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ENVIRONMENTAL MANAGEMENT & CONSERVATION | RESEARCH ARTICLE

Assessment of rainfall variability, rainwater harvesting potential and storage requirements in Odeda Local Government Area of Ogun State in South-western Nigeria

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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 extra-tropical factors which operate during different months, seasons and years. Rainfall variability in terms of coefficient of variation ranges from 24 to 39% and 26 to 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 and 6 m^3, respectively. The rainwater harvesting potential for the area of study ranges between 18.16 and 27.45 m^3 and 15.23 and 30.40 m^3 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.

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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

Observed changes in rainfall were due majorly to local factors and also non-local factors. A change from wet to dry years and from dry years to wet years takes place every five to six years. Collected and stored rainwater can be used for domestic water purposes such as drinking and cooking, bathing, toilet flushing, dishwashing and laundry. However, when considered for drinking and cooking, the stored rainwater should be treated to avoid the risk of water-borne diseases and heavy metals. Collection and storage of rainwater is recommended in areas with poor water supply but having high rainfall. For a household consisting of father, mother and four children, storage container size required should be a minimum of 1 m3 and a maximum of 6 m^3.

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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, Filho, Mbuge, & Cheruiyot, 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 (Cruddas, Carter, Parker, Rowe, & Webster, 2013; Opare, 2012), 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 & Adeboye, 2010), areas with abundant annual rainfall (Ghis & Schondermark, 2013), highly contaminated and saline coastal areas (Samaddar, Murase, & Okada, 2014) as well as arid and semi-arid regions (Abdulla & Al-Shareef, 2009; Branco, Suassuna, & Vainsencher, 2005).

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

Factors militating against the adoption and scaling of domestic rainwater harvesting (DRWH) include use of poor roofing materials and high cost of storage tank (Cruddas et al., 2013; Opare, 2012), 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 coordination (Mwenge Kahinda & Taigbenu, 2011), space requirements (Traboulsi & Traboulsi, 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 waterborne diseases (Dobrowksy, Mannel, et al., 2014; Dobrowsky, Van Deventer, et al., 2014; Mwenge Kahinda, Taigbenu, & Boroto, 2007; O'Hogain, McCarton, McIntyre, Pender, & Reid, 2011; Roebuck et al., 2011) and contaminants (Lee, Yang, Han, & Choi, 2010; Mendez et al., 2011; Sturm, Zimmermann, Schütz, Urban, & Hartung, 2009; Zhang et al., 2014) are concerns that need to be addressed to facilitate the uptake of DRWH.

The quantity of rainwater harvested depends on monthly precipitation, roof catchment area and roof run-off coefficient (Woltersdorf, Liehr, & Döll, 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 and 150 m^2. Imteaz, Adeboye, Rayburg, and Shanableh (2012) recommended a tank size of 7,000 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

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five-month dry period, while Mwenge Kahinda, Taigbenu, and 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, and Tait (2012) recommended storage tank size limit of 1.2–1.5 m^3. Moreover, Imteaz, Ahsan, and Shanableh (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).

Besides, Boelee et al. (2013) recommended careful participatory planning, design and management of DRWH storage to minimize associated health risks, while Bocanegra-Martinez et al. (2014) presented multi-objective optimization approach to DRWH. Further, Fernandes, Terencio, and Racheco (2015) proposed a threshold of 0.8 (Annual water demand/Annual harvestable rainwater) to distinguish low-to-high demand RWH applications and recommended low-storage capacity for low-demand applications.

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; Gwenzi, Dunjana, Pisa, Tauro & Nyamadza, 2015; Kohlitz & Smith, 2015; Kwaadsteniet, Dobrowsky, Deventer, Khan, & Cloete, 2013; Thomas, Kirisits, Lye, & Kinney, 2014; Zhang et al., 2014).

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 (Amado & Barroso, 2013; Bocanegra-Martinez et al., 2014; Souza & Ghisi, 2012), mitigation of storm run-off and conservation of potable water (Campisano, Gnecco, Modica, & Palla, 2013), sixfold 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 (Słyś & 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 vary 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% 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

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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 (Abaje, Ndabula, & Garba, 2014; Ogungbenro & Morakinyo, 2014), rainfall seasonality in Niger Delta on monthly and annual scales (Adejuwon, 2012), annual rainfall and temperature variability (Akinsanola & Ogunjobi, 2014), annual and monthly rainfall patterns in Ekiti State (Akinyemi, Ayeni, Faweya, & Ibraheem, 2013), inter- and intra-annual rainfall variability and distribution pattern over North-west Nigeria (Ekpoh & 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 & Olaniyan, 2012), monthly rainfall trends in Nasarawa State (Ekwe, Joshua, Igwe, & Osinowo, 2014), monthly rainfall distribution in Benin-Owena River Basin (Ikhile & Aifesehi, 2011), socio-demographic aspects of RWH practices in Ibadan (Lade & Oloke, 2015), DRWH practices in Enugu, uses and advantages (Ajayi & Ugwu, 2008), spatiotemporal 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 & Mama, 2014), required storage capacity for DRWH (Otti & Ezenwaji, 2013), DRWH technology (Shittu, Okareh, & Coker, 2015), monthly variability in harvestable rainwater and maximum storage requirement (Ubuoh, Ege, Ogbuji, & Onifade, 2012). Oke and Oyebola (2015) advocated mobilization and motivation of house owners.

Our literature survey revealed that factors affecting rainfall variability in South-west 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 extra-tropical factor include El Nino Southern Oscillation (Olaniran, 2015).

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

Giannini, Saravanan, and Chang (2003) also reported that land–atmosphere interactions amplify SST-driven signal which is responsible for inter-annual and inter-decadal variability of rainfall, while Nicholson and 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 south-west of Nigeria (Adegoke & Sojobi, 2015; Ganiyu, Akinniran, & Adeyemo, 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

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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, Awomeso, & Eruola, 2010).

Within the State, <12.5% of the populace have access to weekly regular public water supply (Odjeba, Idowu, Ikenweiwe, Martins, & Sadeeq, 2015), while Agbelemoje 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; Federal Republic of Nigeria, 2000; Gbadegesin & 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 and hepatitis (Dahunsi, Owamah, Ayandiran, & Oranusi, 2014; Otufale & 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 (Amori, Oduntan, Okeyode, & Ojo, 2013; Dahunsi et al., 2014).

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 & Jibiri, 2010) which is above the safe limit recommended by WHO (2004a).

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, Popola, Oyedepo, & Oluderu, 2010). The drudgery from fetching water has been found to affect the women's health who spend an average of 1 h daily covering about 1 km to fetch water (Coster & Otufale, 2014; Otufale & Coster, 2012).

Rainwater harvesting has been successfully deployed in the eastern part of Nigeria such as Edo State with appreciable success and is practiced by >80% of the households (Tobin, Ediagbonya, Ehidiamen, & Asogun, 2013), while between 3 and 6.6% in the south-western part of Nigeria (Gbadegesin & Olorunfemi, 2007; Lade & Oloke, 2015). 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 & Adeboye, 2010).

Further, since rainwater harvesting and infrastructure are affected by rainfall variability (Adegoke & Sojobi, 2015; Aladenola & Adeboye, 2010; Food and Agriculture Organization, 2007; Worm & Hattum, 2006), 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

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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 South-western Nigeria as shown in Figure 1. It lies between longitudes 3° 26′ 76″ and 3° 47′ 28″ and latitudes 7° 29′ 88″ and 7° 05° 54″. Being one of the largest LGA in Abeokuta which is the State capital, it has a population of 109, 449 based on the 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 and 22–35°C, respectively (Kilanko-Oluwasanya, 2009). Southwesterly wind prevails during rainy season, beginning from March to November, while Northwesterly wind dominates during the dry season, beginning from December to March. Geologically, the town is overlaid by crystalline basement which is basically granitic rocks and is being mined commercially for construction purposes.

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 (Amori et al., 2013; Kilanko-Oluwasanya, 2009) 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 the literature. In addition, four seasons identified in the 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, and Lamb (2010); Hu et al. (2015), Perry (2006) and Vanem and Walker (2013),

Figure 1. Map depicting location of Odeda LGA in South-west Nigeria.

Source: Isaac Idowu Balogun.

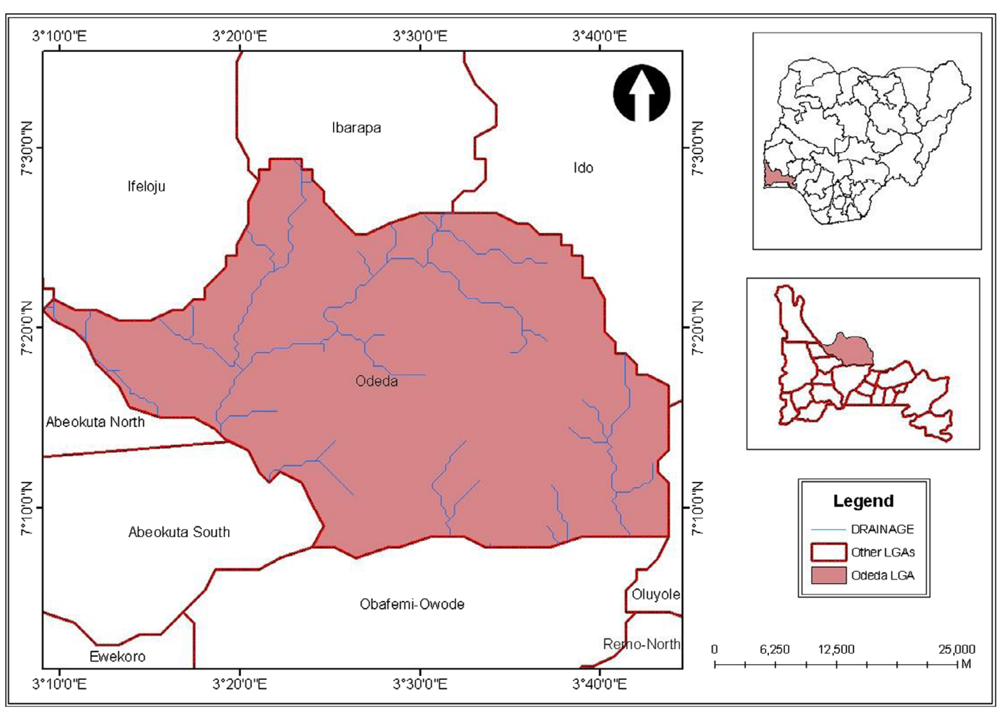

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Table 1. Different Global Seasonal classifications of climate from the literature

Class	(1)		(2)		(3)		(4)
Seasons	**Months**	**Seasons**	**Months**	**Seasons**	**Months**	**Seasons**	**Months**
Spring	Mar, Apr and May	Pre-mon-soon	MAM	Spring	Apr, May and Jun	Spring	Feb, Mar and Apr
Summer	Jun, July and Aug	Monsoon	JJAS	Summer	Jul, Aug and Sep	Summer	May, Jun and Jul
Autumn	Sep, Oct and Dec	Post-mon-soon	Oct,Nov, Dec	Fall	Oct, Nov and Dec	Autumn	Aug, Sep and Oct
Winter	Dec, Jan and Feb	Winter	Jan, Feb	Winter	Jan, Feb and Mar	Winter	Nov, Dec and Jan

while classification (2) was adopted for India by Mahajan and Dodamani (2015) and classification (3) was utilized by Sayemuzzaman and Jha (2014) for the USA.

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 and July (MJJ), autumn which streamlines with September Equinox [August, September and October (ASO)] and lastly, winter which is described as December Solstice [November, December and January (NDJ)].

2.3. Data collection, methods and analysis

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

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

$$\bar{S}1 = \frac{1}{\bar{R}} \sum_{n=1}^{12} \left| X_n - \frac{\bar{R}}{12} \right| \tag{1}$$

where X_n is the mean rainfall of month n; $\bar{R}$ is the mean annual rainfall.

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

$$\mathrm{SPI} = \frac{X - \bar{X}}{\sigma} \tag{2}$$

where X is the rainfall in each particular month, season or year depending on the time scale being used; $\bar{X}$ is the mean rainfall in each particular month, season or year depending on the time scale being used; and σ is the 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.

The rainfall data were also subjected to time series analyses on monthly and seasonal scales using statistical tests which include Mann–Kendal test, linear regression, SPI and Hoeffding's *D* statistics. Furthermore, the potential of rainwater to meet domestic water demands and storage requirements was also evaluated.

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Table 2. Seasonality index (SI) (Kanellopoulou, 2002) and annual standardized precipitation index (SPI) (McKee et al., 1993)

Seasonality index		**Standardized annual precipitation index**	
Rainfall regime	SI	Classification	SPI
Very equable	≤ 0.19	Near normal	−0.99 to 0.99
Equable but with a definite wetter season	0.2–0.39	Moderately wet years	1.0 to 1.49
Rather seasonal with a shorter drier season	0.40–0.59	Moderately dry years	−1.0 to −1.49
Seasonal	0.60–0.79	Very wet	1.5–1.99
Markedly seasonal with a long drier season	0.80–0.99	Severely dry years	−1.5 to −1.99
Most rain in three months or less	1.00–1.19	Wet extreme	≥ +2.0
Extreme, almost all rain in one–two months	≥ 1.20	Dry extreme	≤ −2.0

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 the 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, Ourashi, and Mamo (2014), was calculated as follows:

$$t_m = \frac{4\sum_{i=1}^{n-1} N_i}{n(n-1)} - 1 \tag{3}$$

$$r_m = \pm r_g \sqrt{\frac{4n+10}{9n\,(n-1)}} \tag{4}$$

where n is the number of years; r_g is the desired probability point of the normal distribution appropriate to a two-tailed test; and 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 analyse the rainfall values for residual rainfall. The residual rainfall was obtained by subtracting the predicted rainfall data obtained by from the linear regression equations from the observed values. The probability values for Hoeffding's D statistic were computed using the equation provided by Blum, Kiefer and Rosenblatt (1961) as follows:

$$\frac{(n-1)\pi^4 D}{60} + \frac{\pi^4}{72} \tag{5}$$

where n is the number of years of data and D is the Hoeffding's D statistic.

Hoeffding's D statistic was also used because it is typically used to detect non-linear and non-monotonic associations and has been found to outperform other statistical methods (Fujita et al., 2009).

Hoeffding's D statistic was obtained utilizing the formula provided by Santos, Takahashi, Naka, and Fujita (2014) as follows:

$$D = \frac{(n-2)(n-3)D_1 + D_2(n-2)D_3}{n(n-1)(n-2)(n-3)(n-4)} \tag{6}$$

$$\text{where } D_1 = \varepsilon_i\left(Q_i - 1\right)\left(Q_i - 2\right);D2 = \varepsilon_i\left(R_i - 1\right)\left(R_i - 2\right)\left(S_i - 1\right)\left(S_i - 2\right); \tag{7}$$

$$D3 = \varepsilon_i\left(R_i - 2\right)\left(S_i - 2\right)\left(Q_i - 1\right) \tag{8}$$

where R_i is the rank of x_i; S_i is the rank of y_i; and Q_i known as bivariate rank = 1 + number of points with both x and y values < the ith point.

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

$$\rho_n = \frac{1}{30}\sqrt{\frac{2\left(n^2 + 5n - 32\right)}{9n(n-1)(n-3)(n-4)\alpha}} \tag{9}$$

where α is the level of significance.

Hoeffding's measure ρ_n varies from −1/60 to 1/30 (Santos et al., 2014), which is equivalent to −0.0167–0.033. The acceptable range of α was obtained by inserting the upper and lower limits of ρ_n given above. The acceptable range of α was found to be 1.32–3.87%. The 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:

$$t = \frac{\bar{X} - \mu}{s/\sqrt{n}} \tag{10}$$

where t is the test value, $\bar{X}$ is the mean of observed values, μ is the claimed mean, S is the standard deviation of data and n is the 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 ($\overline{R_m}$), roof area (A), percentage of roof area utilized for rainwater harvesting (β) and roof run-off coefficient (C) as given in Equation 5.

$$Q_m = \overline{R_m} \times A \times \beta \times C \tag{11}$$

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

Furthermore, roof run-off coefficient (C) varies between 0.75 and 0.95 from the literatures (Fernandes et al., 2015; Roebuck, 2007; Tomaz, 2005; Woltersdorf et al., 2015). C value of 0.8 was adopted for this study as utilized by Otti and Ezenwaji (2013) and Shittu et al. (2015) and accounts for leakage, spillage, infiltration, roof surface wetting and evaporation (Lee et al., 2010) and is within the range of 70–85% of harvestable rainfall suggested by Helmreich and Horn (2009).

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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:

$$\bar{X} + Z(\alpha/2)\left(\frac{\sigma}{\sqrt{n}}\right) = \text{Upper Confidence Limit (UCL)} \tag{12}$$

$$\bar{X} - Z(\alpha/2)\left(\frac{\sigma}{\sqrt{n}}\right) = \text{Lower Confidence Limit (LCL)} \tag{13}$$

where $\bar{X}$ = Mean = $\overline{R_m}$; $Z(\alpha/2)$ = Confidence coefficient; $\left(\sigma/\sqrt{n}\right)$ = Standard error of mean and $Z(\alpha/2)\left(\sigma/\sqrt{n}\right)$ = Maximum error of estimate (MEE), σ = Standard deviation of monthly rainfall for each month and 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 8.

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:

$$Q_{\text{UCL}} = [\bar{R}_m + \text{MEE}] \times A \times \beta \times C \tag{14}$$

$$Q_{\text{LCL}} = [\bar{R}_m - \text{MEE}] \times A \times \beta \times C \tag{15}$$

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:

$$Q_{\text{UCL}} = \bar{R}_m \times A \times \beta \times C[1 + \text{COV}] \tag{16}$$

$$Q_{\text{LCL}} = \bar{R}_m \times A \times \beta \times C[1 - \text{COV}] \tag{17}$$

and the results were shown in Table 10.

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 2 as well as Table 3.

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 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 rainfall in winter and autumn were moderately variable with index between 20 and 30%.

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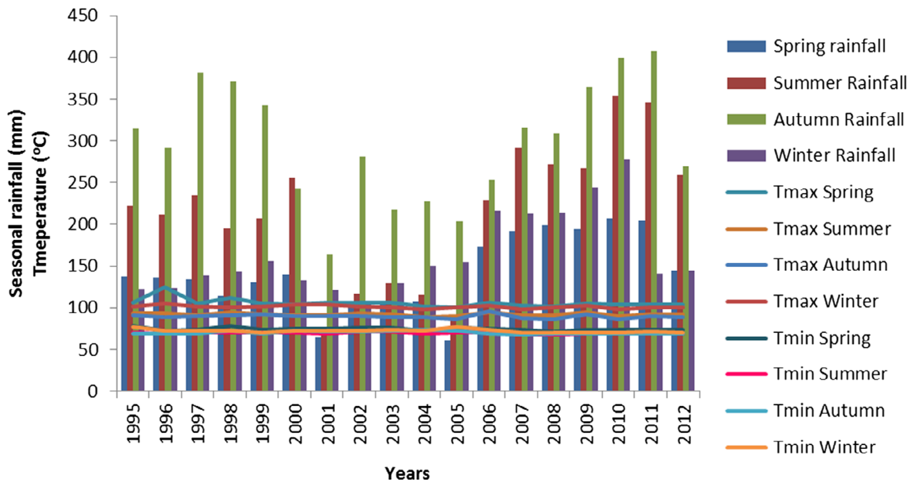
Figure 2. Climograph of seasonal rainfall in Odeda LGA in Ogun State, South-west, Nigeria.



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).

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 is presented in Figure 4.

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, and 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 were also attributed to changes in regional circulation patterns (Zang & Liu, 2013).

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

Parameters	Spring	Summer	Autumn	Winter
Mean	141.41	214.68	297.44	162.54
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_{sx}	−0.08	−0.19	−0.11	1.17

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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.

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 and 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.

Between 2006 and 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.

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

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

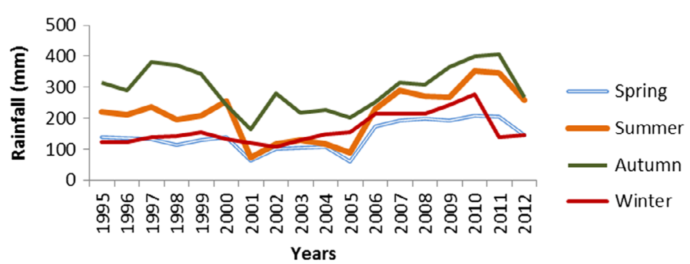

Figure 4. SPI for annual rainfall from 1995 to 2012 for the study area.

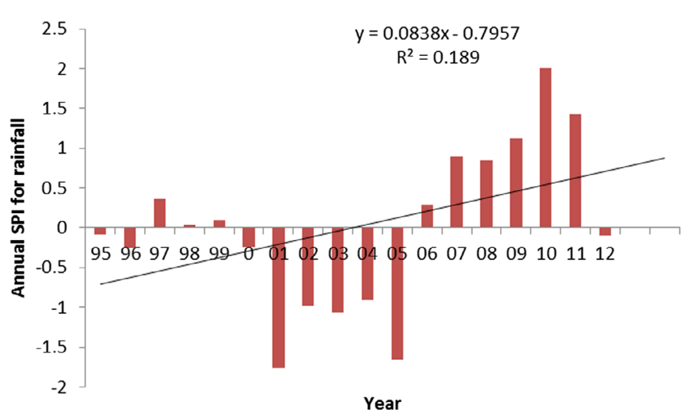

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Table 4. Classification of annual rainfall based on SPI

Classification	Year
Near normal	1995, 1996, 1997, 1998, 1999, 2000, 2002, 2004, 2006, 2007, 2008, 2012
Moderately dry	2003
Moderately wet	2009, 2011
Severely dry	2001, 2005
Extremely wet	2010

moderate variability between 20 and 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–April (Akinyemi et al., 2013) had an increasing rainfall range of 1.19–2.27 mm/year with a mean of 1.63 mm/year, while the wet season months of May–October witnessed an increasing rainfall range of 0.20–2.28 mm/year with a mean of 1.37 mm/year.

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 and 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, Talaee, & Mohammadi, 2011). Based on the slope of linear regression as depicted in Table 6, the highest increasing trend of 2.36 mm/year occurred in May, followed by 2.28 mm/year in June and 2.27 mm/year in November.

Based on the M–K test, insignificant increasing trend took place in August and September, although both have slope values of 0.78 and 0.20 mm/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.

Figure 5. Graph of monthly rainfall in Odeda LGA, south-west Nigeria.

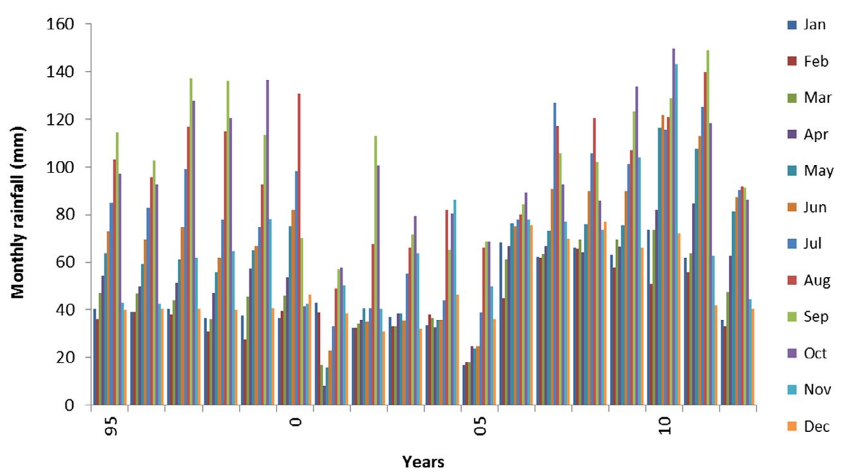

Table 5. Descriptive characteristics of monthly rainfall in Odeda, Ogun State, Nigeria.

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean (mm)	45.8	41.3	47.4	52.7	63.4	69.5	81.8	97.9	101.9	97.7	67	48.6
Max (mm)	73.5	65.8	73.7	84.8	107.6	121.7	126.8	140	148.8	150	143.1	76.9
Min (mm)	17	18.2	17	8.2	23.9	23	33	66	56.9	41.4	40.5	31
SD	15.7	12.7	16.8	19.4	26.1	28.8	29.5	25.4	27.7	28.7	26	15.6
COV (%)	34	31	35	37	41	41	36	26	27	29	29	32
C_{sx}	0.38	0.46	−0.15	−0.50	0.12	−0.13	−0.25	−0.26	−0.07	0.04	1.58	0.93

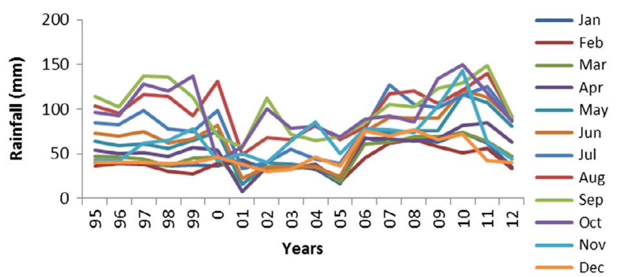

Figure 6. Line graph of monthly rainfall variation for the study period.

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 6.7 mm/year, followed by winter (5.44 mm/year) and spring (4.50 mm/year), while autumn recorded the least increasing trend of 1.59 mm/year.

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 (2015) who advocated the use of SPI to detect significant trends in hydrological parameters.

Though M–K 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, Haché, Perreault, and Bobée (2004) also reported insignificant changes in rainfall for Togo and Benin located in West Africa.

P {D} values for all the months and seasons were found to be > ρ_n 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 > 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.

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Table 6. Trend results for Mann–Kendall, linear regression, SPI Tests and Hoeffding's *D* statistics for monthly rainfall

	Mann–Kendall				Linear Regression		SPI	Hoeffding's D Statistics		
	N	t_m	r_m	Trend	Slope	R_{corr}	Slope	D	P{D}	ρ_n
Jan	18	0.18	±0.15	Significant increase	1.55	0.34	0.098	0.1159	4.5517	0.0661
Feb	18	0.27	±0.14	Significant increase	1.19	0.44	0.109	0.0925	3.9058	0.0661
Mar	18	0.31	±0.13	Significant increase	1.57	0.68	0.096	0.0740	3.3952	0.0661
Apr	18	0.31	±0.13	Significant increase	1.74	0.32	0.092	0.0765	3.4642	0.0661
May	18	0.36	±0.12	Significant increase	2.36	0.27	0.093	0.0740	3.3952	0.0661
Jun	18	0.33	±0.13	Significant increase	2.28	0.25	0.085	0.0742	3.4008	0.0661
Jul	18	0.19	±0.15	Significant increase	1.95	024	0.068	0.0878	3.7761	0.0661
Aug	18	0.05	±0.17	Insignificant increase	0.78	0.07	0.032	0.1144	4.5103	0.0661
Sep	18	0.02	±0.17	Insignificant increase	0.20	−0.07	0.001	0.1247	4.7945	0.0661
Oct	18	0.29	±0.13	Significant increase	0.62	−0.09	0.022	0.1258	4.8249	0.0661
Nov	18	0.19	±0.15	Significant increase	2.27	0.15	0.090	0.1001	4.1156	0.0661
Dec	18	0.28	±0.13	Significant increase	1.48	0.35	0.098	0.0885	3.7954	0.0661

Note: R_{corr} = correlation coefficient.

Figure 7. Comparison of monthly SPI from 1995 to 2012.

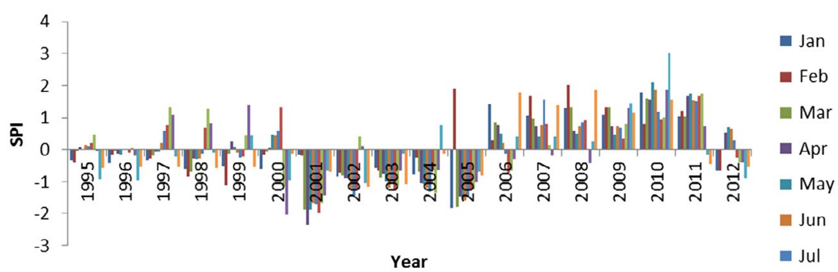

Table 7. Trend results for Mann–Kendall, linear regression, SPI Tests and Hoeffding's *D* statistics for seasonal rainfall

	Mann–Kendall				Linear regression	SPI	Hoeffding's *D* statistics		
Seasons	N	t_m	r_m	Trend	Slope	Slope	D	P{D}	ρ_n
Spring	18	0.62	± 0.26	Significant increase	4.500	0.102	0.0988	4.0797	0.0661
Summer	18	0.62	± 0.26	Significant increase	6.70	0.083	0.0356	2.3354	0.0661
Autumn	18	0.09	± 0.16	Insignificant increase	1.59	0.023	0.1178	4.604	0.0661
Winter	18	0.35	± 0.13	Significant increase	5.44	0.116	0.0741	3.398	0.0661

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 2000–2005, 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

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Figure 8. Comparison of Seasonal SPI from 1995 to 2012.

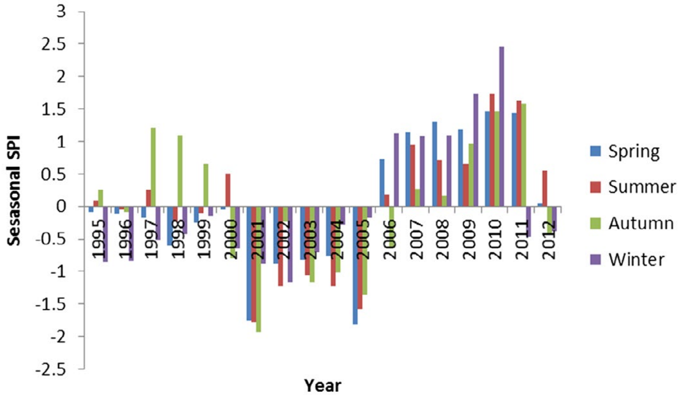


Figure 9. Seasonal residual rainfall for Odeda LGA from 1995 to 2012.

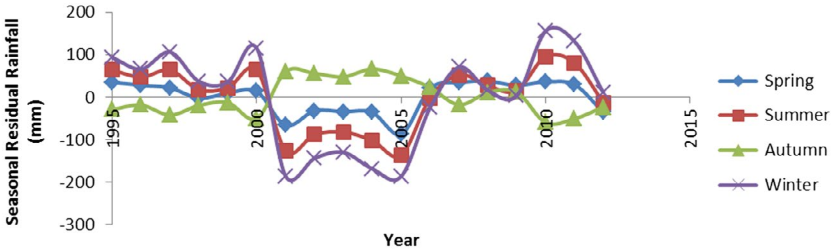
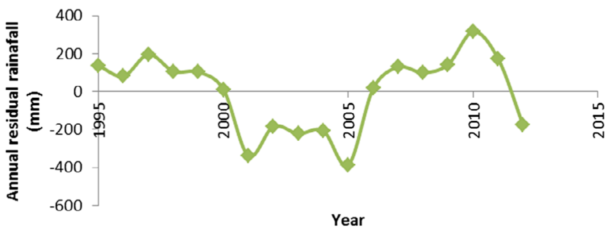


Figure 10. Annual residual rainfall for Odeda LGA from 1995 to 2012



of the rainfall pattern. This result corroborated the findings of Ibrahim, Balzter, Kaduk, and Tucker (2015) who observed the oscillating pattern of approximately five (5)-year periodicity for rainfall in Sub-Saharan West Africa.

Also, the annual residual rainfall graph displayed 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 clyclical pattern as well. The most profound periodicity for the region was five (5) years.

The wet state was predominant between 1995 and 2000, while the dry state was predominant between 2000 and 2006 and there was a reversal to the wet states between 2006 and 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 (World Meteorological Organization, 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 was obtained in seasonal and annual time scales. They both exhibited alternation between wet and dry states. For most of the months, wet state was observed between 1995 and 2000, dry state between 2000 and 2005 and a reversal wet state between 2005 and 2010.

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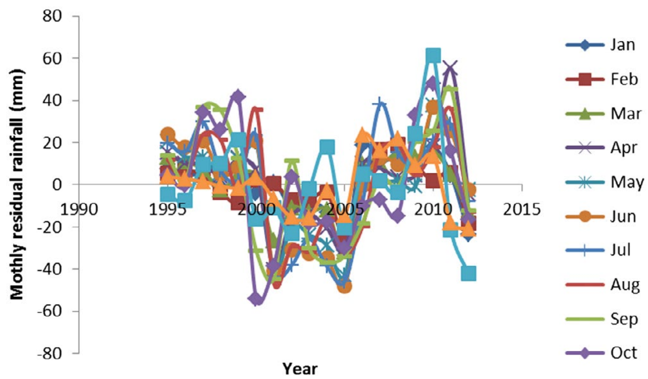
Figure 11. Monthly residual rainfall for Odeda LGA from 1995 to 2012.



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 time scales.

Nicholson (2013) identified the factors responsible for inter-annual rainfall variability and were 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 months of May–June, before the onset of rain, TEJ was very strong in January–March, AWJ between July and September, while WAWJ was influential in May–September.

Other factors responsible for rainfall variability on monthly, seasonal and annual time scales in the area of study were attributed to non-linear West African Monsoon (WAM) and relief (Barbe, Lebel, & Tapsoba, 2002; Eltahir & Gong, 1996), Indian Ocean SST and anticyclones over NE China (Hastenrath & Wolter, 1992; Quan, Diaz, & Fu, 2003), global inter-hemispheric SST differences (Semazzi, Mehta, & Sud, 1988) and local surface hydrology such as local evapotranspiration which contributes 27% of rainfall in West Africa (Gong & Eltahir, 1996).

Also important are land surface feedback mechanisms such as soil moisture, lowered surface roughness and dust generation (Rowell, Folland, Maskell, & Ward, 1995). From the residual rainfall analyses, it may be implied that different forcing mechanisms operate during different months, seasons and years (Long & Entekhabi, 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 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 9).

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, Dahunsi, and Afolayan (2015)

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Table 8. Monthly harvestable rainwater (MHRW) based on maximum error estimate of $\overline{R_m}$

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

recommended 7.5 lpcd for both drinking and cooking which covered 4.5 lpcd and 3 lpcd recommended by WHO (2004b, 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 30-day month, the estimated NPWD was 150×4 plus additional 40 litres (for two remaining days), which gives 640 litres.

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 and emergencies such as ceremonies. 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 m^3) and 1620 litres (1.62 m^3), respectively. Therefore, total estimated monthly household water demand (HHWD) for a six-member household was 6.228 m^3, while total annual HHWD was 74.74 m^3.

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 and 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 9. Monthly harvestable rainwater (HRW) based on coefficient of variation limits

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

Table 10. Water demand for various applications

Applications	Water demand (lpcd)	Sources
Bathing	6	WHO (2005)
Toilet flushing	10	WHO (2005)
Dishwashing	4	Authors[1]
Laundry (weekly)	10	WHO (2005)
Drinking and cooking	7.5	Sojobi et al. (2015)

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

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Table 11. Domestic rainwater harvesting potential (DRHP) based on MEE limits

Scenarios	Total annual HRW (m^3)	% Annual NPWD	% Annual PWD	% Total annual HHWD
UCL	27.45	49.64	141.20	36.73
Mean	22.45	41	115.48	30.04
LCL	18.16	32.84	93.42	24.30

Table 12. Domestic rainwater harvesting potential (DRHP) based on COV limits

Scenarios	Total annual HRW (m^3)	% Annual NPWD	% Annual PWD	% Total annual HHWD
UCL	30.40	54.91	156.38	40.67
LCL	15.23	27.51	78.34	20.38

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 and 40.67% of the total annual HHWD as displayed in Table 12.

4. Conclusions

Rainfall variability has been demonstrated for our study area and it may be attributed to tropical and extra-tropical factors which operate during different months, seasons and years. Rainfall variability in terms of COV ranges from 24 to 39% for the seasons and 26 to 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 the M–K 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 time scales. 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 are 1 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 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 27.51–54.91% of non-potable household water demand as well as 78.34–156.38% of household potable water demand for a six-member household.

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.

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The significance of this research and contribution to the 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 characterizes our study area.

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References

Abaje, I. B., Ndabula, C., & Garba, A. H. (2014). Is the changing rainfall patterns of Kano State and its adverse impacts an indication of climate change? *European Scientific Journal, 10*, 192–206.

Abdulla, F. A., & Al-Shareef, A. W. (2009). Roof rainwater harvesting systems for household water supply in Jordan. *Desalination, 243*, 195–207. http://dx.doi.org/10.1016/j.desal.2008.05.013

Adejuwon, J. O. (2012). Rainfall seasonality in the Niger Delta Belt, Nigeria. *Journal of Geography and Regional Planning, 5*, 51–60.

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

Agbelemoje A., & Odubanjo O. J. (2001). Assessment of domestic water supply sanitation in rural communities in Ijebu North Area of Ogun State, Nigeria. *Journal of Environmental Extension, 2*, 81–87.

Ajayi, A. R., & Ugwu, C. C. (2008). Rainwater harvesting for agriculture and domestic supply in Enugu North Agricultural Zone, Nigeria. *Journal of Agricultural Extension, 12*(1), 1–12.

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

Akinyemi, O., Ayeni, O. A., Faweya, O., & Ibraheem, A. G. (2013). Statistical study of annual and monthly rainfall patterns in Ekiti State. *International Journal of Pure and Applied Science Technology, 15*(2), 1–7.

Aladenola, O., & Adeboye, O. (2010). Assessing the Potential for Rainwater Harvesting. *Water Resources Management, 24*, 2129–2137. doi:10.1007/s11269-009-9542-y.

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

Amakom C. M., & Jibiri N. N. (2010). Uranium.

Amori, A. A., Oduntan, O. O., Okeyode, I. C., Ojo, S. O. (2013). Heavy metal concentration of groundwater deposits in odeda region, Ogun state, Nigeria. *E3 Journal of Environmental Research and Management, 4*, 253–259.

Aper, J. A., & Agbehi, S. I. (2010). Pattern of domestic water supply in Ugbokolo Community in Benue State, Nigeria. *International Journal of Water & Soil Resources, 1*, 72–82.

Barbe, L. L., Lebel, T., & Tapsoba, D. (2002). Rainfall Variability in West Africa during the Years 1950–90. *Journal of Climate, 15*, 187–202. http://dx.doi.org/10.1175/1520-0442(2002)015<0187:RVIWAD>2.0.CO;2

Biazin, B., Sterk, G., Temesgen, M., Abdulkedir, A., & Stroosnijder, L. (2012). Rainwater harvesting and management in rainfed agricultural systems in sub-Saharan Africa – A review. *Physics & Chemistry Of The Earth, 47–48*, 139–151.

Bibi, U. M., Kaduk, J., & Balzter, H. (2014). Spatial-Temporal Variation and Prediction of Rainfall in Northeastern Nigeria. *Climate, 2*, 206–222. http://dx.doi.org/10.3390/cli2030206

Biswas, B. K., & Mandal, B. H. (2014). Construction and Evaluation of Rainwater Harvesting System for Domestic Use in a Remote and Rural Area of Khulna. *Bangladesh. ISRN Otolaryngology,* 1–6. doi:10.1155/2014/751952

Bluman, A. G. (2013). *Elementary statistics. A step by step approach* (6th ed.). New York, NY: McGraw-Hill.

Blum, J. R., Kiefer, J., & Rosenblatt, M. (1961). Distribution free tests of independence based on the sample distribution function. *Annals of Mathematical Statistics, 32*, 485–98.

Bocanegra-Martinez, A., Ponce-Ortega, J. M. P., Napoles-Rivera, F., Serna-Gonzalez, M., Castro-Montoya, A. J., & El-Hawagi, M. M. (2014). Optimal design of rainwater collecting systems for domestic use into a residential development. *Resources, Conservation and Recycling, 84*, 44–56. http://dx.doi.org/10.1016/j.resconrec.2014.01.001

Boelee, E., Yohannes, M., Poda, J., McCartney, M., Cecchi, P., Kibret, S., & Laamrani, H. (2013). Options for water storage and rainwater harvesting to improve health and resilience against climate change in Africa. *Regional Environmental Change, 13*, 509–519. doi:10.1007/s10113-012-0287-4.

Branco, A. D. M. Suassuna, J., & Vainsencher, S. A. (2005). Improving Access to Water Resources through Rainwater Harvesting as A Mitigation Measure: The Case of the Brazilian Semi-Arid Region. *Mitigation and Adaptation Strategies for Global Change, 10*, 393–409. http://dx.doi.org/10.1007/s11027-005-0053-8

Campisano, A., Gnecco, I., Modica, C., & Palla, A. (2013). Designing domestic rainwater harvesting systems under different climatic regimes in Italy. *Water Science and*

Downloaded by [197.211.53.15] at 04:36 01 April 2016

Technology, 67, 2511–2518. doi:10.2166/wst.2013.143

Chao-Hsien, L., & Yu-Chuan, C. (2014a). Framework for Assessing the Rainwater Harvesting Potential of Residential Buildings at a National Level as an Alternative Water Resource for Domestic Water Supply in Taiwan. *Water, 6*, 3224–3246. doi:10.3390/w6103224.

Chao-Hsien, L., & Yu-Chuan, C. (2014b). Dimensionless Analysis for Designing Domestic Rainwater Harvesting Systems at the Regional Level in Northern Taiwan. *Water, 6*, 3913–3933. doi:10.3390/w6123913.

Clark, R., Gonzalez, D., Dillon, P., Charles, S., Cresswell, D., & 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 Modelling and Software, 72*, 117–125. http://dx.doi.org/10.1016/j.envsoft.2015.07.009

Coster, A. S., & Otufale, G. A. (2014). Household's water-use demand and willingness to pay for improved water services in Ijebu-Ode Local Government Area, Ogun State, Nigeria. *Journal of Environment & Earth Science, 4*, 166–174.

Cruddas, P., Carter, R., Parker, A., Rowe, N., & Webster, J. (2013). Tank costs for domestic rainwater harvesting in East Africa. *Proceedings of ICE: Water Management, 166*, 536–545. doi:10.1680/wama.11.00113.

Dahunsi, S. O., Owamah, H. I., Ayandiran, T. A., & Oranusi, S. U. (2014). Drinking water quality and public health of selected towns in South Western Nigeria. *Water Qual Expo Health, 6*, 143–153. doi:10.1007/s12403-014-0118-6.

Dobrowsky, P. H., Mannel, D., De Kwaadsteniet, M., Prozesky, H., Khan, W., & Cloete, T. E. (2014). Quality assessment and primary uses of harvested rainwater in Kleinmond, South Africa. *Water SA, 40*, 401–406. doi:10.4314/wsa.v40i3.2.

Dobrowsky, P. H., Van Deventer, A., De Kwaadsteniet, M., Ndlovu, T., Khan, S., Cloete, T. E., & Khan, W. (2014). Prevalence of virulence genes associated with pathogenic Escherichia coli strains isolated from domestically harvested rainwater during low- and high-rainfall periods. *Applied and Environmental Microbiology, 80*, 1633–1638.

Efe, S. I. (2006). Quality of rainwater harvesting for rural communities of Delta State, Nigeria. *The Environmentalist, 26*, 175–181. doi:10.1007/s10669-006-7829-6.

Ekpoh, I. J., & Nsa, E. (2011). Extreme climatic variability in North-Western Nigeria: An analysis of rainfall trends and patterns. *Journal of Geography and Geology, 3*, 51–62.

Ekwe, M. C., Joshua, J. K., Igwe, J. E., & Osinowo, A. A. (2014). Mathematical of monthly and annual rainfall trends in Nasarawa State, Nigeria. *IOSR Journal of Mathematics, 10*, 56–62.

Eltahir, E. A. B., & Gong, C. (1996). Dynamics of wet and dry years in West Africa. *Journal of Climate, 9*, 1030–1042. http://dx.doi.org/10.1175/1520-0442(1996)009<1030:DOWADY>2.0.CO;2

Esterhuyse, P. (2012). Social capital in a rainwater-harvesting project in rural South. *Irrigation and Drainage, 61*, 95–105. doi:10.1002/ird.1690

Food and Agriculture Organization. (2007). *Report on water and sanitation in Africa*. Rome: Author.

Fernandes, L. F. S., Terencio, D. P. S., & Racheco, F. A. L. (2015). Rainwater harvesting systems for low demanding applications. *Science of The Total Environment, 529*, 91–100. http://dx.doi.org/10.1016/j.scitotenv.2015.05.061

Fry, L. M., Cowden, J. R., Watkins, J. W., Clasen, T., & 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*, 9535–9541. doi:10.1021/es100798j.

Federal Republic of Nigeria. (2000). *Water supply and sanitation interim strategy note*. Abuja, Nigeria: FRN.

Fujita, A., Sato, J., Demasi, M., Sogayar, M., Ferreira, C., & Miyano, S. (2009). Comparing Pearson, Spearman and Hoeffding's D measure for gene expression association analysis. *Journal of Bioinformatics & Computational Biology, 7*, 663–684.

Ganiyu, M. O., Akinniran, Y. N., & Adeyemo, S. A. (2013). Rainfall pattern and trend on arable crops production in Oyo State, Nigeria (1990-2009). *World Rural Observ., 5*, 7–11.

Gbadegesin, N. N., & Olorunfemi, F. (2007). *Assessment of rural water supply management in selected rural areas of Oyo State, Nigeria*. Nairobi: African Technology Policy Network. Retrieved from http://www.atpsnet.org/Files/working_paper_series_49.pdf

Gebremichael, A., Ourashi, S., & Mamo, G. (2014). Analysis of seasonal rainfall variability for agricultural water resource management in Southern region. *Ethiopia Journal of Natural Sciences Research, 4*, 56–79.

Ghis, E., & Schondermark, P. V. (2013). Investment feasibility analysis of rainwater use in residences. *Water Resources Management, 27*, 2555–2576. doi:10.1007/s11269-013-0303-6.

Giannini, A., Saravanan, R., & Chang, P. (2003). Oceanic Forcing of Sahel rainfall on interannual to interdecadal time scales. *Science, 302*, 1027–1030. http://dx.doi.org/10.1126/science.1089357

Gong, C., & Eltahir, E. (1996). Sources of moisture for rainfall in West Africa. *Water Resources Research, 32*, 3115–3121. http://dx.doi.org/10.1029/96WR01940

Guhathakurta, P., & Saji, E. (2013). Detecting changes in rainfall pattern and seasonality index vis-à-vis increasing water scarcity in Maharashtra. *Journal of Earth System Science, 122*, 639–649. http://dx.doi.org/10.1007/s12040-013-0294-y

Gurung, T. R., & Sharma, A. (2014). Communal rainwater tank systems design and economies of scale. *Journal of Cleaner Production, 67*, 26–36. http://dx.doi.org/10.1016/j.jclepro.2013.12.020

Gwenzi, W., Dunjana, N., Pisa, C., Tauro, T., & 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*, 107–118. http://dx.doi.org/10.1016/j.swaqe.2015.01.006

Hare, F. K. (1983). *Climate and desertification. Revised analysis (WMO-UNDP)*. WCP-44, 5-20, Geneva, Switzerland

Hastenrath, S., & Wolter, K. (1992). Large-scale patterns and long-term trends of circulation variability associated with Sahel rainfall anomalies. *Journal of the Meteorological Society of Japan, 70*, 1045–1055.

Helmreich, B., & Horn, H. (2009). Opportunities in rainwater harvesting. *Desalination, 248*, 118–124. http://dx.doi.org/10.1016/j.desal.2008.05.046

Hu, Q., Pan, F., Pan, X., Zhang, D., Li, Q., Pan, Z., & Wei, Y. (2015). Spatial analysis of climate change in Inner Mongolia during 1961–2012, China. *Applied Geography, 60*, 254–260. http://dx.doi.org/10.1016/j.apgeog.2014.10.009

Ibrahim, Y., Balzter, H., Kaduk, J., & Tucker, C. J. (2015). Land degradation assessment using residual trend analysis of GIMMS NDVI3g, soil moisture and rainfall in Sub-Saharan West Africa from 1982 to 2012. *Remote Sensing, 7*, 5471–5494.

Ikhile, C. I., & Aifesehi, P. E. E. (2011). Geographical distribution of average monthly rainfall in the western section of Benin-Owena River Basin, Nigeria. *African Research Review, 5*, 493–500.

Imteaz, M., Adeboye, O., Rayburg, S., & Shanableh, A. (2012). Rainwater harvesting potential for southwest Nigeria using daily water balance model. *Resources, Conservation & Recycling, 62*, 51–55. Retrieved from: Environment

Downloaded by [197.211.53.15] at 04:36 01 April 2016

Complete, Ipswich, MA. August 11, 2015.

Imteaz, M. A., Ahsan, A., & Shanableh, A. (2013). Reliability analysis of rainwater tanks using daily water balance model: Variations within a large city. *Resources, Conservation and Recycling, 77*, 37–43. http://dx.doi.org/10.1016/j.resconrec.2013.05.006

Imteaz, M. A., Matos, C., & Shanableh, A. (2014). Impacts of climatic variability on rainwater tank outcomes for an inland city, Canberra. *International Journal of Hydrology Science and Technology, 4*, 177–191. http://dx.doi.org/10.1504/IJHST.2014.067730

Islam, K. Z., Islam, M. S., Lacoursiere, J. O., & Dessborn, L. (2014). Low cost rainwater harvesting: An alternate solution to salinity affected coastal region of Bangladesh. *American Journal of Water Resources, 2*, 141–148. http://dx.doi.org/10.12691/ajwr-2-6-2

Johnson, R., & Kuby, P. (2012). *Elementary statistics*. New York, NY: Cengage Learning.

Kalungu, J. W., Filho, W. L., Mbuge, D. O., 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 Heidelberg. doi: 10.1007/978-3-642-40455-9-221-23-1

Kanellopoulou, E. A. (2002). Spatial distribution of rainfall seasonality in Greece. *Weather, 57*, 215–219. http://dx.doi.org/10.1256/004316502760053576

Kendall, M. G. (1975). *Ranked Correlation Methods*. London: Griffin.

Kilanko-Oluwasanya, G. O. (2009). *Better safe than sorry: Towards appropriate water safety plans for urban self-supply systems* (Unpublished PhD Dissertation). Cranfield University, UK.

Kohlitz, J. P., & Smith, M. D. (2015). Water quality management for domestic rainwater harvesting systems in Fiji. *Water Science & Technology: Water Supply, 15*, 134–141. doi:10.2166/ws.2014.093.

Kwaadsteniet, M., Dobrowsky, P., Deventer, A., Khan, W., & Cloete, T. (2013). Domestic rainwater harvesting: Microbial and chemical water quality and point-of-use treatment systems. *Water, Air & Soil Pollution, 224*(7), 1–19. doi:10.1007/s11270-013-1629-7.

Lade, O., & Oloke, D. (2015). Rainwater harvesting in Ibadan City, Nigeria: Socio-economic survey and common water supply practices. *American Journal of Water Resources, 3*, 61–72.

Lebel, S., Fleskens, L., Forster, P. M., Jackson, L. S., Lorenz, S. (2015). Evaluation of In Situ rainwater harvesting as an adaptation strategy to climate change for maize production in rainfed Africa. *Water Resource Management, 29*, 4803-4816. doi:10.1007/s11269-015-1091-y

Lee, J. Y., Yang, J. S., Han, M., & Choi, J. (2010). Comparison of the microbiological and chemical characterization of harvested rainwater and reservoir water as alternative water resources. *Science of The Total Environment, 408*, 896–905. http://dx.doi.org/10.1016/j.scitotenv.2009.11.001

Lekwot, V. E., Samuel, I. O., Ifeanyi, E., & Olisaemeka, O. (2012). Evaluating the potential of rainwater harvesting as a supplementary source of water supply in Kanai (Mali) district of Zangon-katak local government area of Kaduna State, Nigeria. *Global Advanced Research Journal of Environmental Science and Technology, 1*, 38–45.

Liu, E., Luo, Y. L., Zhang, R. H., Wu, Q. H., & Liu, L. P. (2011). Regional atmospheric anomalies responsible for the 2009–2010 severe drought in China. *Journal of Geophysical Research, 116*, D21114. doi:10.1029/2011JD015706

Long, M., & Entekhabi, D. (2000). Interannual variability in rainfall, water vapor flux, and vertical motion over West Africa. *Journal of Climate, 13*, 3827–3841. http://dx.doi.org/10.1175/1520-0442(2000)013<3827:IVIRWV>2.0.CO;2

Mahajan, D. R., & Dodamani, B. M. (2015). Trend Analysis of Drought Events Over Upper Krishna Basin in Maharashtra. *Aquatic Procedia, 4*, 1250–1257. http://dx.doi.org/10.1016/j.aqpro.2015.02.163

Martins, O., Ajayi, O., & Idowu, O. A. (2000). Factors influencing yields of boreholes in Basement Complex aquifers of South-western Nigeria. *Nigeria Journal of Science, 34*, 295–300.

Mazvimavi, D. (2010). Investigating changes over time of annual rainfall in Zimbabwe. *Hydrology and Earth System Sciences, 14*, 2671–2679. http://dx.doi.org/10.5194/hess-14-2671-2010

McKee, T. B., Doesken, N. J., & Kleist, J. (1993, January). *The relationship of drought frequency and duration to time scales*. 8th Conference on Applied Climatology 179–184, January 17–22, Anaheim, California

Mendez, C. B., Klenzendorf, J. B., Afshar, B. R., Simmons, M. T., Barrett, M. E., Kinney, K. A., & Kirisits, M. J. (2011). The effect of roofing material on the quality of harvested rainwater. *Water Research, 45*, 2049–2059. http://dx.doi.org/10.1016/j.watres.2010.12.015

Mwenge Kahinda, J., Taigbenu, A. E., & 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*, 1050–1057. doi:10.1016/j.pce.2007.07.007.

Mwenge Kahinda, J., Taigbenu, A., & Boroto, R. (2010). Domestic rainwater harvesting as an adaptation measure to climate change in South Africa. *Physics and Chemistry of the Earth, Parts A/B/C, 35*, 742–751. doi:10.1016/j.pce.2010.07.004.

Mwenge Kahinda, J., & Taigbenu, A. (2011). Rainwater harvesting in South Africa: Challenges and opportunities. *Physics & Chemistry of The Earth – Parts A/B/C, 36*, 968–976. doi:10.1016/j.pce.2011.08.011

Ndiritu, J., Odiyo, J. O., Makungo, R., Ntuli, C., & Mwaka, B. (2011). Yield-reliability analysis for rural domestic water supply from combined rainwater harvesting and run-of-river abstraction. *Hydrological Sciences Journal, 56*, 238–248. doi:10.1080/02626667.2011.555766.

Nicholson, S. E., & Grist, J. P. (2001). A conceptual model for understanding rainfall variability in the West African Sahel on interannual and interdecadal timescales. *International Journal of Climatology, 21*, 1733–1757. http://dx.doi.org/10.1002/(ISSN)1097-0088

Nicholson, S. E. (2013). The West African Sahel: A review of recent studies on the rainfall regime and its interannual variability. *ISRN Meteorology, 2013*, 1–32. http://dx.doi.org/10.1155/2013/453521

Nijhof, S., Jantowski, B., Meerman, R., & Schoemaker, A. (2010). Rainwater harvesting in challenging environments: Towards institutional frameworks for sustainable domestic water supply. *Waterlines, 29*, 209–219. doi:10.3362/1756-3488.2010.022

Nnaji, C., & Mama, N. (2014). Preliminary assessment of rainwater harvesting potential in Nigeria: Focus on flood mitigation and domestic water supply. *Water Resources Management, 28*, 1907–1920. doi:10.1007/s11269-014-0579-1

Odjeba, E. E., Idowu, O. A., Ikenweiwe, N. B., Martins, O., & Sadeeq, A. Y. (2015). Public perception of potable water supply in Abeokuta Southwest Nigeria. *Journal of Applied Science Environmental Management, 19*, 5–9.

Ogungbenro, S. B., & Morakinyo, T. E. (2014). Rainfall distribution and change detection across climatic zones in Nigeria. *Weather and Climate Extremes, 5–6*, 1–6. http://dx.doi.org/10.1016/j.wace.2014.10.002

O'Hogain, S., McCarton, L., McIntyre, N., Pender, J., & Reid, A. (2011). Physicochemical and microbiological quality of

Downloaded by [197.211.53.15] at 04:36 01 April 2016

water from a pilot domestic rainwater harvesting facility in Ireland. *Water & Environment Journal, 25*, 489–494. doi:10.1111/j.1747-6593.2010.00244.x

Oke, M., & Oyebola, O. (2015). 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 IASI, 5*, 17–39. doi:10.15551/scigeo.v60i2.345

Olaniran, O. J. (2015). *Rainfall anomalies in Nigeria: The contemporary understanding*. Geog. Dept., University of Ilorin Inaugural lecture, Kwara State, Nigeria

Olaoye, R. A., & Olaniyan, O. S. (2012). Quality of rainwater from different roof material. *International Journal of Engineering and Technology, 2*, 1413–1421.

Ologunorisa, T. E., & Adejuwon, J. O. (2003). Annual rainfall trends and periodicity in the Niger Delta, Nigeria. *Journal of Meteorology, 28*, 41–51.

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

Opare, S. (2012). Rainwater harvesting: An option for sustainable rural water supply in Ghana. *GeoJournal, 77*, 695–705. doi:10.1007/s10708-011-9418-6.

Otti, V. I., & Ezenwaji, E. E. (2013). Enhancing community-driven initiative in rainwater harvesting in Nigeria. *International Journal of Engineering and Technology, 3*, 73–79.

Otufale, G. A., & Coster, A. S. (2012). Impact of water scarcity and drudgery of water collection on women's health in Ogun of Nigeria. *Journal of Human Ecology, 39*(1), 1–9.

Perry, M. (2006). *Spatial analysis of trends in the UK climate since 1914 using gridded datasets*. Climate Memorandum No. 21, National Climate Information Centre, UK

Quan, X.-W., Diaz, H. F., & Fu, C.-B. (2003). Interdecadal change in the Asia-Africa summer monsoon and its associated changes in global atmospheric circulation. *Global & Planetary Change, 37*, 171–188.

Roebuck, R. M. (2007). *A whole life costing approach for rainwater harvesting systems: An investigation into the whole life cost implications of using rainwater harvesting systems for nonpotable applications in new-build developments in the UK* (Unpublished PhD Dissertation). University of Bradford, UK

Roebuck, R. M., Oltean-Dumbrava, C., & Tait, S. (2012). Can simplified design methods for domestic rainwater harvesting systems produce realistic water-saving and financial predictions? *Water & Environment Journal, 26*, 352–360. doi:10.1111/j.1747-6593.2011.00295.x

Roebuck, R. M., Oltean-Dumbrava, C., & Tait, S. (2011). Whole life cost performance of domestic rainwater harvesting systems in the United Kingdom. *Water & Environment Journal, 25*, 355–365. doi:10.1111/j.1747-6593.2010.00230.x

Rowell, D. P., Folland, C. K., Maskell, K., & Ward, N. (1995). Variability of Summer rainfall over tropical North Africa (1906–92). *Quarterly Journal of the Royal Meteorological Society, 121*, 669–670.

Samaddar, S., Murase, M., & Okada, N. (2014). Information for disaster preparedness: A Social network approach to rainwater harvesting technology dissemination. *International Journal of Disaster Risk Science, 5*, 95–109. http://dx.doi.org/10.1007/s13753-014-0017-2

Santos, S. D., Takahashi, D. Y., Naka, A., & Fujita, A. (2014). Comparative study of statistical methods used to identify dependencies between gene expression signals. *Briefings in Bioinformatics, 15*, 906–918.

Sayemuzzaman, M., & Jha, M. (2014). Seasonal and annual precipitation time series trend analysis in North Carolina, United States. *Atmospheric Research, 137*, 183–194. http://dx.doi.org/10.1016/j.atmosres.2013.10.012

Semazzi, F. H. M., Mehta, V., & Sud, Y. C. (1988). An investigation of the relationship between sub-Saharan rainfall and global sea surface temperatures. *Atmosphere-Ocean, 26*, 118–138. http://dx.doi.org/10.1080/07055900.1988.9649293

Shaw, E. M., Beven, K. J., Chappell, N. A., & Lamb, R. (2010). *Hydrology in practice*. London: CRC Press.

Shittu, O. B., Akpan, I., Popola, T. O. S., Oyedepo, J. A., & Oluderu, I. B. (2010). Application of GIS-Rs in bacteriological examination of rural community water supply and sustainability problems with UNICEF assisted borehole: A case study of Alabata community, South-western Nigeria. *Journal of Public Health & Epidemiology, 2*, 238–244.

Shittu, O. I., Okareh, O. T., & Coker, A. O. (2015). Development of rainwater harvesting technology for securing domestic water supply in Ibadan, Nigeria. *International Research Journal of Engineering Science, Technology & Innovation, 4*, 32–37.

Słyś, D., & Stec, A. (2014). The Analysis of Variants of Water Supply Systems in Multi-Family Residential Building. *Ecological Chemistry & Engineering S/Chemia I Inzynieria Ekologiczna S, 21*, 623–635. doi:10.1515/eces-2014-0045

Sojobi, A. O., Owamah, H. I., & Dahunsi, S. O. (2014). Comparative study of household water treatment in a rural community in Kwara state, Nigeria. *Nigerian Journal of Technology, 33*, 134–140. http://dx.doi.org/10.4314/njt.v33i1.18

Sojobi, A. O., Dahunsi, S. O., & Afolayan, A. O. (2015). Assessment of the efficiency of disinfection method for improving water quality. *Nigerian Journal of Technology, 34*, 907–915.

Souza, E. L., & Ghisi, E. (2012). Potable Water Savings by Using Rainwater for Non-Potable Uses in Houses. *Water, 4*, 607–628. http://dx.doi.org/10.3390/w4030607

Sturm, M., Zimmermann, M., Schütz, K., Urban, W., & Hartung, H. (2009). Rainwater harvesting as an alternative water resource in rural sites in central northern Namibia. *Physics and Chemistry of the Earth, Parts A/B/C, 34*, 776–785. http://dx.doi.org/10.1016/j.pce.2009.07.004

Tabari, H., Marofi, S., Aeini, A., Talaee, P. H., & Mohammadi, K. (2011). Trend analysis of reference evapotranspiration in the western half of Iran. *Agricultural and Forest Meteorology, 151*, 128–136. http://dx.doi.org/10.1016/j.agrformet.2010.09.009

Tapsoba, D., Haché, M., Perreault, L., & Bobée, B. (2004). Bayesian Rainfall Variability Analysis in West Africa along Cross Sections in Space–Time Grid Boxes. *Journal of Climate, 17*, 1069–1082. http://dx.doi.org/10.1175/1520-0442(2004)017<1069:BRVAIW>2.0.CO;2

Thomas, R. B., Kirisits, M. J., Lye, D. J., & Kinney, K. A. (2014). Rainwater harvesting in the United States: a survey of common system practices. *Journal of Cleaner Production, 75*, 166–173. http://dx.doi.org/10.1016/j.jclepro.2014.03.073

Tobin, E. A., Ediagbonya, T. F., Ehidiamen, G., & Asogun, D. A. (2013). Assessment of rainwater harvesting systems in a rural community of Edo State, Nigeria. *Journal of Public Health & Epidemiology, 5*, 479–487.

Tomaz, P. (2005). *Aproveitamento de água da chuva para áreas urbanas e fins não potáveis*. Navegar, São Paulo, Brazil (in Portuguese).

Traboulsi, H., & Traboulsi, M. (in press). Rooftop level rainwater harvesting system. *Applied Water Science*. doi:10.1007/s13201-015-0289-8

Ubuoh, A., Ege, C. A., Ogbuji, S., & Onifade, S. (2012). Potentials of domestic rainwater harvesting in Kwa Ibom State, Nigeria using supply side approach. *Journal of Environmental Science and Resource Management, 4*, 1–9.

Ufoegbune, G. C., Oyedepo, J. A., & Awomeso, Eruola, A. O.

(2010). *Spatial analysis of municipal water supply in Abeokuta metropolis* (pp. 1267–1273). Vienna, REAL CORP: South Western Nigeria. Proceedings.

Vanem, E., & Walker, S.-E. (2013). Identifying trends in the ocean wave climate by time series analyses of significant wave heightdata. *Ocean Engineering, 61*, 148–160. http://dx.doi.org/10.1016/j.oceaneng.2012.12.042

Welderufael, W. A., Woyessa, Y. E., & Edossa, D. C. (2011). Hydrological impact of rainwater harvesting in the Modder river basin of central South Africa. *Hydrology and Earth System Sciences Discussions, 8*, 5051–5081. doi:10.5194/hessd-8-5051-2011

WHO (2004a). *Guidelines for drinking water quality Health criteria and other supporting information*. Geneva: Author. Retrieved from http://www.who.int/water_sanitation_health/dwq/GDWQ2004web.pdf

WHO. (2004b). *Water requirements, impinging factors, and recommended intakes*. Author: Geneva. Retrieved June 30, 2015.

WHO. (2005). *Minimum water quantity needed for domestic uses*. Author: Geneva. Retrieved June 30, 2015.

Woltersdorf, L., Liehr, S., & 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*, 1402–1421. doi:10.3390/w7041402

Worm, J., & Hattum, T. V. (2006). *Rainwater harvesting for domestic use*. Retrieved December 14, 2015 from http://journeytoforever.org/farm_library/AD43.pdf

Wu, F., Wang, X., Cai, Y., & Li, C. (In press). Spatio-temporal analysis of precipitation trends under climate change in the upper reach of Mekong River Basin. *Quarternary International*, 1–10. http://dx.doi.org/10.1016/j.quaint.2013.05.049

World Meteorological Organization. (2015). *The Climate in Africa*. Author: Geneva Switzerland. http://www.wmo.int/pages/prog/wcp/wcdmp/documents/1147_EN.pdf

Zang, C., & Liu, J. (2013). Trend analysis for the flows of green and blue water in the Heihe River basin, northwestern China. *Journal of Hydrology, 502*, 27–36. http://dx.doi.org/10.1016/j.jhydrol.2013.08.022

Zhang, Q., Wang, X., Hou, P., Wan, W., Li, R., Ren, Y., & 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*, 178–187. http://dx.doi.org/10.1016/j.jenvman.2013.11.009

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