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AUGMENTING RURAL WATER SUPPLY BY ROOFTOP RAINWATER HARVESTING IN EGBEADA, IMO STATE, NIGERIA

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ABSTRACT

This study was carried out to evaluate the water yielding potentials of existing roof catchments of residential and public buildings in Egbeada, Imo state, Nigeria and to determine the optimum volume of storage to satisfy demand at both household and multi-household levels. The potential of the community for rainwater harvesting was assessed by subjecting 20 years of rainfall data to descriptive statistical analysis and application of appropriate mathematical formulae to calculate available roof areas, design population and water demand. Mass curve analysis and SimTanka simulation model were used to determine the optimum storage to satisfy water demand at the levels considered. The results of the statistical analysis shows that there is a much lower risk that rainwater harvesting will not meet the minimum water demand of the community. The mass curve analysis shows that monthly demands of 6 m^3 (25l/p/d), 8.4 m^3 (35l/p/d) and 9.6 m^3 (40l/p/d) can be met from tank storages of 25 m^3, 41 m^3 and 44.4 m^3, respectively at individual household level. The SimTanka simulation result shows that at individual level, when practiced as a complete water source, a daily water demand of 40l/p/d can be satisfied optimally at 99.8% from a storage of 63.5 m^3 all year round and if practiced as a partial water supply option(only during the dry season) a daily water demand of 60 l/p/d can be satisfied 100 % of the time from rain water storage of 65.5 m^3.However, at multi-household level only a daily demand of 15l/p/d can be satisfied at 100% of the time from a storage of 7,200 m^3. Greater potential exists for rooftop rainwater harvesting at the individual household level than at the multi - household level in Egbeada community.

Keywords: Design population, water demand, roof water yield, optimum storage

1.0 INTRODUCTION

Rooftop rainwater harvesting involves the collection of rainwater from roofs of buildings, its concentration in gutters and conveyance by pipes to a storage system for domestic and/ or animal uses and micro-irrigation (Kun et al., 2004; Mati, et al., 2005). The basic components of a rooftop rainwater harvesting consist of catchment area (roof), conveyance system (guttering, downspouts and piping) and storage tank (cisterns and tanks) (Villarreal and Dixon, 2005; Abdulla and Al-Shareef, 2007; Eroksuz and Rahman, 2010; Stringer et al., 2011; Traboulsi and Traboulsi, 2017).

Roof catchments are regarded as the most basic requirement of a rooftop rainwater harvesting system (RWHS) (Igbojionu, 2000; Olaoye and Olaniyan, 2012). Roofing materials that could be used for rooftop rainwater harvesting include aluminum, galvanized iron, tile and slate (Gould, 1993; Chang et al., 2004).

The conveyance system is required to transfer the water collected on the rooftops to the storage tanks and may consist of gutters and down-pipes. The gutters may be constructed of plain galvanized iron and aluminum sheets or local materials such as wood and bamboo (TWDB, 1997).

The water storage tank usually represents the biggest investment in rainwater harvesting system. Pacey and Cullis (1986) identified common vessels used for small scale water storage to include plastic bowls and buckets, jerry cans, drums and for large storage of rainwater, a tank (above ground storage vessel or a cistern (underground storage vessel). Many authors have emphasized that the sizing of the tank correctly to provide adequate storage capacity will determine reliability and sustainability of the system. The work of Thomas (1997) presented local rainfall data and weather pattern, roof sizes, runoff coefficient, which varies between 0.5 and 0.9, users number and consumption rate as factors that may determine storage requirements. Various methods have been used to arrive at hydrologically optimum volume of storage to satisfy a given demand. Ntale (1996) reported the use of such methods as mass curve analysis, behavior analysis, sequence peak algorithm and dimensionless design curve while Vyas (1999) illustrated the use of a personal computer based software (SimTanka) to obtain the optimal size of a covered storage tank. The programme requires at least 15 years monthly rainfall record, daily consumption per capita, population of users and area of catchment as input data.

Although there is an existing experience with rooftop rainwater harvesting in the area, the level at which it is being practiced is hardly sufficient to provide the much needed solution to the current water supply problem. Experience has shown that rooftop rain water harvesting can hardly augment the water needs of households during the dry season. Expanding the present scale at which rainwater harvesting is practiced in the area can fill in the gap needed to ensure all year round supply of water to the community. With the availability of suitable roof catchments and high precipitation, rooftop rainwater harvesting offers a viable option for augmenting the water needs of the community. Therefore, the broad objective of the study is to evaluate the potential of rainwater in meeting the water needs of the Egbeadacommunity at both individual household and multi-household levels.

2.0 MATERIALS AND METHODS

2.1 Description of the study area

The study area is Egbeada community in Ubomiri Mbaitoli L.G.A of Imo State, Nigeria situated on latitude 05°29' and longitude 07°26'. The annual rainfall varies from 1517 mm to 2750 mm with an average of about 2184 mm, mean annual temperature varies from 24.2 to 28°C, while annual humidity ranges between 60 to 89%. It is characterized by two distinct seasons; dry and rainy season. The dry season runs from November to February, while the rainy season starts in March and ends in October with a short break in August. According to 20 years rainfall record the average number of rainy days is estimated at 140.The projected population of the community is estimated at about 3000 inhabitants and has an estimated annual growth rate of 2.5 %. The average number of people per household is estimated at 8 while water consumption per capita is 30 l/p/d (National Population commission, 2006). The map showing the study area is as shown in figure 1. There is basically one type of roof in Egbeada – the galvanized corrugated iron sheets. The average roof area of residential buildings is 85 m^2 while the total roof area of public buildings suitable for RWHS is 6,100 m^2.

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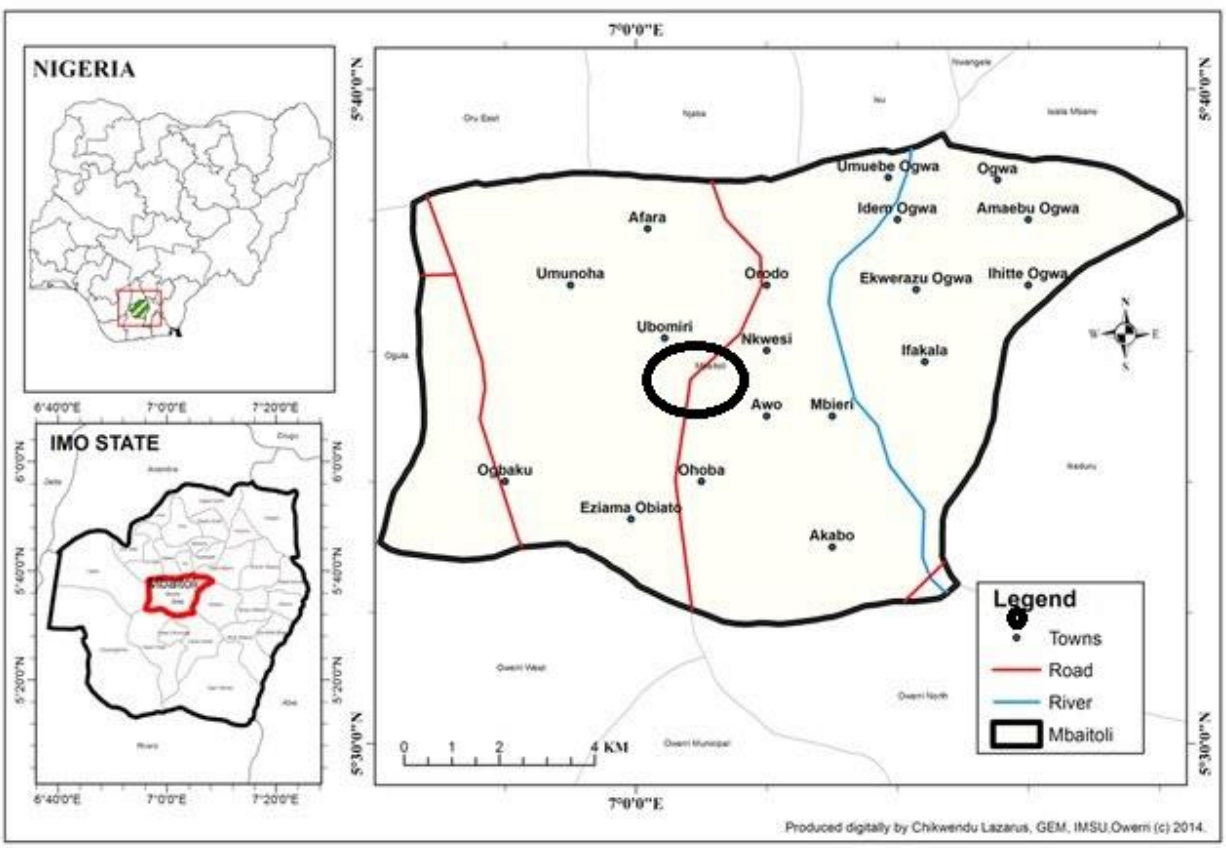

Figure 1: Map showing the study area Ministry of Land and Survey Owerri Nigeria (2014)

2.2 Method of data generation and analysis.

A head count was undertaken to determine the population of the study area. During the exercise the number of the buildings was also determined. The dimensions (lengths and widths) of roofs of residential and public buildings were physically measure as projections on a plane surface to determine their areas. The rainfall data for 20 years was collected from Meteorological Centre, Owerri, Imo State. The population of Egbeada for the design period of 10 years was computed and analysied using the formula:

$$P_f = P_c (1+r)^n \quad (1)$$

Where,

P_f is future/design population
P_c is current population
r is population growth rate in percent
n is design period in years.

Water demand during the dry season was computed using the equation;

$$D= P_n \times D_{pd}/1000 \times L \quad (2)$$

Where,

D is water demand in m^3;
P_n is design population;
D_{pd} is per capita water demand in l/pd;
L is length of dry period in days

The coefficient of variation (CV) which indicates how the data obtained vary from the mean was computed using equation (3)

$$Cv= \frac{\sigma}{\mu} \quad (3)$$

Where,

Y_r is monthly roof yield in m^3;
C is coefficient of runoff (0.9);
A_r is roof area in m^2;
R_m is monthly rainfall in mm.

SimTanka simulation model was used to calculate the optimal storage tank size for each of the roof catchments (residential and public buildings) taking into consideration, the past rainfall data of the area, daily water consumption per capita and roof areas. At the level of reliability chosen for the system, the software calculated the size of the tank and the percentage of time when demand can be met by the system. For the purposes of comparison of the sizing methods, conventional mass curve analysis was also used to estimate the reservoir capacity based on the plot of cumulative monthly roof runoff and cumulative monthly demand against time (month) for 3 consecutive dry years (1981 – 1983).

3.0 RESULTS AND DISCUSSION

Table 1: Probability of annual rainfall at Egbeada, Imo State, Nigeria

Equal to or greater than (years)	Number of years	Probability(% = or >)	Frequency
1500	20	100	1.00
1700	19	95	1.05
1900	16	80	1.25
2100	11	55	1.83
2184	10	50	2.00
2300	7	35	2.86
2500	4	20	5.00
2700	2	10	10.00

Table 2: Statistical parameters of rainfall at Egbeada, Imo State, Nigeria

Month	Minimum Rainfall	Maximum Rainfall	Mean Value	Standard Deviation	Coefficient of Variation(CV)
Jan.	0.40	78.2	16.6	24.3	1.46
Feb.	0.20	98.1	21.7	25.2	1.16
March	3.80	260.6	127.7	72.5	0.57
April	70.1	336.7	169.7	62.5	0.37
May	102.0	404.7	269.5	76.1	0.28
June	137.7	508.9	281.7	103.3	0.37
July	166.1	450.2	296.5	88.6	0.30
Aug.	103.0	481.4	329.4	104.5	0.32
Sept.	222.0	669.6	340.3	106.4	0.31
Oct.	74.50	498.9	265.9	116.6	0.44
Nov.	3.20	121.1	55.9	53.4	0.96
Dec.	0.70	35.3	9.1	11.3	1.23

The environmental feasibility of any rainfall harvesting system depends primarily on amount, the type of rainstorms, length of dry season and availability of other water resources. Rainfall characteristics of Egbeada show that there are great potentials for rainwater harvesting as water augmenting source.

An analysis of a 20 year rainfall data for the area yielded a mean annual rainfall of 2184 mm. the analysis also shows a minimum annual rainfall depth of 1517 mm and a maximum annual rainfall depth of 2750 mm. The average annual rainfall of 2184 mm when considered over a geographical area of 2.8 km^2 will give about 6.12 x 10^3 m^3 in form of rain. With an average household roof area of 85 m^2, a yield of about 167 m^3 is expected annually. When compared with annual household water demand of 175 m^3, it can be deduced that household rooftop rainwater harvesting system can guarantee about 95% of annual water demand for individual households. The calculated percentage probability of occurrence of different amounts of annual rainfall presented in table 1, shows at least 1500 mm of rainfall could be expected every year. On the average of once in 2 years, the rainfall may exceed 2184 mm (the mean annual rainfall) and once in 10 years it may equal or exceed 2700 mm. This therefore shows that the area has greater potential for rainwater harvesting. The coefficient of variability of rainfall during rainy season indicated in the table 2 ranges between 0.28 and 0.57. The purpose was to measure the relative dispersion of the data points sequence around the mean values, which is to show the difference. These values are low implying that there is a much lower risk that rainwater harvesting will not meet the minimum water demand of the community.

Table 3: Results of SimTanka Simulation

Complete water supply system at household level				
Roof area	Daily water	Monthly water	Percentage of time	Tank volume
	m^2	Demand (l/ p/d)	Demand (m^3)	m^3
85	25	6.2	100	31.2
85	30	7.44	99.9	36.2
85	35	8.68	99.9	43.6
85	40	9.92	99.8	63.5

Partial water supply at individual and multi-household levels				
85	60	15	100	65.5
6100	15	1743.75	100	7192.9

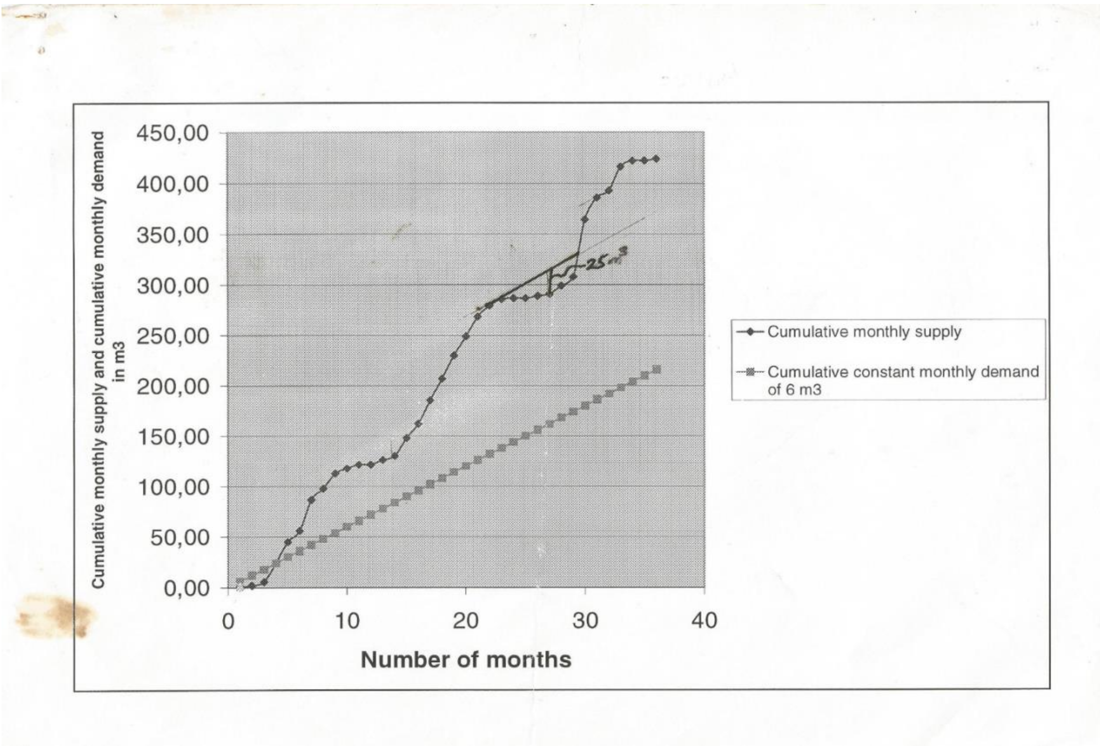

Figure 2: Mass curve diagram for estimating storage tank size for complete water supply at household level for monthly demand of 6 m^3 (25 l/p/d)

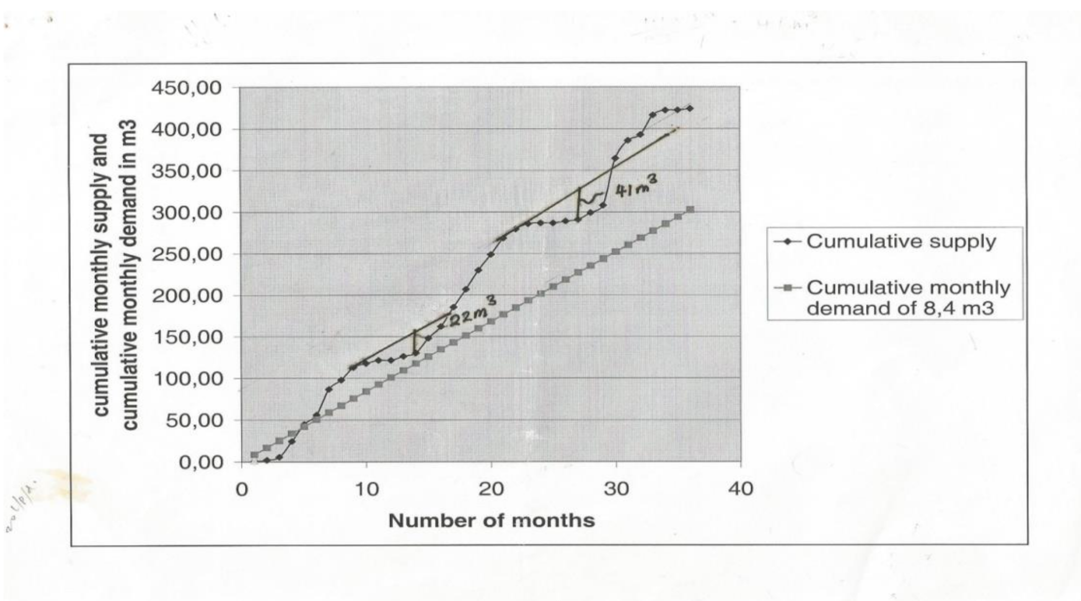

Figure 3: Mass curve diagram for estimating tank storage size for complete water supply at house hold level for monthly demand of 8.4 m^3 (35l/p/d).

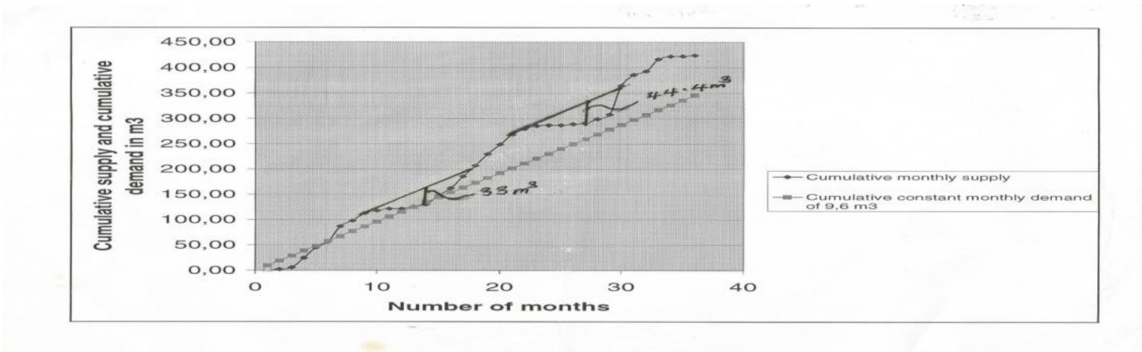

Figure 4: Mass curve diagram for estimating storage tank size for complete water supply at household level for monthly demand of 9. 6 m^3 (40 l/p/d).

The results of the SimTanka simulation presented in table 3 show that there are good potentials for rooftop rainwater harvesting as a complete water supply source or as a partial water supply option when practiced at the household level. For instance as complete supply source, monthly demands of 6.2m^3(25 l/p/d), 8.68m^3(35 l/p/d) and 9.92 m^3(40 l/p/d) can be met at an average of 100%, 99.9% and 99.5% all year round from rainwater tanks of 31.2m^3, 43m^3 and 63.5m^3respectively and as a partial water supply option a daily water demand of 60 l/p/d or monthly demand of 15 m^3 can be met 100% of the time during the dry season(November – February.) from rainwater storage of 65.5 m^3.

The results of the mass curve analysis presented in figures 2 – 4 confirm the high potentials of rooftop rainwater harvesting as water supply augmenting source at household level. For example as a complete water source, monthly demands of 6 m^3 (25 l/p/d), 8.4 m^3 (35 l/p/d) and 9.6 m^3 (40 l/p/d) can be satisfied from tank storages of 25 m^3, 41 m^3 and 44.4 m^3 respectively which compare favourably well with results obtained from SimTanka simulation (Vyas, 1999).

However, at multi-household level lower potentials exist for rooftop rainwater harvesting as a partial water supply option due to inadequate roof areas of existing public buildings. The results of the simulation in this regard indicate that only a daily demand of 15 l/p/d can be satisfied 100 % of the time during the dry season (November – February) from rainwater storage of 7,200 m^3. To make up for the shortfall, households should be encouraged to install a 10 m^3 rainwater collection system.

4.0. CONCLUSION

This study has enabled the potentials of the study area for rooftop rainwater harvesting as a water supply augmenting option to be assessed and quantified. The assessment shows that there are greater potentials for rooftop rainwater harvesting at household level than at the multi – household level due to roof catchment limitation. The study also shows that to overcome this limitation so as to make multi - household rooftop rainwater system viable each household needs to construct a tank with storage capacity of 10 m^3. Finally this work has illustrated how mass curve analysis and modern computer based tool can be used in water yield studies.

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