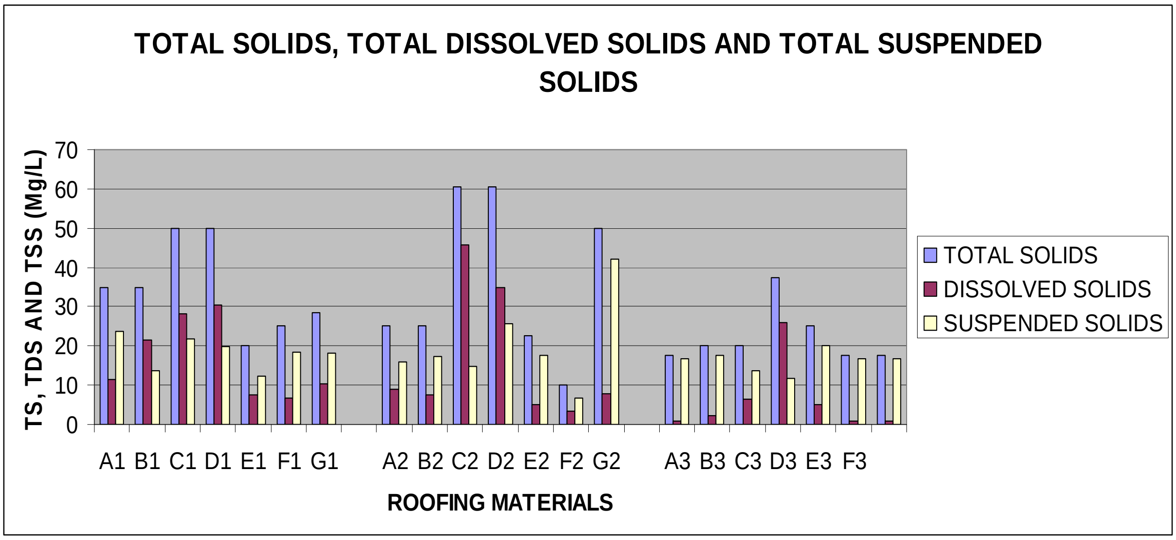


Fig. 6: Assessment of total solids, total dissolved solids and total suspended solids of water harvested from different roofing materials at various rainfall periods.

Figure 7 showed Dissolved oxygen (DO) and Biological oxygen demand (BOD) comparative assessment of different roofing materials during various rainfall periods in the study area. The dissolved oxygen content of analyzed water samples falls within the range of 1.53 to 3.58 mg/l. An appreciable increasing trend of dissolved oxygen content was observed as the months progresses, with the highest value obtained from red aluminum roofing sheet sample for September. While the lowest was obtained from old galvanized roofing sheet sample for May. A lower BOD value was observed from all analyzed samples with a range of 0.31 to 1.61. There is a normal distribution in the trend of BOD for the three sampling period with the corrugated asbestos having the highest, followed by aluminum roofing sheets, then the galvanized roofing sheet except a little variation in the month of May when highest value was obtained from the control sample.

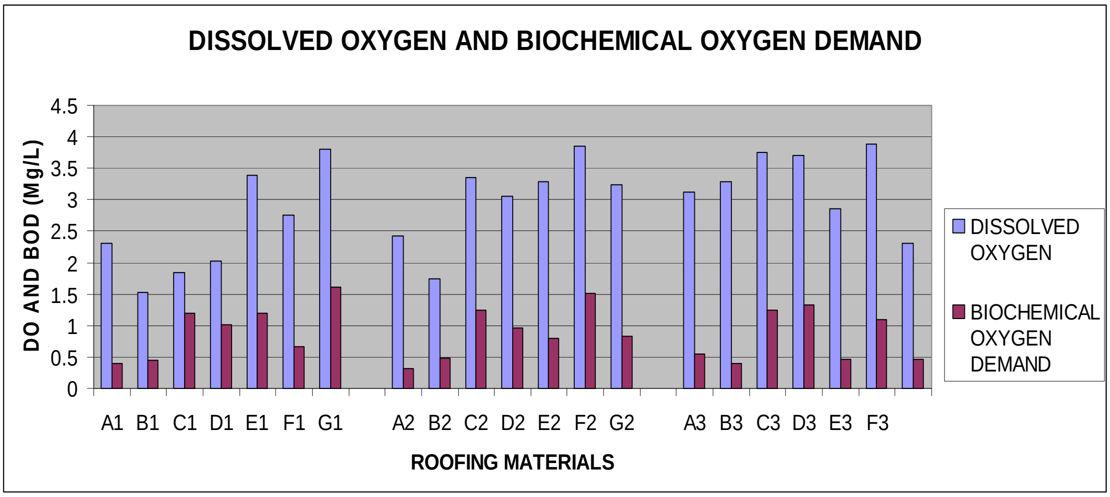


Fig. 7: Assessment of Dissolved oxygen and Biological oxygen demand of water harvested from different roofing materials at various rainfall periods.

Figure 8 showed Total hardness, Ca hardness and Mg hardness comparative assessment of different roofing materials during various rainfall periods in the study area. This study also observed that asbestos roofing sheet samples posses the highest level of total hardness. This is traceable to the level of magnesium and calcium carbonate content of the roofing sheet. Hardness of water results from the effect of calcium and magnesium carbonate on water which makes it difficult to form lather with soap. Studies have also confirmed the relationship between water hardness and heart diseases (König 1998 and Ayeni 1994). However, all analyzed samples are safe for human consumption owing to the regulatory limits.

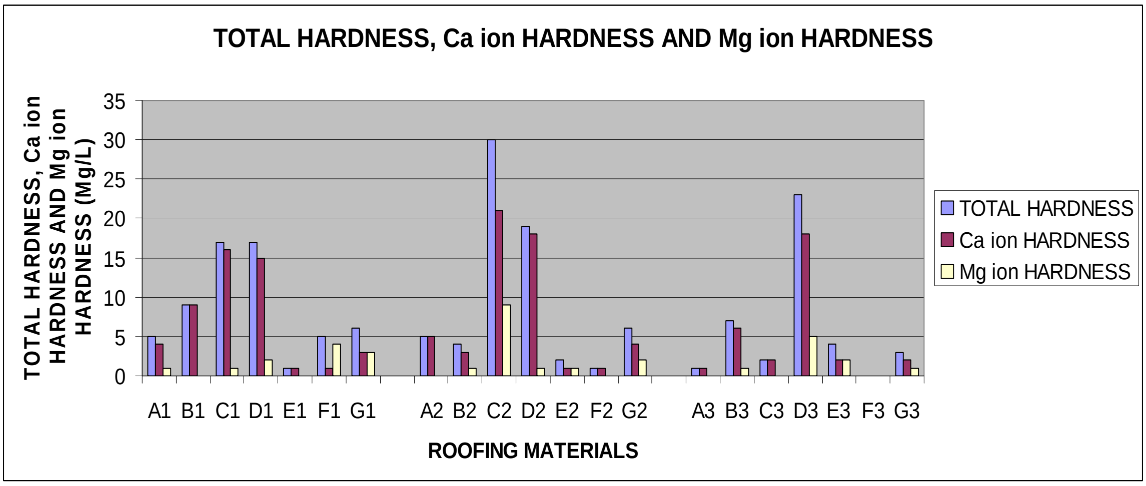


Fig. 8: Assessment of Total hardness, Ca hardness and Mg hardness content of water harvested from different roofing materials at various rainfall periods.

Figure 9 showed Chloride and Carbonate content comparative assessment of different roofing materials during various rainfall periods in the study area. The chloride and carbonate concentration are very low in all analyzed samples which ranges from 20 to 35mg/l. Majority of the water sample analyzed gave values that are relatively similar except with high value of carbonate obtained from old galvanized iron roofing sheet sample for September, and high value of chloride obtained from new galvanized iron roofing sheet sample for May. The lowest value obtained from new asbestos roofing sheet sample for September. Naturally occurring chlorides is caused by dissolving minerals. It may be found in large amount in industrial brine, where it combines with sodium. Chloride gives a salty taste to water and may increase the corrosiveness of water.

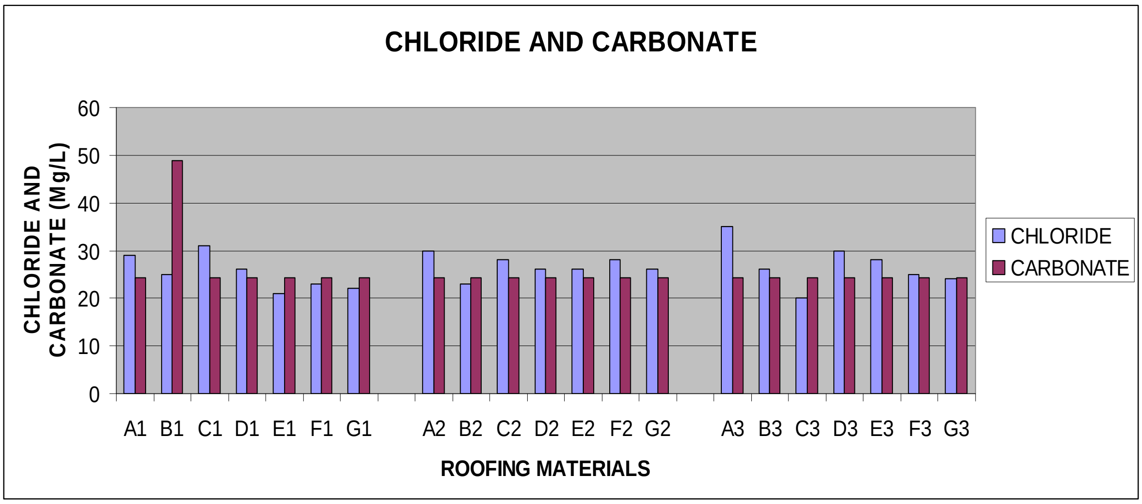


Fig. 9: Assessment of Chloride and Carbonate content of water harvested from different roofing materials at various rainfall periods.

Table 4: Physical, chemical and bacteriological analysis of harvested roof top water sample

Samples	Acidity (mg/l)	Alkalinity (mg/l)	Fe ion (mg/l)	Na ion (mg/l)	Zn ion (mg/l)	Pb ion (mg/l)	Bacteria Count per 100 ml	E Coli (24 hours)
A1	1	NIL	NIL	1.0	0.59	0.12	TNTC	50
B1	1	NIL	NIL	2.0	0.60	0.08	TNTC	50
C1	0.3	NIL	NIL	NIL	NIL	NIL	NIL	NIL
D1	0.3	NIL	NIL	1.0	NIL	NIL	TNTC	NIL
E1	0.7	NIL	NIL	NIL	NIL	NIL	TFTC	NIL
F1	0.7	NIL	NIL	NIL	NIL	NIL	15	NIL
G1	0.7	NIL	NIL	1.0	NIL	NIL	NIL	NIL
A2	0.7	NIL	NIL	1.0	0.60	0.14	NIL	NIL
B2	0.4	NIL	NIL	NIL	0.36	0.05	NIL	NIL
C2	0.3	NIL	NIL	NIL	NIL	NIL	TNTC	NIL
D2	0.3	NIL	NIL	NIL	NIL	NIL	TFTC	NIL
E2	0.7	NIL	NIL	NIL	NIL	NIL	NIL	NIL
F2	0.6	NIL	NIL	NIL	NIL	NIL	NIL	NIL
G2	0.7	NIL	NIL	NIL	NIL	NIL	NIL	NIL
A3	0.3	NIL	NIL	NIL	0.58	0.18	54	50
B3	0.8	NIL	NIL	NIL	0.47	0.07	TNTC	20
C3	0.3	NIL	NIL	NIL	NIL	NIL	35	20
D3	0.2	NIL	NIL	NIL	NIL	NIL	23	NIL
E3	0.3	NIL	NIL	NIL	NIL	NIL	2	NIL
F3	0.3	NIL	NIL	NIL	NIL	NIL	1	>160
G3	0.8	NIL	NIL	NIL	NIL	NIL	10	50
WHO LIMIT	NS	100	1.0	NS	0.01	0.01	NS	NS

5. CONCLUSION

In the present study area, the choice of roofing materials and design is not considered based on the water needs of the individual rather it is based on individual financial status and taste despite the problem water supply encountered in the area. However, to mitigate the water problem in the area, effective roof top rain water harvesting system should be employed. For meaningful water harvesting from roof top, it was obvious from research that the steeper the roof slope the more the rainwater harvested irrespective of rainfall amount and duration. Furthermore, in view of the finding presented in the above, it is observed that though the quality of water harvested from the selected roofing materials at different rainfall period falls within the WHO standard limit, some level of contamination was prominent. The water from asbestos roofing sheet has the highest level of pollution, followed by galvanized iron roofing sheet and the aluminum roofing sheet is the least polluted. As revealed from the analysis, most of the samples require at least some level of treatment particularly in respect to the bacteriological contamination in order to ensure their potability considering the regulatory standards. However, all water samples are quite safe for all other domestic uses such as; laundry, bathing, toilet flushing and other cleaning works.

6. RECOMMENDATIONS

Based on this study, the following suggestions are recommended to the people of this community;

1. Community should explore the rainwater harvesting system as an alternative to the acute shortage of water supply in the area.
2. Ensure roof design with appreciable roof slope in order to enhance efficient rainwater harvesting.
3. Cultivate the use of Aluminum roofing sheets in the building design, but if incapacitated due to cost of aluminum, the coated galvanized iron roofing sheet should be adopted.
4. Safety and health measures should be paramount in storage of harvested water.
5. The state and the local government should launch an enlightenment campaign on the essentials of rainwater harvesting as means of water conservation.

Finally, harvested rainwater system is a solution to the insistence problem public water supply thereby enhancing better living environment free of over abstraction of groundwater and flood disaster.

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