



ESTIMATING THE POTENTIAL FOR RAINWATER HARVESTING IN ILORIN, NORTH CENTRAL, NIGERIA

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Abstract

Rainwater harvesting is one of the viable ways of supplementing the surface and underground scarce water resources in areas where existing water supply system is inadequate to meet demand as being one of the potent measures for reducing impact of climate change on water supplies. The aim of this study was to estimate the rainwater harvesting potential of a typical house roof top in Ilorin Township for the purpose of supplementing household water needs. Ilorin has a mean annual rainfall of 1,244 mm which makes rainwater harvesting ideal. Intra annual variability lies between 0.04 and 0.4. Annually 590 m³ of rainwater can be harvested per household. Estimated annual water demand for flushing and laundry were 18, 24.12 m³, respectively. Harvested rainwater in Ilorin can meet household monthly water demand for toilet flushing and laundry except for December. The excess rainwater stored in September and October is enough to supplement the short fall in the dry months provided there is adequate storage. Water savings potential is highest in June and September which is the two-rainfall peak period in Nigeria.

Keywords: Water demand, house rooftop, household, rainfall, runoff, rainwater

Introduction

Water is the most indispensable resource on earth for survival. In Nigeria and other parts of the world, the increasing scarcity of water in terms of quality is fast becoming an unpleasant reality (Ezemonye *et al.*, 2016). Increase of water demand due to population growth, urbanization and changing hydrological phenomena create serious water scarcity problems (Ahuchaogu *et al.*, 2023). These factors place demand on water administrators to consider urgently other options that can reduce the water stress that the population is facing (Liliana *et al.*, 2015). Drinking, washing, cooking, and other daily activities require portable water that is devoid of contaminants that might cause waterborne diseases. Access to clean water and safe treatment facilities are the main measures taken to prevent certain waterborne illnesses (Forstinus *et al.*, 2016). According to World Health Organisation (2014) and Pichel *et al.* (2019), Accessibility to drinking water has been a major challenge to rural communities in developing countries, with nearly 2.5 billion lacking access to adequate sanitation. As a result of this, the need to take advantage of rainwater in urban areas, mainly to meet consumption needs for which the use of drinking water is not imperative.

One of the effective ways to augment water supply, especially in regions with irregular water access is rainwater harvesting. However, the success of such a system depends on proper design, implementation and maintenance. Rainwater harvesting technique is now widely used for the provision and supply of both portable and non-portable supply of water especially in developing countries where potable water supply is insufficient to meet the growing needs of the society (Olaoye and Olaniyan, 2012). Rainwater harvesting is a renewable and ecologically sound practice that involves collecting and preserving rainwater for a wide range of uses (Pande, 2020; Zhou *et al.*, 2021). Due to the growing concern about shortages of water and the necessity for effective management of water resources (Shelar, 2022; Zhao *et al.*, 2020), this technique has received increased attention. Rainwater is typically collected from surfaces such as rooftops and conveyed into storage tanks or reservoirs for usage afterwards (Pande and Moharir, 2021). It can be used for irrigation, gardening, and even non-potable uses within buildings like the flushing of toilets (Moharir *et al.*, 2023; Wu *et al.*, 2022).

Rainwater Harvesting (RWH) practice can be traced back millennia, the degree of its modern

implementation varies greatly across the world, often with systems that do not maximize potential benefits (Campisano *et al.*, 2017). Today rainwater harvesting is being used worldwide for drinking (human and livestock) and agricultural purposes. It is also a good option in areas where good quality fresh surface water or groundwater is lacking. Rainwater harvesting is eco-friendly, and it is also an economic practice. Rainwater collection may reduce flooding in certain areas. It also reduces the demand for Groundwater and the Water Bills (Hari, 2019).

Previously, the concept of rainwater harvesting has received very little consideration (especially for drinking purposes) in larger donor financed projects, but recently, with the increasing pressure on available water resources, renewed interest has emerged. Rainwater harvesting system can be installed in both new and old buildings. The application of appropriate rainwater harvesting technology is important for the utilization of rainwater as a water source. The most common uses of water captured through rainwater harvesting (RWH) systems include toilet flushing, landscape irrigation, vehicle washing and laundry, but if the water is treated, the systems can also be used to supply water for drinking, bathing and dishwashing (May and Prado, 2006).

The advantages of rainwater harvesting go beyond meeting immediate water supply needs. This practice may considerably decrease the discharge of stormwater, which can otherwise cause erosion, flooding, and water contamination (Nong *et al.*, 2023; Wu *et al.*, 2023). Additionally, because rainwater is usually soft and does not have the chemical compounds and minerals found in conventional water sources, it is suitable for a wide range of applications. Rainwater harvesting stands out as a practical and environmentally friendly approach to ensuring a safer and more resilient water future for populations around the world as concerns about availability and environmental impact continue to grow (Li *et al.*, 2023; Qiu *et al.*, 2023). The African Development Bank (2008) defines rainwater harvesting as “the collection of the runoff for productive use”, particularly in areas where rainfall varies between 200 and 1000 mm; while for Sapkota *et al.* (2015), it is the collection and use of rainwater for domestic purposes. The work done by these authors shows that the volume of rainwater harvested would help to save a significant amount of drinking water, especially if also ecological or water-saving devices replaced the regular flush toilets. Rainwater was being conserved/harvested only for two hostel areas. And they used two methods of distribution of harvested rainwater (Rapid depletion method and Rationing method). Finally, the cost for construction of tank was calculated.

Studies have reported that water supply in Ilorin is unreliable and erratic (Ifabiyi and Ahmed, 2011). About

62.9% of the population had access to pipe borne water (Aderibigbe *et al.*, 2008). This means the percentage of the population that has access to pipe borne water as of this day would have reduced. Thus, alternative source of water supply is needed to ensure community development and economic growth. Due to the foregoing, there is an urgent need to propose strategies helping to mitigate the problem of water shortage that the population of Ilorin are currently facing. To this end, the objective of this paper is to propose an estimation through which users can select a rainwater harvesting system for non-drinking water consumption. Furthermore, depending on their catchment area, we calculated the amount of non-drinking water required (*i.e.*, the water consumed by flush toilets or washing machines) that can be replaced with rainwater'.

Rainwater harvesting is a good approach in areas with significant rainfall but no conventional, centralized supply system, according to research. Rainwater harvesting is unavoidable in rural areas, but the potential of rainwater harvesting techniques is diminishing as rural areas become more urbanized, resulting in the abandonment of older techniques. As a result, a strategy to implement the efficient rainwater harvesting technique on a large scale must be launched with a concerted effort by various government, non-governmental, and general public agencies. On that note, the goals of this paper are twofold: to estimate the potential for rainwater harvesting for a typical household in Ilorin Township, and to collect the necessary rainfall data for estimating the potential for rainwater harvesting.

Materials and Methods

Description of the Study Area

Ilorin is a large city and the official capital of Kwara State, Nigeria (Figure 1) consists of three local government areas namely, Ilorin east, Ilorin west and Ilorin south. Ilorin is located approximately on latitude 8°30' and 8°50' North of the Equator and longitude 4°20' and 4°35' East of the Greenwich Meridian (Solihu and Bilewu, 2022). Ilorin is the gateway city between southern and northern Nigeria, with a projected population of 974,000 people in 2021 spread across a total area of 764.046 km² and a population density of 1188 people per square kilometer (Idrees *et al.*, 2021).

The geology of the Ilorin consists of Precambrian basement rock. The elevation on the western side varies from 273m to 333m above sea level while on the Eastern side it varies from 273m to 364m. Ilorin is majorly drained by Asa River which flows in a south-north direction (Ajadi *et al.*, 2016). The climate of Ilorin is characterized by both wet and dry seasons. The temperature of Ilorin ranges from 33°C to 34°C from

November to January while from February to April; the value ranges between 34°C to 53°C. The mean monthly temperatures are very high varying from 25°C to 28.9°C. The diurnal range of temperature is also high in the area. The total annual rainfall in the area is about 1200mm. The diurnal regime of moderate rain in the area shows clear nighttime rainfall maximum. Relative humidity at Ilorin in the wet season is between 75 to

80% while in the dry season it is about 65%. The daytime is sunny. The sun shines brightly for about 6.5 to 7.7 hours daily from November to May (Ajadi *et al.*, 2016). The geology of the Ilorin consists of Precambrian basement rock. The elevation on the western side varies from 273m to 333m above sea level while on the Eastern side it varies from 273m to 364m. Ilorin is majorly drained by Asa River which flows in a south-north direction (Ajadi *et al.*, 2016).

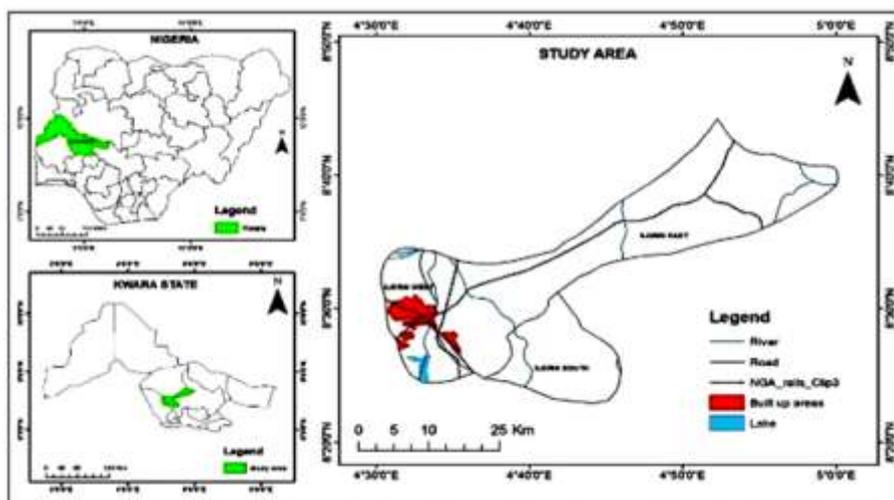


Figure 1: Maps showing the study area (Olanrewaju and Negedu, 2015).

Despite having one rainy season with two peak periods in June and September which implies more rainwater availability for harvesting, the third world country has been left without sufficient, reliable, or clean water. Limited supply of water resources has become a more and more critical issue in urban development. While naturally available water supplies are expected to remain stagnant or decline in the future, population growth demands an increase in water to support every

sector of the society. Thus, alternative source of water supply is needed to ensure community development and economic growth.

Sampling

A typical house each was sampled in different housing estate and the following house roof area (HRA) (Figure 2) was obtained as shown in Table 1. The building type in each of the housing estates sampled was prototype and the total and average roof areas were determined.

Table 1: Sample of Houses with their Respective Roof Area

S/N	HOUSING ESTATE	ROOF AREA(m ³)
1	Mandate	245
2	Irewolede	310
3	Kulende	290
4	Royal Valley	275
Total		1120
Average		280

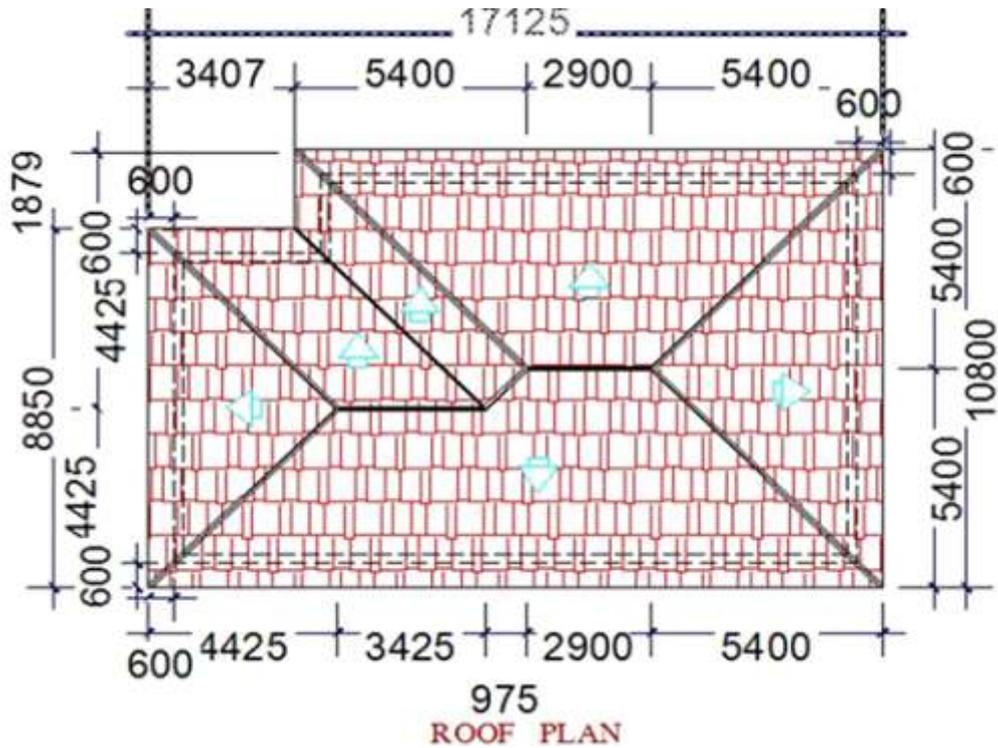


Figure 2: A typical house roof as water harvesting catchment medium

Rainfall data analysis

Runoff collection from rainfall events can be classified into two broad categories: land based, and roof based. The emphasis of this study is on roof-based rainwater harvesting potential in Ilorin. The amount of rainwater that can be harvested depends on roof area, rainfall depth and storage and runoff coefficient which depend on roof material and design (Thomas and Martinson, 2007). Thirty years' monthly rainfall data (1986–2015) collected from Ilorin Lower Niger River Basin and Rural Development Authority was analyzed in order to determine the rainfall pattern, average monthly and annual rainfall and wet and dry months of the years under investigation (Table 2). A 3-year monthly rainfall data mainly 1986, 1995 and 2015 were plotted against their respective months in order to show the bimodal nature of the rainfall distribution in the basin (Figure 3). The cumulative annual rainfall was also plotted against their respective years.

The intra annual variability was determined by finding the coefficient of variation of the monthly rainfall and is expressed in Equation 1 as:

$$CV = \frac{S_v}{V_a} \quad (1)$$

where, CV is the coefficient of variation of the monthly rainfall, S_v is the standard deviation of the monthly rainfall (in millimeters), V_a is mean of the monthly rainfall (in millimeters)

The volume of rainwater that could be harvested per household per month was determined by adapting equation expressed in Ghisi *et al.* (2006). Equation 2 is given as modified:

$$VR = \frac{R \times H_{RA} \times RC}{1000} \quad (2)$$

where, VR is *monthly* volume of rainwater per household (in cubic meters), R is monthly rainfall depth (in millimeters), H_{RA} is *household* roof area (in square meters) and RC is runoff coefficient (no unit).

Table 2 Rainfall data of Ilorin from 1986 to 2015

S/N	Year	Rainfall (mm)	Ranking (M)	Probability (P) (%)	Return Period (T) (Year)
1	1986	1272.5	1750.4	57.85	1.73
2	1987	1323.9	1515.9	50.10	2.00
3	1988	1278.2	1503.2	49.68	2.01
4	1989	1233.4	1495.0	49.41	2.02
5	1990	1035.1	1474.3	48.72	2.05
6	1991	1326.7	1454.9	48.08	2.08
7	1992	838.6	1450.5	47.94	2.09
8	1993	1495.0	1396.1	46.14	2.17
9	1994	1750.4	1393.9	46.07	2.17
10	1995	1396.1	1353.2	44.73	2.24
11	1996	990.2	1326.7	43.85	2.28
12	1997	1503.2	1323.9	43.75	2.29
13	1998	980.7	1294.9	42.79	2.34
14	1999	1294.9	1278.2	42.24	2.37
15	2000	892.1	1272.5	42.05	2.38
16	2001	744.2	1272.0	42.04	2.38
17	2002	1068.8	1244.0	41.11	2.43
18	2003	1215.9	1233.4	40.76	2.45
19	2004	1272.0	1222.6	40.40	2.48
20	2005	1092.0	1215.9	40.18	2.49
21	2006	1353.2	1168.0	38.60	2.59
22	2007	1474.3	1092.0	36.09	2.77
23	2008	1515.9	1068.8	35.32	2.83
24	2009	1393.9	1046.6	34.59	2.89
25	2010	1046.6	1035.1	34.21	2.92
26	2011	1450.5	990.2	32.72	3.06
27	2012	1454.9	980.7	32.41	3.09
28	2013	1222.6	892.1	29.48	3.39
29	2014	1244.0	838.6	27.71	3.61
30	2015	1168.0	744.2	24.59	4.07
Total				1233.61	75.67
Mean				41.12	2.52

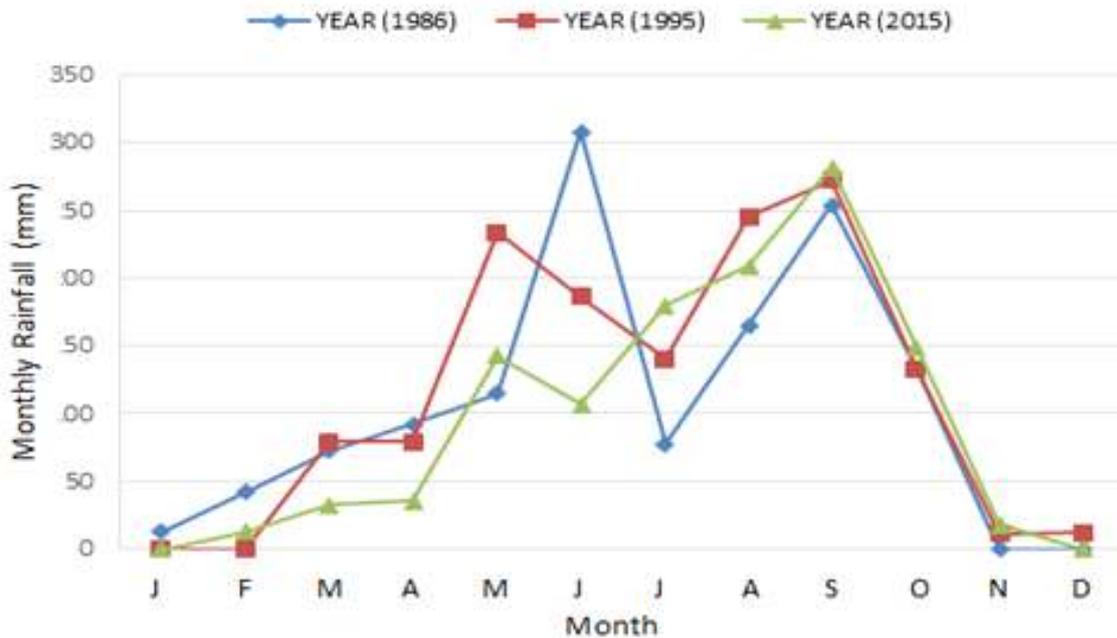


Figure 3: Rainfall distribution in Ilorin in 1986, 1995 and 2015

The average roof area per dwelling in Ilorin was calculated as 280 m² from field survey. Similarly, runoff coefficient for hard roof in humid tropics is taken as 0.90 (Thomas and Martinson, 2007). The average household size in Nigeria is four persons according to the recent data (NPC, 2009). Household water demand per day for WC flushing was 60 L on the basis of 12 L per capita a day based on survey. This was used to calculate the monthly water demand for flushing. The household monthly water demand for laundry was also calculated with weekly water demand of 120 L per household and this was used to estimate the monthly demand for laundry at 4.3 weeks/month (30 L per person for laundry per week). The total monthly and annual water demand for flushing and laundry were calculated by summation of the demand for flushing and laundry for each month and the total for the 12 months, respectively.

The basic monthly balance was estimated by subtracting monthly water demand from collected monthly rainwater and is as expressed in Equation 3.

$$W_a = I_v + V_c - V_u \tag{3}$$

where, W_a is water available, I_v is Initial volume in storage, V_c is volume collected, V_u is volume used. The quantity of rainwater required to satisfy all the intended needs were estimated using the demand approach. The monthly demands (1.50 and 2.01 m³) for flushing, laundry and flushing combined were

considered as the initial volume in storage. The shortfalls in the dry months were added to the initial volume to give the quantity required for the dry months.

Determination of Runoff Coefficient

The roof size of a house or building determines the catchment area and run-off of rainwater. The collection of water is usually represented by a run-off coefficient (RC). The run-off coefficient for any catchment is the ratio of the volume of water that runs off a surface to the volume of rainfall that falls on the surface. A run-off coefficient of 0.9 means that 90% of the rainfall will be collected. Coefficient accounts for losses due to spillage, leakage, infiltration, catchment surface wetting and evaporation, which will all contribute to reducing the amount of runoff. Runoff coefficient varies from 0.5 to 1.0 depending on return period which are available in literatures as shown in Table 3. Hence, the appropriate run off coefficient is selected in relation to the return period in years.

Table 3: Runoff coefficient for rooftop (Te Chow et al., 1988)

Return period (Years)	Runoff coefficient
2	0.75
5	0.80
10	0.83
25	0.88
50	0.92
100	0.97
500	1.00

Determination of total amount of available rainwater for the household

The expression for the determination of this parameter is given in Equation 4

$$Demand = Total\ roof\ area \times Amount\ of\ rainfall \times Runoff\ coefficient \quad (4)$$

$$S = RACr$$

where, S is mean annual rainwater supply m^3 ,
R is mean annual rainfall m, A is catchment area
 m^2 , Cr is runoff coefficient

Hence,

$$S = 1.244m \times 280m^2 \times 0.90 = 313.5m^3/year = 26.1m^3/month$$

Therefore, the required rainwater for this household is calculated as given in Equation 5.

$$Demand = Water\ use \times Household\ population \times 365\ days \quad (5)$$

$$\begin{aligned} &= 120 \times 4 \times 365 \\ &= 175,200\ litres/year \\ &= 14,600\ litres/month \end{aligned}$$

Results and Discussion

The bimodal rainfall pattern of Ilorin is shown in Figure 3. In 1986, the rainfall depth of 72.9 and 307.8 mm were recorded in March and June while in December, no rainfall was recorded. Similarly, in the year 2015, the observed rainfall in April and September were 35.8 and 281.7 mm respectively. The intra annual variability ranges between 0.04 and 0.4. This shows that there was high variability in the rainfall distributions but the variability over the years was low in Ilorin. High seasonal variations and changes in

future rainfall distribution is expected with climate change (IPCC, 2015). Roof water harvesting can help to reduce the vulnerability of water supply in urban areas considering the fact that centralized water reservoirs are more sensitive and vulnerable to prolonged drought and climate change (Kuczera, 2007). Figure 3 shows the variations in the annual rainfall depth. The highest annual rainfall depth of 1,750.4 mm was observed in 1994 while the lowest annual rainfall of 744.2 mm was observed in 2001. The mean annual rainfall was 1,244.2 mm. Rainwater harvesting and storage will help to ensure sustainability in water supply for domestic and other uses considering the high seasonal variability.

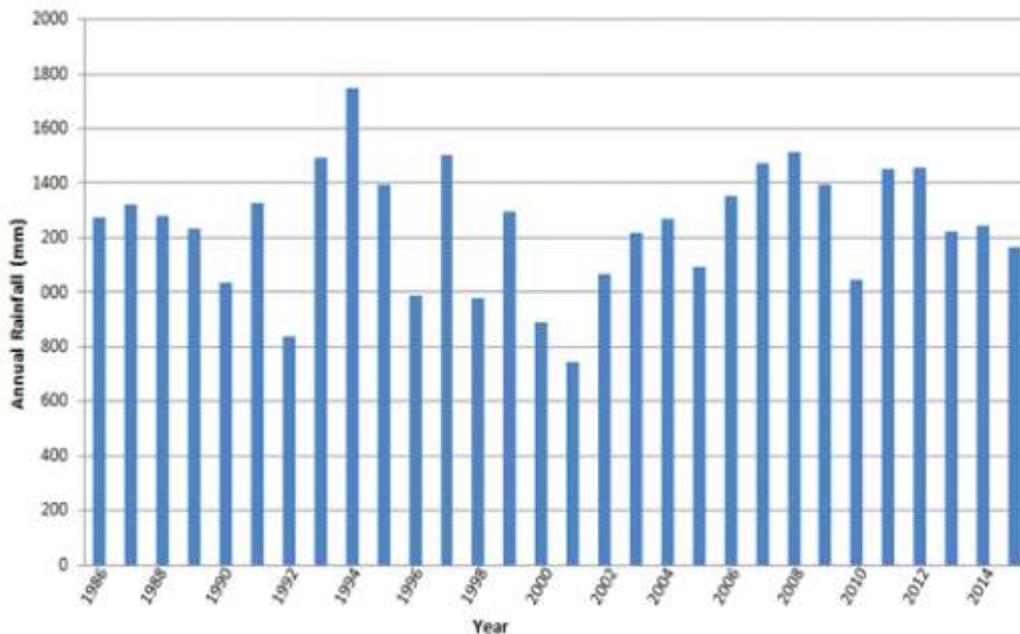


Figure 3: Annual rainfall depth of Ilorin from 1986 to 2015

As shown in Table 4, the monthly water demand for flushing and laundry is 1.50 and 0.51 m³ respectively while the annual water demand for the same purposes is 18.0 and 6.12 m³, respectively. Likewise, the total monthly and annual water demand for laundry and flushing combined per household is 2.01 and 24.12 m³, respectively. Annual rainwater harvesting potential per household was 589.68 m³, with the highest volume of 60.45 m³ and lowest volume of 1.66 m³ collected in September and December, respectively. The annual water demand for laundry and flushing were 18 m³ and 24.12 m³, respectively (Table 4). There was no shortfall observed for any of the months but if there had been any, it can be met with excess rainwater from October and November. However, the size of the storage tank to be designed for use will depend on the available space and affordability by individual households rather than roof area and demand by users.

Conclusion

In order to determine the potential of rainwater in Ilorin, a 30-year rainfall data of Ilorin was obtained from the Ilorin Lower Niger River Basin and Rural Development Authority, Ilorin. The monthly rainfall

data for selected years was plotted against their corresponding months. The annual total rainfall was also plotted against their years. The rainfall data were analysed to obtain inter annual variations. The monthly and annual household water demand for laundry and flushing was determined. Annual rainwater harvesting potential per household was 589.68 m³, with the highest volume of 60.45 m³ and lowest volume of 1.66 m³ collected in September and December respectively. The annual water demand for laundry and flushing were 18 m³ and 24.12 m³ respectively. There was no shortfall observed for any of the months but if there had been any, it can be met with excess rainwater from October and November. Rainwater collection systems can provide water for purposes not requiring drinking water quality. Rainwater usage will aid significant potable water savings in Ilorin, Nigeria and many parts of the world if well harnessed. The challenges of water shortages being currently experienced in the country during the dry season will be solved using the abundant rainwater during the wet season. Water savings potential is highest in June and September which is the two-rainfall peak period in Nigeria. The work therefore, shown clearly that rainwater harvest in Ilorin township is of high potential and if adequately explored can greatly reduce impact of water scarcity in the city.

Table 4: Household monthly harvested rainwater and monthly balance after flushing and laundry

Month	Average monthly rainfall (mm)	Volume of rainwater (m ³ /month)	Flushing Water demand (m ³)	Laundry Water demand (m ³)	Total Water demand (m ³)	Monthly balance, Vol. - demand (m ³)
Jan	21.0	5.29	1.5	0.51	2.01	3.28
Feb	19.8	4.98	1.5	0.51	2.01	2.97
March	36.9	9.29	1.5	0.51	2.01	7.28
April	93.9	23.66	1.5	0.51	2.01	21.65
May	157	39.56	1.5	0.51	2.01	37.55
June	197.1	49.66	1.5	0.51	2.01	47.65
July	167.9	42.28	1.5	0.51	2.01	40.27
Aug	168.8	42.53	1.5	0.51	2.01	40.52
Sept	239.8	60.45	1.5	0.51	2.01	58.44
Oct	169.9	42.81	1.5	0.51	2.01	40.8
Nov	42.1	10.6	1.5	0.51	2.01	8.59
Dec	6.6	1.66	1.5	0.51	2.01	-0.35
Total	1320.8	589.68	18	6.12	24.12	308.65
Average	110.1	49.14	1.5	0.51	2.01	25.72

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