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Abstract

Rainfall variability with periodicity of 5-6 years has been demonstrated for our study area and may be attributed to tropical and extratropical factors which operate during different months, seasons and years. Rainfall variability in terms of coefficient of variation ranges from 24-39% and 26-41% for the seasons and months. The mean increase of 1.63 mm/year and 1.37 mm/year experienced in the dry season months (November –April) and the wet season months (May-October) respectively is insignificant from a water management perspective. Hoeffding’s D statistics revealed prevalence of non-monotonic trend in all the months and seasons. Recommended minimum and maximum storage capacity requirements for a six-member household to maximize rainwater harvesting are 1 m³ and 6 m³ respectively. The rainwater harvesting potential for the area of study ranges between 18.16 m³-27.45 m³ and 15.23-30.40 m³ based on the maximum error estimate and coefficient of variation methods. Domestic rainwater harvesting has the potential to meet 27.51% -54.91% of non-potable household water demand as well as 78.34% -156.38% of household potable water demand for a six-member household. It is highly encouraged as a supplementary water source especially in rural and peri-urban areas to reduce their vulnerability to acute shortage of water infrastructure.

Keywords: climograph, domestic rainwater harvesting; rainfall variability; rainwater harvesting potential; seasonal classification of climate; standardized precipitation index; storage requirements; water demand

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Our area of research focus revolves around pragmatic solutions to environmental issues such as climate change and their impacts on water resources, environmental and resources management challenges. Rainwater harvesting as supplementary water source is one of the means to reduce the vulnerability of the populace in rural and peri-urban areas to water stress.
PUBLIC INTEREST STATEMENT

This research has revealed the variability in rainfall with periodicity of 5-6 years in Odeda Local Government Area of Ogun State, Southwest of Nigeria. It also demonstrated the potential of harvested rainwater in meeting domestic water demands for potable and non-potable applications as well as the corresponding storage water requirements. Primary water treatment is imperative when the harvested rainwater is used for potable purposes. In order to harness this valuable resource, non-weathering roofing materials are recommended for future construction of residential buildings in rural and peri-urban areas with limited water infrastructural facilities and high rainfall.

1. Introduction

Sustainable access to water for potable and non-potable uses continues to pose a huge challenge in developing countries. Sub-Saharan Africa (SSA) alone accounts for 40% of the global population without access to safe drinking water (Sojobi, Owamah & Dahunsi, 2014). In Africa, it was estimated that 75-250 million people would be exposed to increased water stress by 2020 (Kalungu et al, 2014). This worrisome situation is further aggravated by poor water governance, extreme social inequality, population growth and climate change in Africa.

Rainwater harvesting (RWH) has been proposed as one of the options to improve water supply especially in rural and peri-urban areas of low-income countries (Opare, 2012; Cruddas et al, 2013), areas without reticulated water supply (Ndiritu, Odiyo, Makungo, Ntuli & Mwaka, 2011), water-scarce, remote and marginalized areas (Nijhof, Jantowski, Meerman & Schoemaker, 2010), areas where existing water supply is inadequate (Aladenola and Adeboye, 2010), areas with abundant annual rainfall (Ghisi & Schondermark, 2013), highly contaminated and saline coastal areas (Samaddar, Murase & Okada, 2014) as well as arid and semi-arid regions (Branco, Suassuna, Vainsencher, 2005; Abdulla & Al-Shareef, 2009).

Literature survey revealed several types of RWH which includes infield RWH (IRWH), in situ RWH, roof-based RWH (RRWH) and land-based storm-water harvesting (Abdulla and Al-Shareef, 2009; Welderufael, Woyessa & Edossa, 2011; Lebel, Fleskens, Forster, Jackson & Lorenz, 2015; Clark, Gonzalez, Dillon, Charles, Cresswell & Naumann, 2015)

Factors militating against the adoption and scaling of domestic rainwater harvesting (DRWH) include use of poor roofing materials and high cost of storage tank (Opare, 2012; Cruddas, Carter, Parker, Rowe & Webster, 2013), huge capital cost of acquisition, installation and maintenance of DRWH systems (Roebuck, Oltean-Dumbrava & Tait, 2011), limited knowledge of the potentials of RWH (Kohlitz & Smith, 2015), lack of finance, legislation and co-ordination (Mwenge Kahindra and Taigbenu, 2011), space requirements (Traboulsi H. & Traboulsi M., 2015) and poor quality of DRW (Oke & Oyebola, 2015).

In addition, lack of skills (Kalungu et al, 2014), lack of social capital (Esterhuyse, 2012), risk of water-borne diseases (Mwenge Kahindra et al, 2007; O’ Hogain et al, 2011; Roebuck et al, 2011; Dobrowsky et al, 2014a) and contaminants (Lee, Yang, Han & Choi, 2010; Mendez,
Klenzendorf, Afshar, Simmons, Barrett, Kinney & Kirisits, 2011; Stump, Zimmermann, Schutz, Urban & Hartung, 2012; Zhang, Wang, Hou, Wan, Li, Ren & Ouyang, 2014) are concerns that need to be addressed to facilitate uptake of DRWH.

The quantity of rainwater harvested depends on monthly precipitation, roof catchment area and roof runoff coefficient (Woltersdorf, Lühr & Doll, 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.

Several studies have been done on different issues pertaining to rainwater harvesting. For example, with respect to storage, Woltersdorf et al (2015) recommended tank size of 30 m$^3$ for a roof size of 100 m$^2$ while Ndiritu et al (2011) recommended a storage tank size of 40 m$^3$ for a roof size area range between 75-150 m$^2$. Imteaz, Adeboye, Rayburg, & Shanableh (2012) recommended a tank size of 7000 litres to achieve 100% reliability for toilet flushing and laundry.

Likewise, Biswas and Mandal (2014) observed that a 4,000 L concrete tank installed with a roof area of 40 m$^2$ was adequate to take care of water demands of four-member household for five-month dry period while Mwenge Kahinda, Taigbenu & Boroto (2010) recommended an optimum tank size of 0.5 m$^3$ which achieved water savings of 10-40%.

In order to achieve a good water-saving efficiency and limit financial losses, Roebuck, Oltean-Dumbrava & Tait (2012) recommended storage tank size limit of 1.2-1.5 m$^3$. Moreover, Imteaz et al. (2013) recommended design of rainwater tank size to achieve rainwater accumulation potential (RAP) of 0.8-0.9 and as well opined that 100% reliability is unachievable even with 10,000 litre tank with 300 m$^2$ roof area (Imteaz, Matos & Shanableh, 2014).


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, Cowden, Watkins, Clasen & Mihelcic, 2010; Kwaadsteniet, Dobrowsky, Deventer, Khan & Cloete, 2013; Kohlitz and Smith, 2015; Thomas, Kirisits, Lye & Kinney, 2014; Zhang et al, 2014; Gwenzi, Dunjana, Pisa, Tauro & Nyamadza, 2015).
In addition, 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.

Furthermore, the benefits of domestic RWH have been found to include achievement of 30-87.6% water savings [Bocanegra-Martinez et al, 2014; Souza and Ghisi, 2012; Amado and Barroso, 2013], mitigation of storm runoff and conservation of potable water (Campisano, Gnecco, Modica & Palla, 2013), six-fold improvement in crop yield when RWH irrigation was combined with fertilizer applications (Biazin, Sterk, Temesgen, Abdulkedir & Stroosnijder, 2012), financial savings and cost-effective improvement of urban drainage systems (Slyś 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 DRWH and that the water saving efficiency depends on storage tank size, demand fraction, storage fraction and climate. Also, Chao-Hsien and Yu-Chuan (2014a) observed that DRWH potential depends on climatic, building characteristics, economic and ecological factors and that with respect to climatic factors, quantity of precipitation is the most crucial factor.

In addition, Chao-Hsien and Yu-Chuan (2014b) found that effective roof area and storage capacity for DRWH varies from one climatic region to another and that failure to account for rainfall variability leads to underestimation of storage capacities. Likewise, Nnaji and Mama (2014) observed that RWH potential is a function of rainfall coefficient of variation (COV), level of water consumption and roof area per capita. The authors recommended integration of rainwater systems in bungalow residential buildings in rainforest regions of Nigeria with COV range of 0.85-1.01, where DRWH has the potential to meet 100% of domestic water demand.

Also, Bocanegra-Martinez et al (2014) demonstrated the variability in the amount of harvested rainwater with highest value recorded in September, followed by October and August and recommended year-round storage. Distribution of rainfall on monthly, seasonal and annual scales is important for planning DRWH, agriculture as well as general water applications. Understanding of seasonality pattern of rainfall is very useful for planning DRWH storage. Guhathakurta and Saji (2013) utilized seasonality index in identifying rainfall regimes while Akinsanola and Ogunjobi (2014) classified annual rainfall based on standardized annual precipitation index (McKee, Doesken & Kleist, 1993).

Numerous studies have been done on rainwater harvesting, climate variability and rainfall pattern in Nigeria. These research efforts have focused on change detection in rainfall pattern (Ogungbenro and Morakinyo, 2014; Abaje, Ndabula & Garba, 2014), rainfall seasonality in Niger Delta on monthly and annual scales (Adejuwon, 2012), annual rainfall and temperature variability (Akinsanola and Ogunjobi, 2014), annual and monthly rainfall patterns in Ekiti State (Akinnyemi, Ayeni, Faweya & Ibraheem, 2013), inter- and intra-annual rainfall variability and distribution pattern over North-West Nigeria (Ekpoh and Nsa, 2011).
Furthermore, other research efforts have investigated quality of RWH in Delta State (Efe, 2006), quality of rainwater from different roof materials in Oyo State (Olaoye and Olaniyan, 2012), monthly rainfall trends in Nasarawa State (Ekwe, Joshua, Igwe & Osinowo, 2014), monthly rainfall distribution in Benin-Owena River Basin (Ikhile and Aifesehi, 2011), socio-demographic aspects of RWH practices in Ibadan (Lade and Oloke, 2015), DRWH practices in Enugu, uses and advantages (Ajayi and Ugwu, 2008), spatio-temporal variation and prediction of monthly rainfall over North-East Nigeria (Bibi, Kaduk & Balzter, 2014).

In addition, other researches have focused mainly on DRWH potential (Lekwot, Samuel, Ifeanyi, & Olisaemeka, 2012; Nnaji and Mama, 2014), required storage capacity for DRWH (Otti and Ezenwaji, 2013), DRWH technology (Shittu et al, 2015), monthly variability in harvestable rainwater and maximum storage requirement (Ubuoh, Ege, Ogbuji & Onifade, 2012). Oke and Oyebola (2014) advocated mobilisation and motivation of house owners.

Our literature survey revealed that factors affecting rainfall variability in Southwest Nigeria can be classified as tropical and extra-tropical factors. The tropical factors include inter-tropical Discontinuity, tropical easterly jet, sea surface temperature and biogeophysical feedback mechanism while the extratropical factor include El Nino Southern Oscillation (Olaniran, 2015).

Omogbai (2010a) demonstrated that 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 Southwest 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 Southwest Nigeria. The author also attributed the sea-surface temperature to the combined action of the cold Benguella undercurrent and Ekman transport.

Giannini, Saravanan & Chang (2003) also reported that land-atmosphere interactions amplify SST-driven signal which is responsible for interannual and interdecadal variability of rainfall while Nicholson & Grist (2001) reported deep, well developed equatorial westerlies, Africa easterly jet (AEJ) and Tropical easterly jet (TEJ) to influence rainfall variability in West Africa.

In another study, Akinsanola and Ogunjobi (2014) attributed rainfall variability to local factors such as orography, boundary layer forcing and moisture build up. Study of rainfall variability is very important because it has been found to affect rural water supply and food production in the Southwest of Nigeria (Adetayo, 2015; Ganiyu et al, 2013).

Most of the rural and peri-urban areas of Ogun State experience acute water shortage as a result of the poor water supply coverage of Ogun State Water Corporation (OSWC), the agency of government saddled with the responsibility of providing public water supply within the State. This situation is further aggravated by the poor funding of OSWC which limits expansion of water infrastructure and services, regular power outage prevalent within the
State as well as the rapid population increase in the rural and peri-urban areas within the State (Ufoegbune, Oyedepo, Aomeso and Eniola, 2010).

Within the State, < 12.5% of the populace have access to weekly regular public water supply (Odjegba et al, 2015) while Agbelemojo and Odubanjo (2001) reported that 3% of residents within the State have access to clean and safe piped water. As a result of this ugly scenario, residents resort to other alternative sources such as private piped borehole, shallow hand-dugwells, rain, rivers/streams and water vendors (Coster & Otufale, 2014; FRN, 2000, Gbadegesin and Olorunfemi, 2007).

Sadly, our literature review revealed that most of these alternative sources are unwholesome for drinking and are contaminated by pathogens which have led to water-borne diseases such as typhoid, cholera, dysentery, hepatitis (Dahunsi, Owanah, Ayandiran and Oranusi, 2014; Otufale and Coster, 2012). Furthermore, these water sources have been found to be polluted by heavy metals such as uranium, lead (Pb), Nickel (Ni), Chromium (Cr), Cadmium (Cd), Zinc (Zn) and arsenic (Dahunsi et al, 2014; Amori, Oduntan, Okeyode and Ojo, 2013).

Majority of the residents in Odeda are middle-low income earners who rely on shallow groundwater supply of poor quality (Dahunsi et al, 2014). Consumption of the boreholes and wells in Odeda exposes the residents to chemical toxicity as a result of the contamination of the groundwater by uranium (Amakom and Jibiri, 2010) which is above the safe limit recommended by WHO (2003).

Uranium chemical toxicity has been known to cause kidney and genetic mutations, developmental malfunctions and cancer in severe cases. Bacteriological assessment of the groundwater also revealed contamination by Coliform and E. coli (Shittu, Akpan, Popoola, Oyedepo and Oluderu, 2010). The drudgery from fetching water have been found to affect the women’s health who spend an average of 1 hour daily covering about 1 km to fetch water (Otufale and Coster, 2012, Coster and Otufale, 2014).

Rainwater harvesting has been successfully deployed in Eastern part of Nigeria such as Edo State with appreciable success and is practiced by > 80% of the households (Tobin, Ediagbon, Ehdimen, Asogun, 2013) while between 3-6.6% in the South Western part of Nigeria (Lade and Oloke, 2015; Gbadegesin and Olorunfemi, 2007). Also, residents in Odeda rely on RWH during the wet season because of the poor quality of the shallow wells attributed to the poor sewage and sewerage and open defecation prevalent in the area (Shittu et al, 2010).

This study is, therefore, embarked upon with a view to encourage the adoption and utilization of rainwater harvesting to reduce the vulnerability of the rural and peri-urban populace to the prevalent poor water supply and also mitigate health risks associated with other water sources. Indeed, rainwater harvesting has been recommended for use to supplement other water sources and as a buffer during emergencies (Aladenola and Adeboye, 2010).
Further, since rainwater harvesting and infrastructure is affected by rainfall variability (FAO, Worm and Hattum, 2006; Aladenola and Adeboye, 2010, Adegoke & Sojobi, 2015), the effects of rainfall variability on the rainwater harvesting potential and appropriate storage requirements were also investigated to address the inadequate water storage and RWH facilities that is rampant in the rural and peri-urban areas (Aper & Agbehi, 2010). Also, trends in the monthly, seasonal and annual rainfall were studied to ascertain if it is increasing or not.

The significance of this research is that it has incorporated rainfall variability in the calculation of rainwater harvesting potential and in the calculation of storage water requirements. In addition, as a supplementary source of water, it demonstrated the percentage of domestic water demands that can be met by rainwater harvesting for potable and non-potable purposes. Furthermore, results from this study will sensitize, encourage and guide engineers/architects in planning for DRWH in the design and construction of residential buildings.

2 Materials and Methods

2.1 Study Area

Odeda doubles as a town and headquarters of Odeda Local Government Area (LGA) in Ogun State, located in Southwestern Nigeria as shown in Figure I. It lies between longitudes $3^0 26' 76''$ and $3^0 47' 28''$ and latitudes $7^0 29' 88''$ and $7^0 05' 54''$. Being one of the largest LGA in Abeokuta which is the State capital, it has a population of 109,449 based on 2006 population census. The town enjoys tropical climate with uni-modal peak rainfall between June and November, average annual and monthly rainfall of 1,220 mm and 102 mm respectively as well as monthly maximum and minimum temperature ranges of 29-36 $^0C$ and 22-35 $^0C$ respectively (Kilanko-Oluwasanya, 2009). Southwesterly wind prevails during rainy season beginning from March to November while northerly wind dominates during the dry season beginning from December till March. Geologically, the town is overlaid by crystalline basement which is basically granitic rocks and is being mined commercially for construction purposes.
Figure 1. Map depicting location of Odeda LGA in South-West Nigeria

Public water supply in the town is erratic, highly unreliable and is limited to once per week while in some areas such as the GRAs, borehole is not allowed (Kilanko-Oluwasanya, 2009). Owing to the inadequate public water availability, residents rely mainly on self-supply systems such as boreholes and hand-dug wells which are often contaminated (Kilanko-Oluwasanya, 2009; Amori, Oduntan, Okeyode & Ojo, 2013) and limited in depth (Martins, Ajayi & Idowu, 2000).

### 2.2 Seasonal classification of climate

Our literature review showed similarity as well as disparity in seasonal climate classification used globally. Four (4) classifications were observed in literature. In addition, four seasons identified in literature namely were spring (pre-monsoon), summer (monsoon), autumn (post-monsoon) and winter (winter) as shown in Table 1. Classification (1) was adopted for Europe and Asia by Shaw, Beven, Chappell & Lamb (2010); Hu, Pan F., Pan X., Zhang, Li, Pan Z & Wey (2015), Perry (2006), Vanem and Walker (2013) while classification (2) was adopted for India by Mahajan and Dodamani (2015) and classification (3) was utilized by Sayemuzzan and Jha (2014) for USA.

Table 1. Different Global Seasonal classifications of climate from literature

<table>
<thead>
<tr>
<th>Class</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seasons</td>
<td>Months</td>
<td>Seasons</td>
<td>Months</td>
<td>Seasons</td>
</tr>
<tr>
<td>Spring</td>
<td>Mar, Apr, May</td>
<td>Pre-monsoon</td>
<td>MAM</td>
<td>Spring</td>
</tr>
<tr>
<td>Summer</td>
<td>Jun, July, Aug</td>
<td>Monsoon</td>
<td>JJAS</td>
<td>Summer</td>
</tr>
<tr>
<td>Winter</td>
<td>Dec, Jan, Feb</td>
<td>Winter</td>
<td>Jan, Feb</td>
<td>Winter</td>
</tr>
</tbody>
</table>
Climate classification (4) was utilized for our study area to depict the seasonal rainfall variability in Nigeria. The four seasons are: Spring which coincides with March Equinox comprising February, March and April (FAM), Summer which coincides with June Solstice consisting of May, June, July (MJJ), Autumn which streamlines with September Equinox [August, September, October (ASO)] and lastly, Winter which is described as December Solstice [November, December, January (NDJ)].

2.3 Data collection, methods and analysis

The rainfall and temperature data spanning 18 years from 1995-2012 was obtained from Ogun State Water Corporation which has the only weather-monitoring station in the State. Eighteen years was used owing to scarcity of available data which is prevalent in the State and in Southwest Nigeria.

Seasonality Index as described by Guhathakurta and Raji (2013) was computed as follows:

\[
SI = \frac{1}{R} \sum_{n=1}^{12} \left| X_n - \bar{R} \right|
\]  

(1)

where \(X_n = \text{mean rainfall of month } n\); \(\bar{R} = \text{mean annual rainfall}\)

SPI as described by Akinsanola and Ogunjobi (2014) and Adegoke and Sojobi (2015) were computed as follows:

\[
SPI = \frac{X - \bar{X}}{\sigma}
\]

(2)

where \(X = \text{rainfall in each particular month, season or year depending on the time scale being used}\); \(\bar{X} = \text{mean rainfall in each particular month, season or year depending on the time scale being used}\); \(\sigma = \text{standard deviation of rainfall in each particular month, season or year depending on the time scale being used}\). The SI classification is shown in Table 2.

Table 2. Seasonality Index (SI) (Kanellopoulou, 2002) and Annual Standardized Precipitation Index (SPI) (McKee et al, 1993)

<table>
<thead>
<tr>
<th>Rainfall regime</th>
<th>Seasonality Index</th>
<th>Standardized Annual Precipitation Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very equable</td>
<td>(\leq 0.19)</td>
<td>Near normal</td>
</tr>
<tr>
<td>Equable but with a definite wetter season</td>
<td>0.2-0.39</td>
<td>Moderately wet years</td>
</tr>
<tr>
<td>Rather seasonal with a shorter drier season</td>
<td>0.40-0.59</td>
<td>Moderately dry years</td>
</tr>
<tr>
<td>Seasonal</td>
<td>0.60-0.79</td>
<td>Very wet</td>
</tr>
<tr>
<td>Markedly seasonal with a long drier season</td>
<td>0.80-0.99</td>
<td>Severely dry years</td>
</tr>
<tr>
<td>Most rain in 3 months or less</td>
<td>1.00-1.19</td>
<td>Wet extreme</td>
</tr>
<tr>
<td>Extreme, almost all rain in 1-2 months</td>
<td>(\geq 1.20)</td>
<td>Dry extreme</td>
</tr>
</tbody>
</table>

\(\geq +2.0\) \quad \leq -2.0
The rainfall data was also subjected to time series analyses on monthly and seasonal scales using statistical tests which include Mann Kendall test, linear regression, SPI and Hoeffding’s D statistics. Furthermore, the potential of rainwater to meet domestic water demands and storage requirements were also evaluated.

2.4 Trend Analyses of monthly and seasonal rainfall using Mann Kendall, Linear regression, SPI and Hoeffding’s Statistics

Mann Kendall (M-K) was used to analyse rainfall trend in the study period. For M-K rank statistics, S was computed by replacing the observations \( x_i \)’s by their ranks \( k_i \)’s such that each term was assigned a number ranging from 1 to \( n \) which reflects its magnitude relative to the magnitudes of all other terms. For each element \( k_i \), the number \( N_i \) was calculated as the number of \( k_j \) terms preceding it such that \( k_j > k_i \). The parameter \( t_m \), as given by Gebremichael et al (2014) was calculated as follows:

\[
t_m = \frac{4\sum_{i=1}^{n-1} N_i}{n(n-1)} - 1
\]  
\[
 r_m = \pm r_g \sqrt{\frac{4n+10}{9n(n-1)}}
\]

where \( n \) = number of years; \( r_g \) = desired probability point of the normal distribution appropriate to a two-tailed test; \( r_m \) = M-K’s significance test statistics. If \( t_m \) lies within the range of \( \pm r_m \), then the time series does not contain a significant trend (Kendall, 1975).

Owing to the limitations of Mann Kendall test in analysing non-monotonic trend, Hoeffding’s D statistic was also used to analyze the rainfall values for residual rainfall. The residual rainfall was obtained by subtracting the predicted rainfall data obtained from the linear regression equations from the observed values. The probability values for Hoeffding’s D statistic was computed using the equation provided by Blum, Kiefer and Rosenblatt (1961) as follows:

\[
\frac{(n-1)\pi^4 D}{60} + \frac{\pi^4}{72}
\]

Where \( n \) = number of years of data, \( D \) = Hoeffding’s D statistic

Hoeffding’s D statistic was also used because it is typically used to detect non-linear and non-monotonic associations that has been found to outperform other statistical methods (Fujita, Sato, Demasi, Sogaya, Ferreira & Miyano, 2009).

Hoeffding’s D statistic was obtained utilizing the formul provided by Santos, Takahashi, Naka & Fujita (2013) as follows:

\[
D = \frac{(n-2)(n-3)D_1 + D_2(n-2)D_2}{n (n-1)(n-2)(n-3)(n-4)}
\]

Where \( D_1 = \varepsilon_i(Q_i - 1)(Q_i - 2); D_2 = \varepsilon_i(R_i - 1)(R_i - 2)(S_i - 1)(S_i - 2); \)
\[ D_3 = \varepsilon_i (R_i - 2)(S_i - 2)(Q_i - 1) \]  \hfill (8)

Where \( R_i \) = rank of \( x_i \); \( S_i \) = rank of \( y_i \); \( Q_i \) known as bivariate rank = 1 + number of points with both \( x \) and \( y \) values < the \( i \)th point.

The null hypothesis \( H_0 \) of monotonic trend is rejected if \( P\{D\} > \rho_n \) where

\[
\rho_n = \frac{1}{30} \sqrt{\frac{2(n^2+5n-32)}{9n(n-1)(n-3)(n-4)\alpha}}
\hfill (9)
\]

where \( \alpha \) = level of significance.

Hoeffding’s measure \( \rho_n \) varies from \(-1/60\) to \(1/30\) (Santos et al, 2013), which is equivalent to -0.0167 to 0.033. The acceptable range of \( \alpha \) was obtained by inserting the upper and lower limits of \( \rho_n \) given above. The acceptable range of \( \alpha \) was found to be 1.32% to 3.87%. For our selected level of significance for our study was 2% which is within the acceptable range.

Furthermore, the annual rainfall was evaluated using Student’s \( t \) test. The formula used was given by Bluman (2013) as follows:

\[
t = \frac{\bar{X} - \mu}{S/\sqrt{n}}
\hfill (10)
\]

where \( t \) = test value, \( \bar{X} \) = mean of observed values, \( \mu \) = claimed mean, \( S \) = standard deviation of data, \( n \) = number of years of data. The degrees of freedom (df) of the data = n-1 = 17. The null hypothesis of normal distribution is rejected when \( t \) value or p-value of \( t \) is > the critical values. The significance level used was 2%.

2.5 Rainwater harvesting potential and storage requirements

Rainwater harvesting potential for our study was calculated using the monthly balance approach. The monthly harvestable rainwater (\( Q_m \)) was calculated as a function of the product of mean monthly rainfall (\( \bar{R}_m \)), roof area (A), percentage of roof area utilized for rainwater harvesting (\( \beta \)) and roof runoff coefficient (\( C \)) as given in equation 5.

\[
Q_m = \bar{R}_m \times A \times \beta \times C
\hfill (11)
\]

From literatures, roof area varied from 25 m\(^2\) – 200 m\(^2\) (Islam K., Islam M., Lacoursiere & Dessborn, 2014; Biswas and Mandal, 2014; Otti and Ezenwaji, 2013; Ubuoh et al, 2012; Ndiritu et al, 2011, Woltersdof et al, 2015). Roof size area of 100 m\(^2\) was adopted for this study as recommended by Woltersdof et al (2015) and Sturm, Zimmermann, Schutz, Urban & Hartung (2009) and utilized by Otti and Ezenwaji (2013) while the \( \beta \) value of 0.35 suggested by Shittu, Okareh & Coker (2015) was utilized. This is low because of cost prohibition and poor planning of DRWH systems typical in Nigeria.

Furthermore, roof runoff coefficient (\( C \)) varies between 0.75-0.95 from literatures (Woltersdof et al, 2015; Roebuck, 2007; Tomaz, 2005; Fernandez et al, 2015). C value of 0.8
was adopted for this study as utilized by Otii and Ezenwaji (2013), Shittu et al (2015) and accounts for leakage, spillage, infiltration, roof surface wetting and evaporation (Lee et al, 2000) and is within the range of 70-85% of harvestable rainfall suggested by Helmreich and Horn (2009).

Since mean monthly rainfall was utilized, it is imperative to consider the upper and lower confidence limit scenarios beside the mean case scenario owing to rainfall variability and also because mean can hide rainfall variability which occurs in real-life scenarios. Two approaches were utilized in computing the confidence limits namely confidence interval about the mean monthly rainfall as well as confidence interval using Coefficient of Variation (COV) of monthly rainfall. For the first approach, the confidence intervals for mean based on maximum error of estimate (MEE) as described by Johnson and Kuby (2012) as well as Bluman (2013) was utilized and was described as:

$$\bar{X} + Z(\alpha/2) \left( \frac{\sigma}{\sqrt{n}} \right) \text{ Upper Confidence Limit (LCL)}$$

$$\bar{X} - Z(\alpha/2) \left( \frac{\sigma}{\sqrt{n}} \right) \text{ Lower Confidence Limit (LCL)}$$

where $\bar{X}$ = Mean $= \bar{R}_m$; $Z(\alpha/2)$ = Confidence coefficient; $\left( \frac{\sigma}{\sqrt{n}} \right)$ = Standard error of mean and $Z(\alpha/2) \left( \frac{\sigma}{\sqrt{n}} \right)$ = Maximum error of estimate (MEE), $\sigma$ = Standard deviation of monthly rainfall for each month, $n$ = sample size = 18. The confidence interval adopted in our study was 0.99 which gave a confidence coefficient of 2.58 as shown in Table VIII.

Therefore, harvestable rainwater equations for the scenarios of upper confidence limit (UCL) of monthly mean rainfall and lower confidence limit (LCL) of monthly mean rainfall were obtained as:

$$Q_{UCL} = [\bar{R}_m + MEE] \times A \times \beta \times C$$

$$Q_{LCL} = [\bar{R}_m - MEE] \times A \times \beta \times C$$

For the second approach, harvestable rainwater equations for the upper confidence limit (UCL) of monthly mean rainfall and lower confidence limit (LCL) of monthly mean rainfall were obtained as:

$$Q_{UCL} = \bar{R}_m \times A \times \beta \times C \ [1 + COV]$$

$$Q_{LCL} = \bar{R}_m \times A \times \beta \times C \ [1 - COV]$$

and the results were shown in Table X.

3. Results and discussion

3.1 Seasonal analyses of rainfall, Seasonality Index and Annual Standardized Precipitation Index
The basic seasonal rainfall and temperature characteristics of the study area had been shown by the climograph displayed in Figure II as well as Table III.

![Climograph of seasonal rainfall in Odeda LGA in Ogun State, Southwest, Nigeria](image)

**Figure 2. Climograph of seasonal rainfall in Odeda LGA in Ogun State, Southwest, Nigeria**

Based on mean seasonal values, Autumn had the highest contribution of rainfall (36.49%) and the least contribution was by Spring (17.35%) as shown in Table 3. Contributions by Summer and Winter were 26.35% and 19.81% respectively. The maximum seasonal rainfall of 406.86 mm occurred in Autumn while the minimum seasonal rainfall of 61.15 mm occurred in Spring. Also, it was also observed that Autumn recorded the highest seasonal rainfall for throughout the period of study with the exception of year 2000 where Summer recorded the highest seasonal rainfall.

The season with the lowest coefficient of variation (COV) of 0.24 was Autumn while Summer had the highest COV as shown in Table 3. Based on Hare’s (1983) rainfall variability index (which is COV expressed in percentage terms), rainfall in Summer and Spring were highly variable with index > 30%, while rainfalls in Winter and Autumn were moderately variable with index between 20-30%.

Furthermore, maximum and minimum temperature values were found to be fairly stable across all seasons with Autumn also recording the highest maximum and highest minimum temperature.

The seasonal variation of rainfall for Odeda is described in Figure 3. Autumn recorded the highest seasonal rainfall with the exception of year 2000 in which summer recorded the highest rainfall. Winter recorded the least amount of rainfall for most of the study period. Based on coefficient of slope of linear regression equation of the line graph of seasonal rainfall, Summer recorded the highest increasing trend of 6.6965, followed by winter (5.4363), spring (4.5004) and the least by Autumn with (1.5942).

**Table 3. Descriptive characteristics of seasonal rainfall in Odeda LGA, Ogun State**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>141.41</td>
<td>214.68</td>
<td>297.44</td>
<td>162.54</td>
</tr>
</tbody>
</table>
Maximum 206.68 353.76 406.86 277.08
Minimum 61.15 71.94 163.85 108.43
SD 45.56 82.67 71.24 48.2
COV (%) 32 39 24 30
C$_{xx}$ -0.08 -0.19 -0.11 1.17

Figure 3. Line graph of seasonal variation of rainfall in Odeda LGA, Ogun State, Nigeria

Seasonality index (SI) also revealed trend in rainfall pattern. Based on SI value of 0.27 obtained for the area for the period of study, the rainfall regime can be described as equable but with a definite wetter season. Trend in rainfall was also analysed using SPI on an annual scale and the result presented in Figure 4.

Figure 4. SPI for Annual rainfall from 1995-2012 for the study area

It was observed that dry years took place between 2001 and 2005 while wet years were experienced between 2006 and 2011 which corroborated results displayed in Figure 3. Similar to what was obtained in Figure 3, severely dry years were experienced in both 2001 and 2005 while extremely wet year was experienced in 2010 based on SPI classification displayed in Table 4.

Declining trend in rainfall after 2000 was also reported by Wu, Wang, Cai & Li (2013) and was attributed to low water vapour and higher than normal air temperature (Liu, Luo, Zhang, Wu & Liu, 2011). The abrupt changes in rainfall was also attributed to changes in regional circulation patterns (Zhang and Liu, 2013)
In summary, the SPI graph in Figure 4 indicated an extremely low increasing trend in annual rainfall with a slope of 0.0838 and likewise corroborated the changes observed using SI. Based on SPI classification in Table 2, near normal rainfall took place between 1995 and 2000, moderately wet years were experienced in 2009 and 2011, moderately dry years in 2003, severely dry years in 2001 and 2005 and extremely wet years in 2010.

Table 4. Classification of Annual rainfall based on SPI

<table>
<thead>
<tr>
<th>Classification</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderately dry</td>
<td>2003</td>
</tr>
<tr>
<td>Moderately wet</td>
<td>2009, 2011</td>
</tr>
<tr>
<td>Severely dry</td>
<td>2001, 2005</td>
</tr>
<tr>
<td>Extremely wet</td>
<td>2010</td>
</tr>
</tbody>
</table>

3.2 Monthly rainfall analyses

Graph of monthly rainfall revealed singular peaks as shown in Figure 5. The existence of a singular monthly rainfall peak contradicts the bimodal monthly peaks reported by Kilanko-Oluwasanya (2009) who reported monthly rainfall peaks in July and August for Abeokuta. Prior to year 2000, September recorded the highest monthly rainfall between 1995-1998, while October and August recorded the highest monthly rainfall in 1999 and 2000 respectively. Between 2001 and 2005, October recorded the highest monthly rainfall in 2001, 2003 and 2005 while September and November recorded the highest monthly rainfall in 2002 and 2004.

![Figure 5. Graph of monthly rainfall in Odeda LGA, Southwest Nigeria](image)

Between 2006-2012, highest monthly rainfall occurred in October in 2006, 2009 and 2010, while August recorded the highest monthly rainfall in 2008 and 2002, and July and September recorded the highest monthly rainfall in 2007 and 2011 respectively. This
indicates a progressive shift in maximum rainfall from September in pre-2000 period to October and/or August in post-2000 period.

Table 5 revealed that the months with the highest variability of rainfall were May and June with COV of 41% marking the beginning of intense rainfall during the rainy season while the month with the lowest monthly rainfall variability took place in August with COV of 26% implying that the intense rainfall in August has been reasonably consistent.

Table 5. Descriptive characteristics of monthly rainfall in Odeda, Ogun State, Nigeria

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (mm)</td>
<td>45.8</td>
<td>41.3</td>
<td>47.4</td>
<td>52.7</td>
<td>63.4</td>
<td>69.5</td>
<td>81.8</td>
<td>97.9</td>
<td>101.9</td>
<td>97.7</td>
<td>67</td>
<td>48.6</td>
</tr>
<tr>
<td>Max (mm)</td>
<td>73.5</td>
<td>65.8</td>
<td>73.7</td>
<td>84.8</td>
<td>107.6</td>
<td>121.7</td>
<td>126.8</td>
<td>140</td>
<td>148.8</td>
<td>150</td>
<td>143.1</td>
<td>76.9</td>
</tr>
<tr>
<td>Min (mm)</td>
<td>17</td>
<td>18.2</td>
<td>17</td>
<td>8.2</td>
<td>23.9</td>
<td>23</td>
<td>66</td>
<td>56.9</td>
<td>41.4</td>
<td>40.5</td>
<td>31</td>
<td>30</td>
</tr>
<tr>
<td>SD</td>
<td>15.7</td>
<td>12.7</td>
<td>16.8</td>
<td>19.4</td>
<td>26.1</td>
<td>28.8</td>
<td>29.5</td>
<td>25.4</td>
<td>27.7</td>
<td>28.7</td>
<td>26</td>
<td>15.6</td>
</tr>
<tr>
<td>COV (%)</td>
<td>34</td>
<td>31</td>
<td>35</td>
<td>37</td>
<td>41</td>
<td>41</td>
<td>36</td>
<td>26</td>
<td>27</td>
<td>29</td>
<td>29</td>
<td>32</td>
</tr>
<tr>
<td>Csx</td>
<td>0.38</td>
<td>0.46</td>
<td>-0.15</td>
<td>-0.50</td>
<td>0.12</td>
<td>-0.13</td>
<td>-0.25</td>
<td>-0.26</td>
<td>-0.07</td>
<td>-0.04</td>
<td>1.58</td>
<td>0.93</td>
</tr>
</tbody>
</table>

Based on Hare’s rainfall variability index (1993), all the months exhibited high variability with COV (%) > 30% with the exception of August, September, October and November which exhibited moderate variability between 20-30%. This indicates higher increasing rainfall during the dry season months and slightly increasing rainfall during the rainy season months.

Also, yearly variation of monthly rainfall was depicted in Figure 6. The dry season months of November to April (Akinyemi et al, 2013) had increasing rainfall range of 1.19mm/year to 2.27mm/year with a mean of 1.63mm/year while the wet season months of May to October witnessed increasing rainfall range of 0.20mm/year to 2.28mm/year with a mean of 1.37mm/year.

Figure 6. Line graph of monthly rainfall variation for the study period

This indicated higher increasing rainfall during the dry season compared to the wet season. In addition, comparison of monthly rainfall for the study period as shown in Figure 6 revealed steep decline in monthly rainfall occurred between 2000 to 2005 and then a general trend of
increase after 2005. High amount of rainfall which took place in 2000 was also reported by Perry (2006).

M-K test revealed that all the months experienced significant increasing rainfall trend with the exception of August and September as shown in Table 6. For the linear regression equation, positive slope indicates an increasing trend while negative slope indicates decreasing trend (Tabari, Marofi, Aeini, Talae & Mohammadi, 2011). Based on the slope of linear regression as depicted in Table 6, the highest increasing trend of 2.36mm/year occurred in May, followed by 2.28mm/year in June and 2.27mm/year in November.

Table 6. Trend results for Mann Kendall, Linear Regression, SPI Tests and Hoeffding’s D Statistics for monthly rainfall

<table>
<thead>
<tr>
<th>Mann Kendall</th>
<th>Linear Regression</th>
<th>SPI</th>
<th>Hoeffding’s D Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>t_m</td>
<td>r_m</td>
<td>Trend</td>
</tr>
<tr>
<td>Jan 18</td>
<td>0.18</td>
<td>±0.15</td>
<td>Significant increase</td>
</tr>
<tr>
<td>Feb 18</td>
<td>0.27</td>
<td>±0.14</td>
<td>Significant increase</td>
</tr>
<tr>
<td>Mar 18</td>
<td>0.31</td>
<td>±0.13</td>
<td>Significant increase</td>
</tr>
<tr>
<td>Apr 18</td>
<td>0.31</td>
<td>±0.13</td>
<td>Significant increase</td>
</tr>
<tr>
<td>May 18</td>
<td>0.36</td>
<td>±0.12</td>
<td>Significant increase</td>
</tr>
<tr>
<td>Jun 18</td>
<td>0.33</td>
<td>±0.13</td>
<td>Significant increase</td>
</tr>
<tr>
<td>Jul 18</td>
<td>0.19</td>
<td>±0.15</td>
<td>Significant increase</td>
</tr>
<tr>
<td>Aug 18</td>
<td>0.05</td>
<td>±0.17</td>
<td>Insignificant increase</td>
</tr>
<tr>
<td>Sep 18</td>
<td>0.02</td>
<td>±0.17</td>
<td>Insignificant increase</td>
</tr>
<tr>
<td>Oct 18</td>
<td>0.29</td>
<td>±0.13</td>
<td>Significant increase</td>
</tr>
<tr>
<td>Nov 18</td>
<td>0.19</td>
<td>±0.15</td>
<td>Significant increase</td>
</tr>
<tr>
<td>Dec 18</td>
<td>0.28</td>
<td>±0.13</td>
<td>Significant increase</td>
</tr>
</tbody>
</table>

Based on M-K test, insignificant increasing trend took place in August and September, although both have slope values of 0.78mm/year and 0.20mm/year and was also corroborated by their very low SPI values of 0.032 and 0.001 respectively as displayed in Table 6 and Figure 7. The months with the highest SPI values were February with the highest SPI value of 0.109, followed by January and December (0.98) and March (0.96). In summary, significant increasing trends took place in the dry season months of November, December, January, February and March.

M-K test revealed that all the seasons exhibited significant increasing rainfall trend with the exception of autumn which exhibited insignificant increasing rainfall trend as shown in Table 7. This was corroborated by the slope of the linear regression which indicated that summer had the highest increasing trend of 6.7mm/year, followed by winter (5.44mm/year) and spring (4.50mm/year) while autumn recorded the least increasing trend of 1.59mm/year.
Figure 7. Comparison of monthly SPI from 1995-2012

Table 7. Trend results for Mann Kendall, Linear Regression, SPI Tests and Hoeffding’s D Statistics for seasonal rainfall

<table>
<thead>
<tr>
<th>Seasons</th>
<th>N</th>
<th>$t_m$</th>
<th>$r_m$</th>
<th>Trend</th>
<th>Linear Regression</th>
<th>SPI</th>
<th>Hoeffding’s D Statistics</th>
<th>$\rho_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>18</td>
<td>0.62</td>
<td>±0.26</td>
<td>Significant increase</td>
<td>4.500</td>
<td>0.102</td>
<td>0.0988</td>
<td>4.0797</td>
</tr>
<tr>
<td>Summer</td>
<td>18</td>
<td>0.62</td>
<td>±0.26</td>
<td>Significant increase</td>
<td>6.70</td>
<td>0.083</td>
<td>0.0356</td>
<td>2.3354</td>
</tr>
<tr>
<td>Autumn</td>
<td>18</td>
<td>0.09</td>
<td>±0.16</td>
<td>Insignificant increase</td>
<td>1.59</td>
<td>0.023</td>
<td>0.1178</td>
<td>4.604</td>
</tr>
<tr>
<td>Winter</td>
<td>18</td>
<td>0.35</td>
<td>±0.13</td>
<td>Significant increase</td>
<td>5.44</td>
<td>0.116</td>
<td>0.0741</td>
<td>3.398</td>
</tr>
</tbody>
</table>

Increasing trend in winter rainfall was attributed to North Atlantic Oscillation which causes westerly flows (Perry, 2006). The increasing trend results were also supported by SPI values in Table 7 as well as Figure 8 with Autumn recording the lowest SPI value of 0.023 and winter recording the highest SPI value of 0.116 followed by spring with SPI of 0.102.

Further, all the seasons had negative SPI values from 2000 to 2005 as shown in Figure 10, which indicated preponderance of moderately dry seasons but with few episodes of severely dry seasons, SPI was able to detect significant trends in rainfall which corroborated Mahajan and Dodamani (2005) who advocated the use of SPI to detect significant trends in hydrological parameters.

Though MK test for monthly rainfall showed increase of 0.20-2.36 mm/year and a seasonal increase of 1.59-6.7 mm/season, from water management point of view, the increase is not significant. This was corroborated by Mazvimavi (2010) who reported statistically insignificant seasonal and annual rainfall for Zimbabwe with a COV range of 23%-40% similar to COV range of 26%-40% and 24%-39% obtained in our study for monthly and seasonal rainfall respectively. The author adduced the general perception of increasing or declining rainfall to the presence of rainfall variability. Likewise, Tapsoba, Hache, Perreault...
and Bobee (2004) also reported insignificant changes in rainfall for Togo and Benin located in West Africa.

Figure 8. Comparison of Seasonal SPI from 1995-2012

$P\{D\}$ values for all the months and seasons were found to be $> \rho_{p}$ value of 0.0661, therefore we reject the null hypothesis $H_0$ of monotonic trend and accept the alternative hypothesis of non-monotonic trend. Therefore, it can be inferred that non-monotonic trend was exhibited across all the months and seasons.

Analysis of annual rainfall by the Student’s $t$ test indicated that the $t$-value of 13.05 was $> t$ the critical value of 2.718. Therefore, we reject the null hypothesis of normal distribution. Thus, it can be inferred that the annual rainfall trend is non-linear.

### 3.5 Residual Trend Analysis of seasonal, annual and monthly rainfall

Residual analyses of seasonal rainfall revealed that Autumn recorded the least residual rainfall in a dry state between 1995 and 2000 while winter experienced the highest residual seasonal rainfall in a wet state. Likewise, wet states were experienced in summer and spring also between 1995 and 2000 as depicted in Figure 11. A reversal of state was experienced during the period of 2000 to 2005 where Autumn recorded the highest residual rainfall in a wet state while Spring, Summer and winter experienced dry states with winter recording the least residual rainfall.

A short reversal of state was experienced in 2007 where winter recorded the highest residual rainfall while a short dry state was experienced between 2008 and 2009. This result depicts an average of five (5) year periodicity of oscillation between the wet and dry states indicating non-linearity of the rainfall pattern. This result corroborated the findings of Ibrahim et al (2015) who observed oscillating pattern of approximately five (5) year-periodicity for rainfall in Sub-Saharan West Africa.

Also, the annual residual rainfall graph displayed in also revealed alternate wet and dry states approximately six (6) years which was within the periodicity of 3-7 years reported for Niger Delta, Nigeria by Ologunorisa and Adejuwon (2003) with significant cyclical pattern as well. The most profound periodicity for the region was five (5) years.
The wet state was predominant between 1995-2000 while the dry state was predominant between 2000-2006 and there was a reversal to the wet states between 2006-2011. This implies a dry state is expected to take place for the next five years beginning from 2013. This dry state was actually corroborated by World Meteorological Organization (WMO) (2015) which reported a drier-than-normal rainfall in Ogun State in 2013 in line with the periodicity pattern of rainfall observed in our studies.

Residual analysis of monthly rainfall indicated non-linear, non-monotonic trend as well as some periodicity similar to what obtained in seasonal and annual timescales. They both exhibited alternation between wet and dry states. For most of the months, wet state was observed between 1995-2000, dry state between 2000-2005 and a reversal wet state between 2005-2010. The monthly residual rainfall graph displayed in Figure 11 exhibited similar alternation between the wet and dry states similar to what was obtained on the seasonal and annual timescales.
Nicholson (2013) identified factors responsible for interannual rainfall variability and was found to include African Easterly Jet (AEJ), Tropical Easterly Jet (TEJ), African Westerly Jet (AWJ) and West African Westerly Jet (WAWJ). According to the author, AEJ is predominant in the month of May-June before the onset of rain, TEJ was very strong in January-March, AWJ between July-September while WAWJ was influential in May-September.

Other factors responsible for rainfall variability on monthly, seasonal and annual timescales in the area of study were attributed to non-linear West African Monsoon (WAM) and relief (Barbe Lebel, Tapsoba, 2002; Eltahir E.A.B. & Gong C., 1996), Indian Ocean SST and anticyclones over NE China (Hastenrath and Wolter, 1992; Quan, Diaz and Fu, 2003), global interhemispheric SST differences (Semazzi et al, 1996), local surface hydrology such as local evapotranspiration which contribute 27% of rainfall in West Africa (Gong and Eltahir, 1996).

Also important are land-surface feedback mechanisms such as soil moisture, lowered surface roughness and dust generation (Rowell et al, 1995). From the residual rainfall analyses, it may be implied that different forcing mechanisms operate during different months, seasons and years (Long and Éntekhabi, 2000) and may be responsible for the rainfall variability being experienced in the area of study.

### 3.6 Rainwater harvesting potential and storage requirements

The monthly harvestable rainwater (MHRW) for the three scenarios of UCL, Mean and LCL were displayed in Table 8. For the UCL scenario, maximum MHRW of 3.32 m$^3$ occurred in September, followed by October (3.22 m$^3$) and August (3.17 m$^3$) while the minimum MHRW was in February (1.37 m$^3$). The corresponding values for the mean and LCL scenarios were 2.85, 2.74, 2.74 m$^3$ and 2.38, 2.31 and 2.25 m$^3$ respectively.

Comparison of the monthly HRW for the different scenarios in Figure 9 revealed that UCL (COV) and UCL (COV) recorded the highest values and lowest values respectively. The corresponding highest and lowest monthly HRW were 3.62 m$^3$ and 0.80 m$^3$ respectively.
Therefore, the recommended maximum storage capacity that should be provided for DRWH is 4 m$^3$ while the minimum storage capacity should be approximately 1 m$^3$.

Table 8. Monthly harvestable rainwater (MHRW) based on Maximum Error Estimate of $\bar{R}_m$

<table>
<thead>
<tr>
<th>Limits</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_{UCL}$ (m$^3$)</td>
<td>1.55</td>
<td>1.37</td>
<td>1.61</td>
<td>1.81</td>
<td>2.22</td>
<td>2.44</td>
<td>2.79</td>
<td>3.17</td>
<td>3.32</td>
<td>3.22</td>
<td>2.32</td>
<td>1.63</td>
</tr>
<tr>
<td>$Q_{MEAN}$ (m$^3$)</td>
<td>1.28</td>
<td>1.16</td>
<td>1.33</td>
<td>1.48</td>
<td>1.78</td>
<td>1.95</td>
<td>2.29</td>
<td>2.74</td>
<td>2.85</td>
<td>2.74</td>
<td>1.88</td>
<td>1.36</td>
</tr>
<tr>
<td>$Q_{LCL}$ (m$^3$)</td>
<td>1.01</td>
<td>0.94</td>
<td>1.04</td>
<td>1.14</td>
<td>1.33</td>
<td>1.46</td>
<td>1.78</td>
<td>2.31</td>
<td>2.38</td>
<td>2.25</td>
<td>1.43</td>
<td>1.09</td>
</tr>
</tbody>
</table>

Table 9. Monthly harvestable rainwater (HRW) based on Coefficient of Variation Limits

<table>
<thead>
<tr>
<th>Limits</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_{UCL}$ (m$^3$)</td>
<td>1.72</td>
<td>1.51</td>
<td>1.79</td>
<td>2.02</td>
<td>2.50</td>
<td>2.74</td>
<td>3.11</td>
<td>3.45</td>
<td>3.62</td>
<td>3.53</td>
<td>2.61</td>
<td>1.80</td>
</tr>
<tr>
<td>$Q_{LCL}$ (m$^3$)</td>
<td>0.85</td>
<td>0.80</td>
<td>0.86</td>
<td>0.93</td>
<td>1.05</td>
<td>1.15</td>
<td>1.47</td>
<td>2.03</td>
<td>2.08</td>
<td>1.94</td>
<td>1.14</td>
<td>0.93</td>
</tr>
</tbody>
</table>

In order to estimate monthly water demand per household, there is need to calculate per capita daily water demand. The water demand is separated into two namely: potable water demand (PWD) and non-potable water demand (NPWD). PWD covers drinking and cooking applications while NPWD covers bathing, toilet flushing and dishwashing. Sojobi et al. (2015) recommended 7.5 lpcd for both drinking and cooking which covered 4.5 lpcd and 3 lpcd recommended by WHO (2004) and WHO (2005) for drinking and cooking respectively.

A total of 20 lpcd was recommended for non-potable water uses such as bathing, toilet flushing and dishwashing as shown in Table 10 excluding laundry which is usually done on weekly basis in typical Nigerian settings. Total estimated weekly per capita NPWD was 150 litres. For a thirty-day month, the estimated NPWD was 150 x 4 plus additional 40 litres (for two remaining days), which gives 640 litres.

Table 10. Water demand for various applications

<table>
<thead>
<tr>
<th>Applications</th>
<th>Water Demand (lpcd)</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bathing</td>
<td>6</td>
<td>WHO (2005)</td>
</tr>
<tr>
<td>Toilet flushing</td>
<td>10</td>
<td>WHO (2005)</td>
</tr>
<tr>
<td>Dishwashing</td>
<td>4</td>
<td>Author¹</td>
</tr>
<tr>
<td>Laundry (weekly)</td>
<td>10</td>
<td>WHO (2005)</td>
</tr>
<tr>
<td>Drinking and cooking</td>
<td>7.5</td>
<td>Sojobi et al (2015)</td>
</tr>
</tbody>
</table>

¹ Gurung and Sharma (2014) recommended a value of 2.5 lpcd which was considered low for a typical Nigerian setting

Leaving allowance for contingencies of 20%, the estimated per capita monthly NPWD is 768 litres. Allowance for contingencies takes care of unexpected NPWD and PWD from guests, emergencies such as ceremonies, etc. The estimated per capita monthly PWD was estimated to be 270 litres leaving room for contingencies as well. The estimated weekly per capita water demand of 202.5 lpcd exceeded the weekly minimum water requirements of 140 lpcd recommended by United Nations (UN) based on 20 lpcd for rural communities in developing countries.
Therefore, for a six-member household comprising father, mother and four children, the total estimated monthly NPWD and PWD were 4,608 litres (4.608 m³) and 1620 litres (1.62 m³), respectively. Therefore, total estimated monthly household water demand (HHWD) for a six-member household was 6.228 m³ while total annual HHWD was 74.74 m³.

For the MEE approach, the percentage contributions of total annual water demand that can only be met by DRWH were computed for the three scenarios were shown in Table 11. For total annual NPWD, between 32.84% and 49.64% can be met by DRWH. For total annual PWD, between 93.42% and 141.20% can be met by DRWH.

Table 11. Domestic Rainwater harvesting potential (DRHP) based on MEE Limits

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Total Annual HRW (m³)</th>
<th>% Annual NPWD</th>
<th>% Annual PWD</th>
<th>% Total Annual HHWD</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCL</td>
<td>27.45</td>
<td>49.64</td>
<td>141.20</td>
<td>36.73</td>
</tr>
<tr>
<td>Mean</td>
<td>22.45</td>
<td>41</td>
<td>115.48</td>
<td>30.04</td>
</tr>
<tr>
<td>LCL</td>
<td>18.16</td>
<td>32.84</td>
<td>93.42</td>
<td>24.30</td>
</tr>
</tbody>
</table>

This indicates that for the mean and UCL scenarios, PWD can be sufficiently met with some excess remaining and 93.42% met in the LCL scenario. In addition, this result also revealed that DRWH can only be used to complement the main water supply for the study area when used for non-potable purposes.

For the COV approach, DRWH has the potential to meet 27.51%-54.91% of the NPWD, 78.34%-156.38% of PWD, and between 20.38%-40.67% of the total annual HHWD as displayed in Table 12.

Table 12. Domestic Rainwater harvesting potential (DRHP) based on COV Limits

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Total Annual HRW (m³)</th>
<th>% Annual NPWD</th>
<th>% Annual PWD</th>
<th>% Total Annual HHWD</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCL</td>
<td>30.40</td>
<td>54.91</td>
<td>156.38</td>
<td>40.67</td>
</tr>
<tr>
<td>LCL</td>
<td>15.23</td>
<td>27.51</td>
<td>78.34</td>
<td>20.38</td>
</tr>
</tbody>
</table>

4. Conclusions

Rainfall variability has been demonstrated for our study area and it may be attributed to tropical and extratropical factors which operate during different months, seasons and years. Rainfall variability in terms of COV ranges from 24-39% for the seasons and 26-41% for the months. The dry season months (November –April) have been experiencing a mean rainfall increase of 1.63 mm/year with a range of 1.19 -2.27 mm/year while the wet season months of May- October recorded a mean increase of 1.37 mm/year with a range of 0.20 -2.28 mm/year. Periodicity of five-six years was observed in the rainfall pattern in our study area which corroborated earlier research findings.
Though MK test revealed significant rainfall in most of the months and likewise significant increase in Spring and Summer, from a water management perspective, the increase was not significant, which corroborates results obtained for some countries with similar rainfall variability. The general perception of increasing or declining rainfall may be attributed to the presence of rainfall variability on monthly and seasonal timescales. Also, Hoeffding’s D statistics revealed prevalence of non-monotonic trend in all the months and seasons.

Taking into account the effects of rainfall variability, the recommended minimum and maximum storage capacity requirements for a six-member household is 1 m$^3$ and 6 m$^3$, respectively.

In addition, based on the maximum error estimate approach, the rainwater harvesting potential for the area of study ranges between 18.16 m$^3$ and 27.45 m$^3$, while based on the coefficient of variation approach, the rainwater harvesting potential ranges between 15.23 and 30.40 m$^3$.

Our results also showed that domestic rainwater harvesting has the potential to meet 27.51% to 54.91% of non-potable household water demand as well as 78.34% to 156.38% of household potable water demand for a six-member household.

Domestic rainwater harvesting is highly encouraged as a supplementary water source especially in rural and peri-urban areas to reduce their vulnerability to acute shortage of water infrastructure.

The significance of this research and contribution to literature is that it has incorporated rainfall variability in the calculation of rainwater harvesting potential and in the calculation of storage water requirements taking into account the effects of rainfall variability which is often neglected in such studies. In addition, as a supplementary source of water, it demonstrated the percentage of domestic water demand that can be met by rainwater harvesting for potable and non-potable purposes. Furthermore, results from this study revealed the periodicity of rainfall pattern which characterize our study area.

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