Nigerian Research Journal of Engineering and Environmental Sciences 5(1) 2020 pp. 399-410

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

Assessment of the Impact of Rainfall Variability on Rainwater Harvesting as an Alternative Domestic Water Supply in the Coastal Areas of Southeastern Nigeria

***Ubuoh, E.A., Ogbonna, P.C. and Egbe, C.A.**

Department of Environmental Management and Toxicology, Michael Okpara University of Agriculture, Umudike, PMB 7267, Umuahia, Abia State, Nigeria.
*ubuohemmanuel@yahoo.com

ARTICLE INFORMATION

Article history:
Received 17 Dec, 2019
Revised 21 Mar, 2020
Accepted 22 Mar, 2020
Available online 30 June, 2020

Keywords:
Rainwater harvesting
Rainfall variability
Rainwater potential
Coastal region
Sustainability

ABSTRACT

This paper assessed the effects of rainfall variability on domestic rainwater harvesting for human consumption as an alternative source of water supply in the coastal areas of Akwa Ibom State, Nigeria. To achieve this, rainfall data for 20 years (1989-2008) was collected from meteorological stations in Akwa Ibom State. Rainfall variation was determined using the coefficient of variation of the monthly rainfall data. Rainwater harvesting potential was evaluated using supply side approach (SSA). The estimation was done by multiplying the iron roof area (150 m^2) with a coefficient (0.9). The results indicated that monthly rainfall variability ranges between 18.39 mm -378.63 mm, with September recording the highest mean value and January had the lowest mean value. Mean annual rainfall variability ranged between 145.6-440.7 mm with 1990 having the lowest annual mean value and 1993 having the highest annual mean. There was a gradual increase in rainfall in April and dropped in July and its peak in September with the maximum storage capacity of 98 m^3 (983,000 liters harvested rain. The result further indicated that the total demand line for rainwater consumption was 18,000 liters above the 20 liters United Nations Standard for rural communities for collecting and storing water for potable and non-potable uses. It is then recommended that rainwater harvested should pass through proper treatment with emphasis on operation and maintenance (O&M) for quality assurance due to incessant gas flaring in the region.

1. INTRODUCTION

Water is one of the basic human needs and requirement for daily living which may be sourced from surface water, groundwater, or rainwater (Gleick, 1996). According to Fang *et al* (2007), Wheida and Verhoeven (2007), available water supply sources are diminishing owing to population rise, climate change, and pollution, causing a globally acknowledged situation of water scarcity, especially in developing countries. Rainwater harvesting (RWH) is any human activity involving collection and storage of rainwater in some natural or artificial container either for immediate use or use before the onset of the next season for domestic, agricultural, industrial and environmental purposes (Kun *et al.,* 2004; Mati *et al.,* 2005).

Rainwater harvesting consists of a wide range of technologies used to collect, store and provide water with the particular aim of meeting the demand for water by humans and/or human activities (Ngigi, 2003; Malesu *et al.*, 2006). It is often an intervention intended to augment the provisioning services of the environment for human well-being (UNEP, 2009). Rainwater harvesting has been proposed and practiced as one of the alternatives to improve water supply especially in rural and peri-urban areas of low-income countries (Cruddas *et al.*, 2013), areas without reticulated water supply (Ndiritu *et al.*,2011), water-scarce, remote and marginalized areas (Nijhof *et al.,*2010), areas where existing water supply is inadequate (Aladenola and Adeboye, 2010), areas with abundant annual rainfall (Ghis and Schondermark, 2013), highly contaminated and saline coastal areas (Samaddar *et al.*, 2014) as well as arid and semi-arid regions (Abdulla and Al-Shareef, 2009).

Notwithstanding the benefits as outlined by Ubuoh (2012), rainwater harvesting and infrastructure are affected by rainfall variability (Aladenola and Adeboye, 2010; Adegoke and Sojobi, 2015; Balogun *et al*, 2016). According to Omogbai (2010), sea surface temperature of the tropical Atlantic Ocean and land–sea thermal contrast between sea surface temperature and rainfall stations are responsible for 87% of rainfall variability in South-west Nigeria, while surface location of inter-tropical discontinuity and land surface temperature of rainfall stations are responsible for 7 and 6% of rainfall variability in Southern Nigeria. Akinsanola and Ogunjobi (2014) attributed rainfall variability to local factors such as topography; boundary layer forcing and moisture build up.

Study of rainfall variability is very important because it has been found to affect adequate rural water supply need and food production in the southwest of Nigeria (Adegoke and Sojobi, 2015). Factors working against the practicability and scaling of domestic rainwater harvesting include use of poor roofing materials and high cost of storage tank (Opare, 2012; Cruddas *et al.*, 2013), huge capital cost of acquisition, installation and maintenance of domestic rainwater systems (Roebuck *et al.*, 2011), limited knowledge of the potentials of rainwater harvesting (Kohlitz and Smith, 2015), lack of finance, legislation and coordination (Mwénge *et al.*, 2011), space requirements (Traboulsi and Traboulsi, 2015), poor quality of domestic rainwater (Oke and Oyebola, 2014), levels of atmospheric pollutants (Ubuoh *et al.*, 2012), lack of skills (Kalungu *et al.,* 2014), lack of social capital (Esterhuyse, 2012), risk of waterborne diseases (Mwenge *et al* , 2007) , while the quality of rainwater harvested depends on roof type, level of atmospheric pollution, geographical location, container size, catchment characteristics, land use practices and local climate (Ubuoh *et al.,* 2012; Balogun *et al.,* 2016).

It has been reported that the benefits of domestic RWH include achievement of water savings (Barroso and Amado, 2013; Bocanegra-Martinez *et al.*, 2014;), mitigation of storm run-off and conservation of potable water (Campisano et al, 2013), financial savings and cost-effective improvement of urban drainage systems (Słyś and Stec, 2014), aquifer recharge (Clark et al., 2015) and reduction of drinking water risks in highly contaminated and saline coastal areas (Samaddar *et al.*, 2014). Campisano et al. (2013) found that frequent precipitation increases the performance of domestic rainwater harvesting (DRWH) and that the water-saving efficiency depends on storage tank size, demand fraction, storage fraction and climate. Notwithstanding this predominance of rivers and streams which are sources of water supply needs for the people, the preponderance of the pollution substances in the area due to oil and gas exploration and exploitation (Ubuoh, 2012) necessitates the need for rainwater harvesting to compliment shortage in domestic water in the area. Although in the southern part of Akwa Ibom State, rainwater is always suspected of acid precipitation due to the continuous gas flaring by Mobil Oil Company (Akpan, 2003; Ekop and Udotong, 2004; Akpan and Umana, 2007), Besides corrosion of zinc roofing sheets by acid rain (Ubuoh, 2012), and saline water intrusion in nearby coastal aquifers (Oyeyemi *et al*., 2015; Ubuoh *et al*., 2017), has been acclaimed all over the world to pose a threat to the sustainable development of rainwater harvesting and economic wellbeing of dwellers in any coastal areas (Oyeyemi *et al.,*2015; Ubuoh *et al.,* 2017). Based on this assertion there is need for atmospheric rainwater harvesting as an alternative source of water supply in the study area for sustainability. This study is, therefore, aimed at the assessment of rainfall variability for domestic rainwater harvesting as a solution to water resource development need in the coastal regions of Nigeria.

2. MATERIALS AND METHODS

2.1. Study Area

This study was conducted in Akwa Ibom State in Southern part of Nigeria. The State has an ocean front which spans a distance of 129 kilometers from Ikot Abasi in the west to Oren in the southeast and is located between latitudes 4° 30′ and 5 ° 30 ′ N and longitudes 7°30′ W and 8°20′ E (Figure 1). It occupies an area of about 6,900 km^2. It is characterized by mangrove swamps, tidal creeks and brackish lagoon. The area is characterized by two seasons, namely, the wet or rainy season and the dry season. The wet or rainy season lasts for about eight months beginning from March- April and lasts until mid - November with an average annual rainfall of approximately 4000 mm. The area is subjected to constant inundation by saline and brackish water (Edet and Okereke, 2001; Ubuoh *et al.*, 2017).

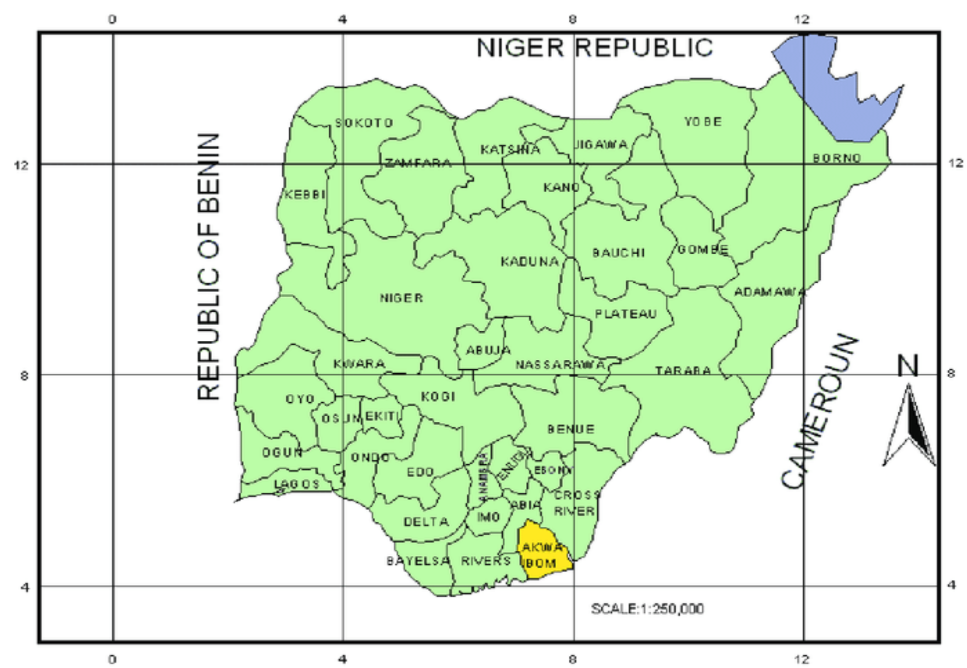

Figure 1: Map of Akwa Ibom State showing study area

2.2. Rainfall Data Collection

Rainwater data was collected from National Meteorological Station (NMS) in Uyo, Akwa Ibom State for the period of 20 years (1989 -2008). Rainfall variability has been accepted as a useful parameter to estimate the reliability of rainfall over any area within a specific time (Ekanem, 2010). Rainfall variation was determined through the coefficient of variation of the monthly rainfall (*CVm*) according to Aladenola and Adebayo (2010).

$$CV_m = \frac{Sv}{Va} \quad (1)$$

Where *CVm* = coefficient of variation of the monthly rainfall, *Sv* = standard deviation of the monthly rainfall (mm) and *Va* = mean of the monthly rainfall (mm)

2.3. Catchment Surface

The rainwater harvesting potential was evaluated by using supply side approach (SSA) which involve: runoff, area of catchments and coefficient of runoff for galvanized iron roofing sheets (0.9) which is constant (Gould and Nissen-Petersen, 1999). The estimation of rainwater available from rooftop for harvesting was calculated by multiplying the roof area (length x breath) (150 m^2) with the coefficient (0.9) and the mean monthly historical rainfall data**.** It was calculated by using Equation 2 (Gould and Nissen- Petersen, 1999).

$$S = R \times A \times Cr \quad (2)$$

Where R = Mean annual rainfall in m, A = Catchment area in m^2 and Cr = Coefficient of runoff

2.4. Storage Tank Capacity

Using daily rainfall data for 20 years, the average monthly rainfall was determined and multiplied by an assumed RA of 80 m^2 and a runoff coefficient of 0.9 in order to obtain monthly volumes of runoff in liters. From the monthly volumes, the cumulative monthly volumes were obtained and both were plotted. On the same graph, a constant demand line was drawn assuming constant withdrawal for a whole year. The maximum difference between the demand line and the cumulative rainfall gave the storage capacity of a tank to store all the rainwater obtained.

2.5. Statistical Technique

A descriptive statistical analysis was applied to rainfall data to examine their central tendency (mean, asymmetry and variance), variability (standard deviation). It was assumed that the annual monthly maximum rainfall data as a normal distribution and considered a single-tailed test. This analysis was performed according to the methodology proposed by Ahammed *et al.* (2014). Standardization of data was performed in order to eliminate potential data redundancy and inconsistent dependencies in a historic record rainfall (1989–2008) based on Ahammed *et al.* (2014).

3. RESULTS AND DISCUSSION

Table 1 shows the summary of the mean monthly rainfall distribution for the study area for 20 years events. From Table 1, the mean monthly rainfall variability for 20 years ranged between 18.39-378.63 mm, with the month of September having the highest mean value, with SD: 49.98 and CV: 13.20 % and January having the lowest mean value with SD: 54.00 and CV: 293.6% respectively. Based on Table 1, a gradual and constant increase in rainfall from January and the peak in the month of September were observed, with April marking the beginning of the peak.

Table 1: Mean monthly rainfall distribution for the study area (mm) (1989-2008)

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
Mean (mm)	18.39	37.93	129.35	190.28	286.83	300.99	310.05	336.79	378.63	268.17	102.29	23.71
SD	54.00	48.37	21.98	4.39	23.48	27.57	30.18	37.90	49.98	18.09	29.79	52.48
CV (%)	293.6	127.5	16.99	2.31	8.19	9.16	9.73	11.25	13.20	6.75	29.12	221.34

SD= Standard deviation, CV= Coefficient variance

The result agreed with the finding of Omolara and Oloke (2013) who reported that heavy rainfall is concentrated from April to October in Ibadan, Nigeria. However, from September, a sudden decrease in the quantity/volume of rainfall down to December was observed, indicating a possible reduction in rainfall, pointing to the need for increasing resilience in the water supply.

Table 2: Statistical summary of mean annual rainfall distribution for the study area (mm) (1989-2008)

S/N	Year	Mean(mm)	Standard Deviation (SD)	Coefficient of variance (CV) (%)
1	1989	198.6	946.15	476.41
2	1990	145.6	957.99	657.96
3	1991	198.3	946.21	477.16
4	1992	167.4	953.13	569.37
5	1993	440.7	892.01	202.41
6	1994	191.6	947.71	494.63
7	1995	221.6	941.06	424.67
8	1996	205.0	944.72	460.84
9	1997	182.2	949.86	521.33
10	1998	223.7	940.53	420.44
11	1999	195.8	946.77	483.54
12	2000	224.9	940.27	418.08
13	2001	200.6	945.70	471.44
14	2002	200.3	945.77	472.18
15	2003	179.3	950.46	530.09
16	2004	180.1	950.28	527.64
17	2005	234.2	938.19	400.59
18	2006	397.7	901.63	226.71
19	2007	258.6	932.73	360.68
20	2008	183.7	949.47	516.86

From Table 2, mean annual rainfall variability in the area ranged between 145.6 -440.7 mm, with SD ranging from 892.01 to 957.99, and CV from 202.41% to 657.96% with 1990 recording the lowest annual mean value and 1993 having the highest annual mean value of rainfall respectively.

Table 3 shows the spreadsheet calculation for the study area. The rainfall data were gleaned from Akwa Ibom State Meteorological station as historical data for 20 years. Mean figures for the rainfall data were used to simplify the calculation signifying a typical field approach to rainwater harvesting storage sizing as shown in Table 3. Monthly rainfall ranged between 23.7-376.63 mm showing December -September periods and monthly rainwater harvested ranged between 2.5 - 51.1 Liters with a total of 308.3 L. Rainwater demand per month is 18000 Litres with the total being 216000 L, and monthly demand for domestic rainwater (DRW) ranging between 18-216 Liters, and the difference between total rainfall harvested (TRH) and monthly total demand (MTD) being 98.3 Liters. Afahakan *et al.* (2016) reported the average rainfall rate for Uyo at about 144 mm/hr. Similar work carried out in Ajayi and Ezekpo (1988), puts the rainfall rate for Uyo at 125 mm/hr.

Omotosho and Oluwafemi (2009) presented a value of 124 mm/hr for Uyo. It should be noted that these two works were done with rain data collected over a 30-year period, and 9-year period respectively.

Table 3: Rainwater harvested in the study area between (1989-2009)

Months	Mean monthly-rainfall (mm)	Monthly rainfall harvested (Liters) (000)	Total rainfall harvested (Liters) (000)	Rainwater demand: utilization (Liters) (000)	Monthly total demand (Liter) (000)	Difference between total rainfall and rainwater demand (Liters) (000)
Oct.	268.168	36	36	18	18	18
Nov.	102.29	13.8	50.0	18	36	14
Dec.	23.77	3.2	53.2	18	54	-1
Jan.	183.9	2.5	55.7	18	72	-16
Feb.	37.93	5.1	60.8	18	90	-29
Mar.	129.35	17.5	78.3	18	108	-30
Apr.	190.28	25.7	104.0	18	126	-22
May	286.83	38.7	142.7	18	144	-1
Jun.	300.985	40.6	183.3	18	162	21
Jul.	210.05	28.4	211.7	18	180	32
Aug.	336.79	45.5	257.2	18	198	77
Sept.	378.63	51.1	308.3	18	216	98.3
Total		308.3		216		

Figure 2 shows the comparison of rainwater harvested and the amount that can be supplied to consumers using cumulative rainwater harvested. The first month which rainfall on the roof meets the demand is the month of March. From the month of April, rainwater was above demand line (DL), while for Nov –Feb, it was below the DL, indicating deficit in rainwater harvesting. During the month of March, rainfall was proportionate to demand marking the beginning of storage being first rain though with poor quality (Ubuoh 2012). According to Woltersdorf *et al.* (2015), while the quality of rainwater harvested depends on roof type, level of atmospheric pollution, geographical location, container size, catchment characteristics, land use practices and local climate. Meanwhile, there was a gradual increase in rainfall during April –June and slightly dropped in July with the peak being September.

Figure 3 shows variability of rainwater harvested from the catchments for the period of 20 years. The line drawn across represents total demand for harvested rainwater for each month, and the bars represent total rainwater harvested for 20 year period in the study area. There was also gradual increase in rainfall intensity after dry season event with total rainwater harvested in the month of June (183.3 Liters) and a maximum storage in the month of September (308.3 Liters).

The months of January -16 m^3 (-16,000 liters), February -29 m^3 (-29,000 liters), March -30 m^3 (-30,000 liters), April -22 m^3(-22,000 litres) and May -1 m^3 (-1000 liters) (Figure 4) were below line of total demand (cumulated for a period of 20 year respectively. The findings of the present study showed that the, the mean monthly rainfall variability for 20 years ranged between 18.39 -378.63 mm, with the high rainfall intensity in the month of September running to January rain events. In agreement with this, studies conducted in Addis Ababa, Ethiopia Adugna *et al.* (2018) reported that during inter annual variability, most of the rain falls within the four rainy months from June through September that store significant quantity of the potable water. A study conducted in Nigeria by Aladenola and Adeboye (2013), Steffen *et al.*, (2013) also reports that RWH can considerably contribute to supplementing the water supply, except for the dry months

November, December, January, and February. The excess rainwater can be stored and utilized for the later dry months provided there will be adequate storage facilities (Adugna *et al.,* 2018). This shows that despite rainfall variability, there is no month of the year that the study area does not experience rainfall. The result is consistent with the finding of Ekanem (2010) who reported that there is no time or month of the year that Akwa State does not experience frontal rainfall with the variation in quantity.

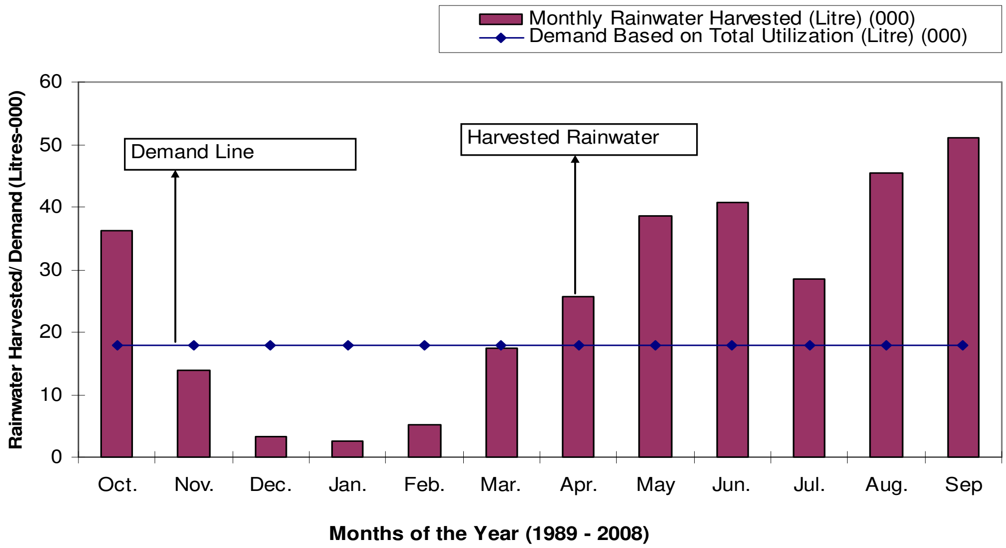

Figure 2: Comparison of rainfall harvested with demand based on total utilization

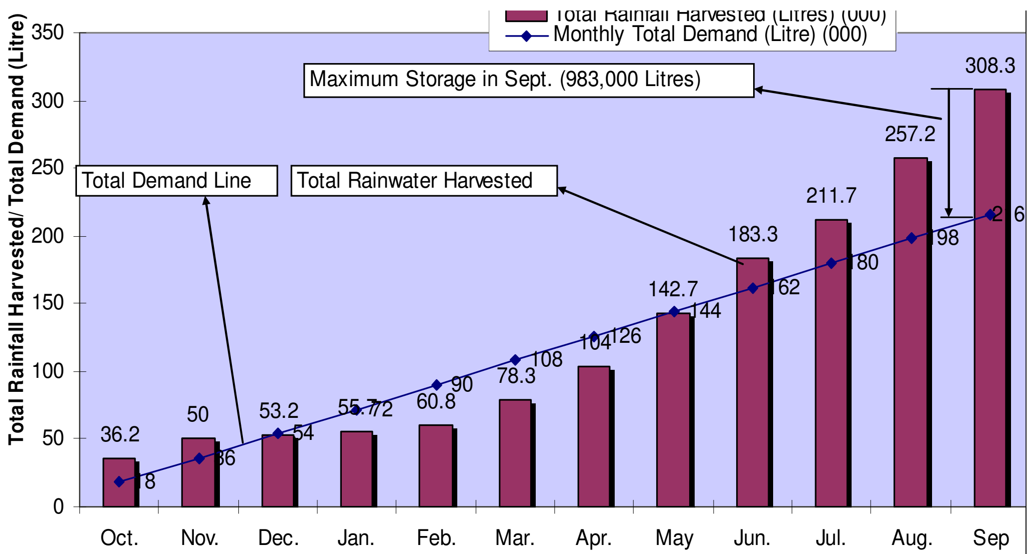

Figure 3: Rainwater harvested with maximum storage requirement in September

E.A. Ubuoh et al. / Nigerian Research Journal of Engineering and Environmental Sciences
5(1) 2020 pp. 399-410

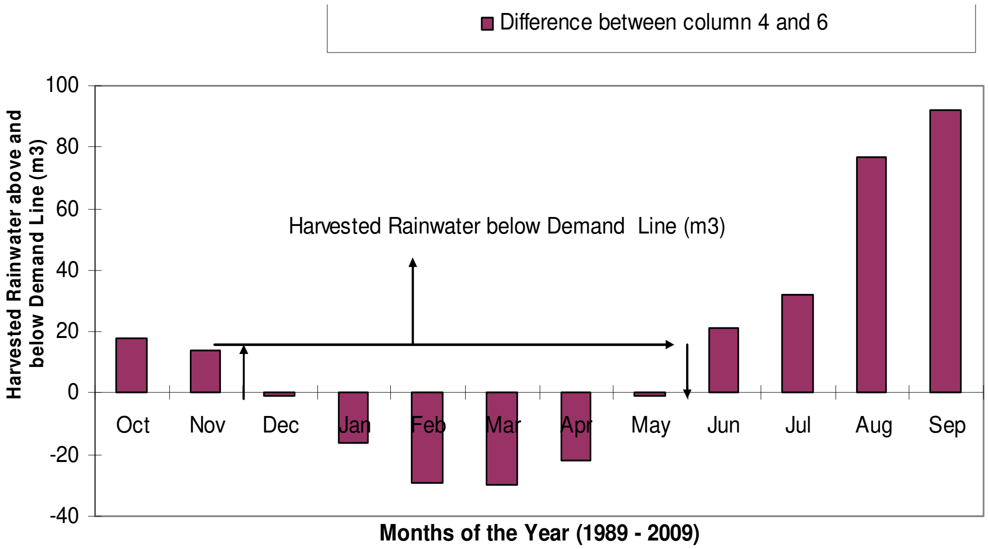

Figure 4: Identification of harvested rainwater below and above demand line

The mean annual rainfall ranged between 145.6-440.7 mm, with the average annual rainfall total of 2550 mm greater than 2500 mm obtained by Ekanem (2010). From the result, it is observed that, average monthly rainfall for 20 years rain event determine the volume of rainwater to be harvested for domestic uses and this was based on the consumption level which was found to be 18 m^3 (18,000 litres), with rooftop area (RA) of 80 m^2 and a runoff coefficient of 0.9 for application respectively. This is in agreement with the finding of Omolara and Oloke (2013) who indicated that an average roof of 80 m^2 will collect 82,835 L/yr (45 L/person/day) for a family of five people which is about the required water demand for drinking and cooking purposes. The result reflects a climate with strong seasonality in rainfall (Adugna *et al.*, 2018). From the results, the months of January, February, March -April) and May were below line of total demand 20 years rainfall events. This indicates that there will be deficits during these months which coincided with the dry season, hence the need for storage capacity to meet daily demand during the dry season. The month of October 18 m^3 (18,000 litres) marks the beginning of rainfall and has the lowest rainwater harvested of 36,000 litres and November 14 m^3 (14,000 litres) are the months indicating marginal storage for the years. Hence harvested rainwater will have to be stored early to cover the shortfall during the dry period. The maximum storage capacity needed to meet demand throughout the year at household level occurs in September as 98 m^3(983,000 litres). This is inconsistent with the finding of Omolara and Oloke, (2013) who observed 82,835 L/yr (45 L/person/day) during October as the maximum storage requirement in Ibadan, and that the maximum storage is required in October with an additional storage capacity of 17 m^3 (17,000 L). The difference in storage capacity could be due to different in the geographical locations e.g nearness to the coast, types of prevailing wind etc. It has been reported that the quantity of rainwater harvested depends on monthly precipitation, roof catchment area and roof run-off coefficient (Woltersdorf *et al.*, 2015). According to United Nations, it is assumed that 20 liters/capita/day water is inevitable for the rural communities in the developing countries (Agarwal and Narain, 1997). The United Nation targets it as minimum water requirement for all domestic purpose including personal hygiene. The norms were set during International Drinking Water Supply and Sanitation Decade (IDWSS). Out of this 20 liters/capita/day water, 10 liters/capita/ day is only for drinking and cooking purpose. From the results, it is then observed that rainwater harvesting potential is eminent in the study area, since the total demand line for rainwater consumption is

18,000 litres with the maximum storage month of September more than 20 litres recommended by the United Nations. But the months of January, February, March and April are deficit in terms of the volume of rainwater for storage, pointing to the need for increasing resilience in the water supply during these periods (Figure 4). The challenge is the pollution of rainwater by acid rain in the study area (Ubuoh, 2012; Dami *et al*., 2012). In line with the pollution of rainwater in this region , Efe (2006) suggested primary treatment to take care of pH, TSS, Fe and colour and preference for aluminium roofing sheets compared to other materials such as corrugated, thatch, asbestos and open surface, while Helmreich and Horn (2009) recommended the use of local materials, skills and equipment to reduce cost Recent researches have also shown that the quality of DRWH can be improved by point-of-use treatment, integration of water safety plans, quarterly testing and utilization of weather-resistant materials such as ceramic tiles, public education and regular maintenance (Fry *et al.,* 2010; Kwaadsteniet *et al*., 2013; Thomas et al., 2014; Zhang *et al.,* 2014; Gwenzi *et al*., 2015; Kohlitz and Smith, 2015).

4. CONCLUSION

The findings of the present study indicated that rainfall was experienced throughout the twenty years. There was a gradual increase in rainfall during April –June and dropped in July and the peak in September with the maximum storage of harvested rainwater as 98 m^3 (983,000 litres). The total demand line for rainwater consumption recorded 18,000 litres above the 20 litres United Nations recommended standard for rural communities. Therefore, **t**o narrow the gap of water supply in the coastal environment, domestic rainwater harvesting (DRWH) as an alternative water supply source is recommended. However, harvested rainwater must pass through an operation and maintenance (O&M) for quality assurance for human consumption.

5. ACKNOWLEDGMENT

The authors wish to acknowledge the assistance and contributions of the staff and students of the Department of Soil and Water Engineering, Federal College of Land Resources Technology (FECOLART) Owerri, Imo State, toward the completion of this research work.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Abdulla, F.A. and Al-Shareef, A.W. (2009). Roof Rainwater Harvesting System for Household Water Supply in Jordan. *Desalination,* 243, pp. 195-207.

Adegoke, C. W. and Sojobi, A. O. (2015). Climate change impact on infrastructure in Oshogbo metropolis, south-west Nigeria. *Journal of Emerging Trends in Engineering and Applied Sciences, 6*, pp. 156–165.

Adugna, D. Jensen, M. B. Lemma, B. and Gebrie, G. S. (2018). Assessing the Potential for Rooftop Rainwater Harvesting from Large Public Institutions. *International journal of environmental research and public health*, 15(2), p. 336.

Afahakan. E. Udofia, K.M. and Umoren, M. A. (2016). Analysis of rain rate and rain attenuation for eart analysis of rain rate and rain attenuation for earth rate and rain attenuation for earth-space communication links over communication links over Uyo -Akwa Ibom State. *Nigerian Journal of Technology* (NIJOTECH), 35(1), pp. 137 – 143.

Agarwal, A. and Narian S. (1997). Rise, fall and Potential of India's Traditional Water Harvesting System, *Centre for Science and Environment*, New Delhi, India, No. 4, p..404.

Ahammed, F., Alankarage-Hewa, G. and Argue, J.R. (2014). Variability of annual daily maximum rainfall of MDhaka, Bangladesh. *Atmospheric Research*, 137, pp. 176–182.

Ajayi, G.O. and. Ezekpo, S.U.B. (1988). Development of climatic maps of rainfall rate and attenuation for microwave applications in Nigeria. *Nigeria Engineering Journal,* 23(4), pp. 13-30.

Akinsanola, A. A. and Ogunjobi, K. O. (2014). Analysis of rainfall and temperature variability over Nigeria. *Global Journal of Human Social Sciences: Geography & Environmental GeoSciences*, *14*(3), pp. 1–18.

Akpan, E. R. and Umana U. A. (2007). Occurrence and Intensity of Acid Rain in the Niger Delta area of Nigeria. *Eroscience,* 3 (1), pp. 12 -15.

Akpan, E. R. (2003). Acidic Precipitation and Infrastructural Deterioration in oil producing communities in Akwa Ibom State. A case study of Eket, South Eastern, Nigeria. *Journal of Environmental Science,* 2(1), pp. 47 – 52.

Aladenola, O. and Adeboye, O. (2010). Assessing the Potential for Rainwater Harvesting. *Water Resources Management, 24*, pp. 2129–2137.

Balogun, I., Adebayo, O.S. and Bosede, O.O. (2016). Assessment of rainfall variability, rainwater harvesting potential and storage requirements in Odeda Local Government Area of Ogun State in South-western Nigeria. *Cogent Environmental Science*, 2, pp. 113859.

Barroso, L. M. and Amado, M. P. (2013). Sustainable construction: Water use in residential buildings in Portugal. *International Journal of Sustainable Construction Engineering and Technology,* 4, pp. 14–22.

Bocanegra-Martinez, A., Ponce-Ortega, J.M.P., Napoles-Rivera, F., Serna-Gonzalez, M., Castro-Montoya, A.J. and El-Hawagi, M. M. (2014). Optimal design of rainwater collecting systems for domestic use into a residential development. *Resources, Conservation and Recycling*, 84, pp. 44-56.

Campisano, A., Gnecco, I., Modica, C. and Palla, A. (2013). Designing domestic rainwater harvesting system pp. 2511–2518.

Clark, R., Gonzalez, D., Dillon, P., Charles, S., Cresswell, D. and Naumann, B. (2015). Reliability of water supply from stormwater harvesting and managed aquifer recharge with a brackish aquifer in an urbanising catchment and changing climate. *Environmental Modeling and Software, 72*, pp. 117–125.

Cruddas, P., Carter, R., Parker, A., Rowe, N. and Webster, J. (2013). Tank costs for domestic rainwater harvesting in East Africa. Proceedings of ICE: *Water Management,* 166(10), pp. 536- 545.

Dami, A., Ayuba, H. K. and Amukali, O. (2012). Effects of Gas Flaring and Oil Spillage on Rainwater Collected for Drinking in Okpai and Beneku, Delta State, Nigeria. *Global Journal of Human Social Science Geography & Environmental Geoscience,* 12(13), pp 25- 29.

Dobrowsky, P. H.. Mannel, D., De-Kwaadsteniet, M., Prozesky, H., Khan, W. and Cloete, T. E. (2014). Quality assessment and primary uses of harvested rainwater in Kleinmond, South Africa. *Water SA,* 40, pp. 401–406.

Edet, A. E. and Okereke, C.S. (2001). Monitoring Seawater Intrusion in the Tertiary-Quaternary aquifer system, Coastal Akwa Ibom area, Southeastern Nigeria-Baseline data University of Calabar. *First International Conference on Saltwater Intrusion and Coastal Aquifers— Monitoring, Modeling, and Management. Essaouira*, Morocco, April 23–25, 2001.

Efe, S. I. (2006). Quality of rainwater harvesting for rural communities of Delta State, Nigeria. *The Environmentalist*, 26, 175–181.

Ekanem, M. E. (2010). *Climate Characteristics*: Akwa Ibom State. A Geographical Perspective: A Special Publication of the Department of Geography and Regional Planning, University of Uyo. Etop J. Usoro and Philip A. Akpan. (Eds). Immaculate Publication Limited. pp. 91-99.

Ekop, O.B. and Udotong, I.R. (2004). Air Quality, Precipitation and Corrosion studies of Mbo Local Government Area, Nigeria *International Journal of Environmental Issues*, 2(1& 2). pp. 33-43.

Esterhuyse, P. (2012). Social capital in a rainwater-harvesting project in rural South. *Irrigation and Drainage*, 61(52), pp. 95-105.

Fang, C.L., Bao, C. and Huang, J.C. (2007). Management implications to water resources constraint force on socio-economic system in rapid urbanization: A case study of the Hexi Corridor, NW China. *Water Resources Management,* 21, pp. 1613–1633.

Fry, L. M. Cowden, J. R. Watkins, J. W., Clasen, T. and Mihelcic, J. R . (2010). Quantifying Health Improvements from Water Quantity Enhancement: An Engineering Perspective Applied to Rainwater Harvesting in West Africa. Environmental *Science and Technology*, 44, pp. 9535–9541.

Ghis, E. and Schondermark, P. V. (2013). Investment feasibility analysis of rainwater use in residences. *Water Resources Management, 27*, pp. 2555–2576.

Gleick, P.H. (1996). Basic water requirements for human activities: Meeting basic needs. *Water International*, 21, pp. 83–92.

Gould, J. and Nissen-Petersen, E. (1999). *Rainwater catchment systems for domestic supply*. Intermediate Technology.

Gwenzi, W., Dunjana, N., Pisa, C., Tauro, T. and Nyamadzawo, G. (2015). Water quality and public health risks associated with roof rainwater harvesting systems for potable supply: Review and perspectives. *Sustainability of Water Quality and Ecology, 6*, pp. 107–118.

Helmreich, B. and Horn, H. (2009). Opportunities in rainwater harvesting. *Desalination*, 248, pp. 118 – 124.

Kalungu, J. W., Filho, W. L., Mbuge, D.O. and Cheruiyot, H. K. (2014). Assessing the impact of rainwater harvesting technology as adaptation strategy for rural communities in Makueni County, Kenya. In: W. L. Filho (Ed.), *Handbook of climate change adaptation* (pp. 1–17). Berlin: Springer-Verlag.

Kohlitz, J. P. and Smith, M. D. (2015). Water quality management for domestic rainwater harvesting systems in Fiji. *Water Science and Technology: Water Supply, 15*, pp. 134–141.

Kun, Z, Linus Z, William H, Mancang L,and Hui, C. (2004). Quality issues in harvested rainwater in arid and semi – arid Loess Plateau of northern China. *Journal of Arid Environment*. 57(4):487 -505.

Kwaadsteniet, M., Dobrowsky, P., Deventer, A., Khan, W. and Cloete, T. (2013). Domestic rainwater harvesting: Microbial and chemical water quality and point-of-use treatment systems. *Water, Air & Soil Pollution, 224*(7): pp. 1–19.

Malesu, M. M. Sang, J. K., Oduor, A. R. Odhiambo, O. J. and Nyabenge, M. (2006). Rain water harvesting innovations in response to water scarcity: The Lare experience, Technical Manual No. 5, World Agroforestry Centre, Nairobi, Kenya.

Mati, B. M., Matesu, M. and Oduor, A. (2005). Promoting rainwater harvesting Eastern and Southern Africa. The Relma experience. *World Agroforestry centre:* Kenya, Nairobi

Mwenge, K. J., Taigbenu, A. E. and Boroto, J. R. (2007). Domestic rainwater harvesting to improve water supply in rural South Africa. *Physics and Chemistry of the Earth*, Parts A/B/C, 32,pp. 1050–1057.

Mwenge, K.J. and Taigbenu, A. (2011). Rainwater harvesting in South Africa: Challenges and opportunities. *Physics and Chemistry of The Earth* - Parts A/B/C, 36(14/15)

Ndiritu, J. Odiyo, J. O. Makungo, R. Ntuli, C.,and Mwaka, B. (2011). Yield-reliability analysis for rural domestic water supply from combined rainwater harvesting and runoff- river abstraction. *Hydrological Sciences Journal, 56*, pp. 238–248.

Ngigi, S. N. (2003). What is the limit of up- scaling rainwater harvesting in a river basin? *Physics and Chemistry of the Earth* 28 pp. 943 - 956.

Nijhof, S. Jantowski, B. Meerman, R. and Schoemaker, A. (2010). Rainwater harvesting in challenging environments: Towards institutional frameworks for sustainable domestic water supply. *Waterlines, 29*, pp. 209–219.

Oke, M. and O. Oyebola, O. (2014). Assessment of rainwater harvesting potential and challenges in Ijebu Ode, South Western part of Nigeria for strategic advice. Scientific Annals of Al. I. Cuza *University of Iaş Volume LX, no. 2., s. II – c, Geography series, 2014* scigeo.v60i2.345.

Omogbai, B. E. (2010). Rain days and their predictability in South-western region of Nigeria. *Journal of Human Ecology, 31*, pp. 185–195.

Omolara, L. and Oloke, D. (2013). Assessment of Rainwater Harvesting Potential in Ibadan, Nigeria. *Environmental Engineering Research*, 18(2), pp. 91-94.

Omotosho, T.V. and Oluwafemi, C.O. (2009). One-minute rain rate distribution in Nigeria derived from TRMM satellite data. *Journal of Atmospheric and SolarTerrestrial Physics* 71(5): pp. 625-633.

Opare, S. (2012). Rainwater harvesting: An option for sustainable rural water supply in Ghana. *GeoJournal, 77*, pp. 695–705.

Oyeyemi, K. D. Aizebeokhai, A.P and Oladunjoye, M. A (2015). Integrated Geophysical and Geochemical Investigations of Saline Water Intrusion in a Coastal Alluvial Terrain, Southwestern Nigeria. *International Journal of Applied Environmental Sciences* 10(4) pp. 1275-1288.

Roebuck, R. M. Oltean-Dumbrava, C. and Tait, S. (2011). Whole life cost performance of domestic rainwater harvesting systems in the United Kingdom. *Water and Environment Journal, 25*, pp. 355–365.

Samaddar, S. Murase, M. and Okada, N. (2014). Information for disaster preparedness: A Social network approach to rainwater harvesting technology dissemination. *International Journal of Disaster Risk Science, 5*, pp. 95–109.

Słyś, D. and Stec, A. (2014). The Analysis of Variants of Water Supply Systems in Multi-Family Residential Building. *Ecological Chemistry and Engineering S/Chemia I Inzynieria Ekologiczna S, 21*, pp. 623–635.

Thomas, R. B., Kirisits, M. J., Lye, D.J. and Kinney, K.A. (2014). Rainwater harvesting in the United States: a survey of common system practices. *Journal of Cleaner Production, 75*, pp. 166–173

Traboulsi, H. and Traboulsi, M. (in press). Rooftop level rainwater harvesting system. *Applied Water Science*, 7(2), pp. 769-775.

Ubuoh, E.A., Nwakanma, C. and Ogbuji, S. (2017). Atmospheric Corrosion of Corrugated Iron Roofing Sheet in Oil Producing Locations in Southeastern Nigeria. *Journal of Environmental Analytical Toxicology,* 7 (1), pp. 1-7.

Ubuoh, E. A. (2012). Spatial and Temporal variations of Acid Rain Formation in Selected Oil Producing Communities in AkwaIbom State, Nigeria. *Canadian Journal on Scientific and Industrial Research,* 3(4), pp. 193-207.

UNEP (2009). *A handbook on rainwater harvesting in the Caribbean.* The United Nations Environment Programme and the Caribbean Environmental Health Institute, Kenya.

Zhang, Q. Wang, X. Hou, P., Wan, W., Li, R., Ren, Y. and Ouyang, Z. (2014). Quality and seasonal variation of rainwater harvested from concrete, asphalt, ceramic tile and green roofs in Chongqing, China. *Journal of Environmental Management, 132*, pp. 178–187.

Wheida, E. and Verhoeven, R. (2007). An alternative solution of the water shortage problem in Libya. *Water Resources Management*, 21, pp. 961–982

Woltersdorf, L. Liehr, S. and Döll, P. (2015). Rainwater Harvesting for Small-Holder Horticulture in Namibia: Design of garden variants and assessment of climate change impacts and adaptation. *Water, 7*, pp. 1402–1421.