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Potential for potable water savings by using rainwater: A Case study of Ibadan, Nigeria

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ABSTRACT
In recent times, Ibadan city in south-west Nigeria has been facing severe shortage of potable water, due to increased population and socio-economic activities. In order to meet the shortfall, rainwater harvesting (RWH) has been used as an alternative water supply. A desk study was conducted to evaluate the potentials of this alternative source for the residential sector of the City. A hydrological analysis was conducted using 30 years of rainfall data from two meteorological stations, with the aim of assessing the potential for a productive rainwater harvesting system for water supply to private individuals, organizations and government agencies. The mean potential for potable water savings is 52.7%, ranging from 0.39-107.57% depending on demand conditions. An average roof size of 150 m^2 in Ibadan City will collect 182,250 litres/year (99.86 litres/head/day) of water for a family of five, which is above the average daily water demand. However, the capacity of a storage tank (182,250 litres) required for an all-purpose water supply system based on RWH is quite large, but these can be reduced to a more practicable size, by collecting and storing water for cooking and drinking only, while non-potable uses are supplemented with water from other sources. This study clearly shows that Ibadan City has good potable water saving potential using rainwater.

Keywords: Benefit-analysis; Potable water; Rainwater usage, Ibadan; Sustainability

1 INTRODUCTION

Water is an essential element of life and is used in multiple ways, such as for domestic and industrial purposes. It is also part of the larger ecosystems on which biodiversity depend. Water is a key resource and sustains both human and natural resources. However, recent climate change and a steady increase in industrial and agricultural activities have restricted the availability of water on an ad-lib basis [1].

It has been noted that as human population increases, and as people seek better living standards; and as economic activities continue to grow in scale and diversity, the demand for fresh water resources continues to grow [2]. Water availability fluctuates between wet and dry periods. However, water is becoming scarce not only in arid and drought-prone areas but also in regions where rainfall is abundant: water scarcity affects the quality of resource available for more stringent requirements [3]

In many regions of the world, rainfall is high for some months and low or negligible for the rest; thus, the harvesting and storage of rainwater and storm water would help alleviate dry season shortages. Rainwater harvesting (RWH) has undergone a major renaissance in the last two decades in many countries. Africa and South-Asia have been at the heart of this revival, with the construction of tens of millions of roof catchments. Kenya and Thailand have been focal points of technological innovation, with other countries following their lead [4].

It has been reported that rainwater usage can promote significant potable water savings in residences in different countries [5]. The performance of a rainwater collector installed in a house in Nottingham (UK) was monitored and mean water saving efficiency was ~57% [6]. In Germany, a study revealed that the potential for potable water savings in a house might vary from 30-60%, depending on demand and roof area [7]. A multi-storey residential building composed of six blocks in Florianopolis (Brazil) was evaluated where, although the specific roof area per person in multi-storey buildings is low, the potential for potable water savings was ~40% [8]. In Australia, 27 houses were analysed in Newcastle and it was concluded that rainwater usage would promote potable water savings of 60% [9]. Other studies on rainwater have also been conducted in China [10], Singapore [11] and Zambia [12] and all these support the potential alternative of rainwater.

In southern Nigeria, rain falls for 8 months per year, with a mean total of 1800-2250 mm. The rainy season is usually from March/April to September/October. During the other months between November and March, the weather is generally dry, and often cold with Harmattan winds. Inadequate supply of potable water for domestic and industrial purposes is a generational challenge the government is finding problematic. The citizens have resorted to RWH as their alternative source of water. RWH is practised at individual, household, commercial and occasionally at local or state government level to augment dwindling water supply to urban centres. A study on the different systems of harvest and storage of rainwater in the cities of south-east Nigeria found that the people in this region need RWH for their survival [13]. The inadequacy of pipe-borne water in Nigeria is still a major concern to many households and businesses.

Rainwater and passive dew harvesting can be exploited as a free and clean (outside urban/industrial zones) water source with little financial investment. Rainwater has much potential as the main water resource of the future because of its high quality [14]. RWH plays a central role in providing secure water supplies and reducing impacts on the environment [15]. RWH may turn hazards (floods and polluted water) into local water resources. The financial benefit is that rain is renewable at acceptable volumes, despite climate change forecasts. RWH systems generally have low operational costs, as they provide water at the point of consumption [16]. However, the benefits of RWH to the regional reticulated supply system includes: reduced treatment, cost of pumping, operation and augmentation costs, reduced peak storm runoff and decreased storm water processing costs. In addition, RWH reduces greenhouse gas emission due to reduced dependence on pumping and potential augmentation from sources, such as desalination [17]. Limitations of RWH are few and easily met by good planning and design [18]. The quality of rainwater is vulnerable due to the effect of air pollution, insects and dirt or organic matter. The type of roofing material used for the catchment area can also adversely affect water quality.

1.1 Prospects of rainwater in Nigeria

Water supply in Nigeria is based on groundwater and surface water. The urban population depends on hand tube wells and borehole water, while rural areas depend on streams and rivers for their supply [19], augmented by hand tube wells. The prevalence of industrial wastes has led to high pollution rates of groundwater, exacerbated by falling groundwater levels during the dry season [20]. The cost of developing surface water is very prohibitive due to poor waste management. Wastes are often dumped into streams and other surface waters. These scenarios have made both groundwater and surface water resources expensive. Rainfall harnessing, thus, constitutes a viable water source and can contribute to flood control.

Dependence on groundwater to meet growing demand has increased tremendously in Nigeria. Seawater intrusion can also be arrested or reduced by artificial recharge [21]. When there is a gross misbalance between the natural recharge and extraction of water over a period, the falling water-table and associated yield becomes problematic. The only option available for society is to increase recharge over and above the rate induced by natural processes. RWH and recharge is one such promising option. It is estimated that prudent artificial recharge schemes and waste water recycling could meet ~25% of India's water requirements by 2050 [22].

2. THE CASE OF IBADAN CITY, NIGERIA

A research is being carried out to evaluate the potential for potable water savings by using rainwater estimated for the residential sector of Ibadan City- this is with the aim of addressing the shortage of water in Ibadan. Ibadan is the capital of Oyo State, in Nigeria with an estimated population of 2,559,853 [19] and a projected population of 7,656,646 in 2015.

Urban water supply in Ibadan City is based on groundwater and surface water [23], due to inadequate water availability in shallow aquifers. In Ibadan, 41.4% of the urban populations are serviced with tube well water [24]. The provision is carried out at individual (household) level. At present, however, the success achieved in hand tube well-based urban water supply is on the verge of collapse due to pollution of groundwater caused by poor waste management in the City and because these wells dry up during the dry season [20]. These result in inadequate access to sufficient water supply to meet societal needs, and users often walk long distances (about 3 km) to obtain water from rivers. Tankers/truck vendors are another source of water supply in the City and provide ~1.2% of the City's demand [24].

The protection of health and well-being of the urban population living in highly polluted areas is also of paramount importance, as water-borne disease is one of the leading causes of death worldwide, especially in children under five years of age. In addition, at any given time, patients suffering from water-borne diseases occupy half of the world's hospital beds [23]. Hence, the provision of unpolluted water is needed, especially in Ibadan, to mitigate the unwanted medical consequences of water shortages.

Rainwater is abundant in southern Nigeria. Ibadan receives heavy rainfall during the rainy season with a mean annual rainfall of 1350 mm. Figure 1 shows rainfall data for Ibadan for the period 1980-2009, indicating that there is abundant rain in the City. RWH is not a common practise in the City. Currently, 9.4% of the city population depends on pipe-borne water, 20.5% on boreholes, 41.4% on wells, 22.9% on streams and 5.8% on springs [25]. Figure 2 shows the percentage contribution of different sources of water in Ibadan. The ponds replenished by rainwater each year are major sources of water supply in rural areas. However, poor waste management and unhygienic practises are increasingly polluting the ponds, streams and groundwater [19]. Hence, attention is needed to address these unhygienic practises, as they deplete water resources.

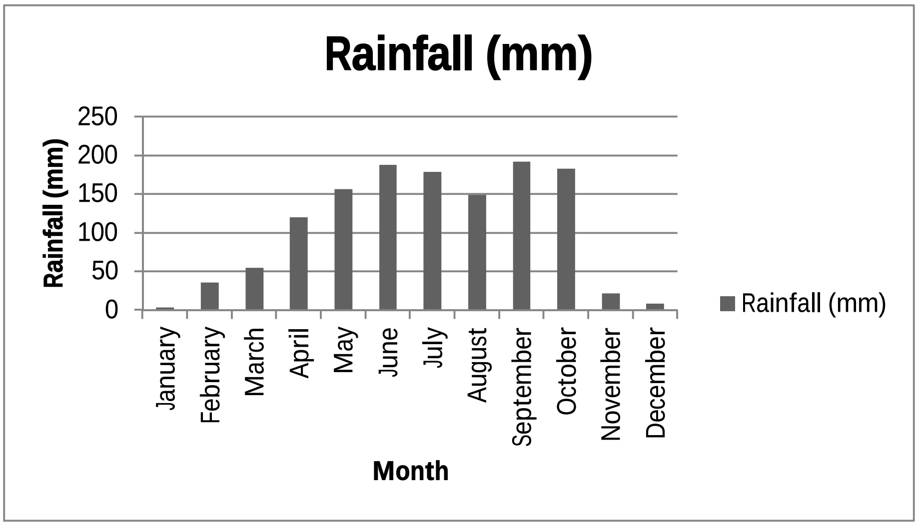

Figure 1. Mean rainfall for Ibadan City for the period 1980-2009

Source: [26]

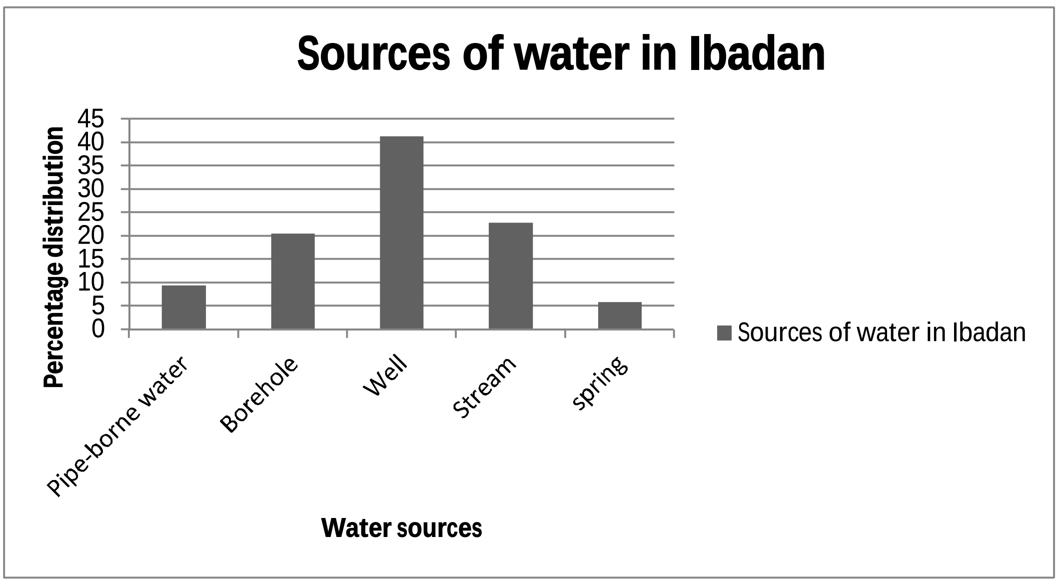

Figure 2. Sources of water in Ibadan City

Source:[24]

In addition, more sources of potable water are needed to augment the current deficit. In the present context, therefore, RWH is being considered as an alternative option for increasing water supply in the City. Thus, there is a need to study the RWH potential of the area, so that it can be used to complement existing supplies and to develop a proper framework for the future development of water resources.

3. STUDY METHODOLOGY

A desk study was conducted to review existing literature on RWH and to appraise the technologies available locally, regionally and globally. This was performed to ascertain existing designs, technologies that are appropriate and can be adapted and adopted for Ibadan City in particular, and Nigeria in general. A hydrological analysis was conducted to describe relationships between seasonal patterns and water availability and relationships between climate and rainfall variability. This desk study is part of a wider on-going research with the aim of evaluating the potential for potable water savings estimated for the residential sector of the city.

Data were obtained on the total volume of potable water consumed per month and the number of people supplied with potable water in Ibadan [25]. Data on population and number of dwellings were needed to calculate the number of people per dwelling in the City. Based on the data available [20, 24], the number of people per dwelling was calculated for the City. It ranges from 3.53-5.34, with a mean of 4.40 people per dwelling. Then, having the number of people per dwelling and the number of people supplied by the water utility in the City [47], it was possible to estimate the number of dwellings supplied by the water utility. This was needed in order to estimate the total roof area and the volume of rainwater that could be harvested in Ibadan. Therefore, to obtain the potable water savings, the monthly water demand was compared to the volume of rainwater that could potentially be harvested in the City.

3.1 Sampled case study

To accomplish the objective specified above, it was necessary to obtain rainfall data, potable water consumption, population and number of dwellings in Ibadan [24]. Figure 3 shows a map of Nigeria indicating the location of Ibadan, which consists of 11 Local Government Areas (Figure 4).

In Nigeria, public drinking water is often unreliable [27]. Ibadan suffers serious water supply problems; cases of dry taps are common in virtually every part of the City. Children and women searching for water are common [28]. In Ibadan, refuse dumps, pit latrines and open dumps are common and environmental sanitation is poor. Ibadan was chosen because it is a residential and urban area with an increasing population [29]. As population grows and urbanization increases, more water is required and greater demand is made on both ground and surface water. The rate of urbanization in Nigeria is rapid, with major cities growing at rates between 10-15% per annum [30]. Hence, human activities, including soil fertility remediation, indiscriminate refuse and waste disposal, use of septic tanks, soak-away pits and pit latrines, are increasing. Groundwater pollution has been attributed to industrialization and urbanization which has progressively developed over time, with little regard for environmental consequences [31]. These processes result in the deterioration of the physicochemical and biological properties of water [32].

In Nigeria, there is a challenge of lack of supply of pipe-borne water. Hence many homes have wells sited around the house at a distance from the septic tank. Some 52% of Nigerians do not have access to improved drinking water supply [33]. For most communities, pipe-borne water from municipal water treatment plants is the most secure source of safe drinking water. However, most treatment facilities fail to meet the water requirements of the served community, due to corruption, poor maintenance, population pressure and pollution [33]. The scarcity of piped water has made communities find alternative water sources; groundwater sources being a ready source. Wells are a common groundwater source readily explored to meet community water requirements or address shortfalls [34]. The most common cause of pollution is attributed to the close proximity of septic tanks to wells and unhygienic use of wells. For instance, some wells have no cover/lids; they are dirty and unkempt, thus making the water susceptible to infection [35]. Groundwater pollution is also caused by the disposal of solid or liquid wastes in pits, abandoned boreholes or even stream channels and landfills [36].

The inhabitants of Ibadan suffer mainly from (in descending order of severity) diarrhea, gastro-enteritis, malaria, measles, tuberculosis, cholera and typhoid [37]. Water-borne diseases are prevalent, including cholera, typhoid, bacillary dysentery, paratyphoid, amoebic dysentery, gastroenteritis and infective hepatitis [38]. Diarrhoeal diseases are largely caused by unsafe water, inadequate sanitation and poor hygiene [36]. There is a seasonal pattern of water borne diseases, with ~50% occurring between July and September [38].

There were major incidences of flooding in 2011; with over 600 people made homeless while over 200 people were killed in the flood [39]. The University of Ibadan suffered a major damage: the fish farm valued at about £1.2m was washed away and over-flooding of the zoological garden leading to the death of animals and the destruction of books estimated at N8m [40].

4 DATA

4.1 Rainfall data

Daily rainfall data were obtained [26]. According to meteorological station staff, data were sometimes incomplete due to strike action in Ibadan or financial problems. The data were processed in order to obtain the mean monthly rainfall for the City.

4.2 Volume of rainwater

The volume of rainwater that could be harvested in the City was calculated as follows.

4.3 Population supplied with potable water

The water utility company gave the number of people supplied monthly with potable water in the City for the period 2009-2010. An arithmetic mean was calculated to determine the number of people supplied with potable water per month.

4.4 Number of people per dwelling

The number of people resident in Ibadan and the number of dwellings were obtained [28]. Thus, the specific number of people per dwelling was estimated using Equation (1):

$$PD = \frac{PC}{NDC} \quad (1)$$

where: PD is the number of people per dwelling, PC is the number of people living in the City, and NDC is the number of dwellings in the City.

4.5 Number of dwellings supplied with potable water

The number of people supplied with potable water was obtained from the water utility company. The number of dwellings supplied with potable water by the water utility company was then estimated using Equation (2):

$$ND = \frac{NP}{PD} \quad (2)$$

where: ND is the number of dwellings supplied with potable water, NP is the number of people supplied with potable water per month (as given by the water utility company) [43], and PD is the number of people per dwelling.

4.6 Roofing size

Since a rainwater-harvesting system (RWHS) is site specific, the roof area was determined from the roof plan using Equation (3)

$$RA = L \times B \quad (3)$$

where

RA is the roof area

L = is the length of building in (m)

B = Breadth of building in (m)

A household roof area in Ibadan City ranges from $135m^2$ to $196m^2$ (authors field survey), thus an average roof plan of 150 m^2 was used for this study.

4.7 Total roof area

The total roof area in the City was obtained considering only the population supplied with potable water. It was determined using Equation (4).

$$TRA = RA \times ND \quad (4)$$

where: TRA is the total roof area of the City (m^2), RA is the weighted mean roof area per dwelling in the City (m^2), and ND is the number of dwellings supplied with potable water.

4.8 Runoff coefficient

A typical runoff coefficient for various rooftops is shown in Table 1.

TABLE1

TYPICAL RUNOFF COEFFICIENT FOR VARIOUS ROOFS

Surface	Type	Coefficient
Roof	Pitch roof tiles	0.75-0.9
	Flat roof with Smooth surface	0.5
	Flat roof with Gravel layer or Thin turf (<150mm)	0.4-0.5

Adapted [41]

4.9 Volume of rainwater

The monthly volume of rainwater that could be harvested in the City was determined considering monthly rainfall data, the total roof area, and a runoff coefficient of 0.90. Such a roof coefficient indicates a loss of the rainwater that is discarded for roof cleaning and evaporation. Thus, the volume of rainwater that could be harvested in the City was determined using Equation (5).

$$VR = \frac{R \times TRA \times R_c,}{1000} \quad (5)$$

where: VR is the monthly volume of rainwater that could be harvested in the City (m^3/month), R is the monthly rainfall in the city (mm/month), TRA is the total roof area in the city (m^2), R_c is the runoff coefficient (non-dimensional), and 1000 is the conversion factor from litres to m^3.

4.10 Potable water demand

The monthly potable water demand considered in the analysis was determined as a function of the data obtained from the utility company for the period 2009-2010.

4.11 Potential for potable water savings

The monthly potential for potable water savings was determined for the City using Equation (6).

$$PPWS = \frac{100\ VR}{PWD} \qquad (6)$$

where:

PPWS is the potential for potable water savings in the City (%), VR is the monthly volume of rainwater that could be harvested in the City (m^3/month), and PWD is the monthly potable water demand in the City (m^3/month).

4.12 Storage tank capacity

Daily rainfall data were obtained for 30 years [26]. The mean monthly rainfall was determined and multiplied by a mean roof area of 150 m^2 and a runoff coefficient of 0.9 in order to obtain monthly volumes of runoff in litres. From the monthly volumes, the cumulative monthly volumes were obtained and both were plotted.

Water demand

Water consumption is 50-115 litres/person/day [42]

Mean water demand = 80.5 litres/head/day

Water demand = 80.5 x n x 365 days/year

Where: n = number of people in the household

In a household of five,

Annual water demand = 80.5x5x365 days/year

= 146,913 litres/year

Water supply = roof area x rainfall x run-off coefficient

= 150 m^2 x 1.350 m x 0.9

= 182.25 m^3/year

= 182,250 litres/yr

= 499.32 litres/day

= 99.86 litres/day (for a household of 5)

Mean monthly supply $= \frac{182.25}{12}$

= 15.19 m^3/day

The storage requirement is estimated by:

1. Plotting the graph for monthly roof run-off for a household of five people. A line for the demand per month is added.
2. Plotting the graph of cumulative roof run-off, by summing the monthly runoff totals.
3. A dotted line is added showing cumulative water use (water demand).

The maximum difference between the demand line and the cumulative rainfall gave the storage capacity of a tank to store all derived rainwater.

5. RESULTS

5.1 Number of people per dwelling

The number of people per dwelling ranged between 3.53-5.34 for the City, with a mean of 4.40 people per dwelling; close to the Oyo State mean of 4.0 people per dwelling [13].

5.2 Roof area

In order to determine an adequate roof area per dwelling, the percentage of houses and flats in multi-storey buildings was obtained for the City. By applying Equation (3), the mean roof area of Ibadan was ~150 m^2 ranging from 135-195.69 m^2.

5.3 Potable water demand

The mean potable water demand obtained for the City was 131 litres per capita per day. Although it is very difficult to collect valid information on water use in a developing country such as Nigeria, hypothetical calculation were made based on the population to obtain an estimate of the amount of water used in 2009. Tables 2 and 3 show the water supply in Ibadan metropolis from 2009-2010.

5.4 Volume of rainwater

The monthly volume of rainwater that could be harvested in the City was calculated through the procedure described in the methodology.

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5.5 Potential for potable water savings

The potential for potable water savings was estimated for the City and it ranged from 0.39% in January to 107.57% in October 2009. Table 4 shows the results of the potential for potable water savings for Ibadan.

Figure 5 presents the maximum, mean and minimum potential for potable water savings observed for Ibadan in 12 months. The potential ranges from a mean of 0.39% in January to 107.57% in October, with an overall mean of 52.7%.

TABLE 2

WATER SUPPLY OF IBADAN METROPOLIS (2009)

Months	Asejire scheme (m^3)	Eleyele scheme (m^3)	Total (m^3)	Water demand (m^3)
January	952,027	182,093	1,134,120	15,588,832
February	725,031	141,309	866,340	14,080,235
March	993,870	145,072	1,138,942	15,588,832
April	1,115,067	125,205	1,240,272	15,085,966
May	676,455	115,613	792,068	15,588,832
June	976,328	117,182	1,093,510	15,085,966
July	891,591	127,633	1,019,224	15,588,832
August	875,709	113,713	989,422	15,588,832
September	685,100	166,322	851,422	15,085,966
October	1,027,610	211,069	1,238,679	15,588,832
November	567,894	194,490	762,384	15,085,966
December	949,741	95,221	1,044,962	15,588,832

Source: [43].

TABLE 3

WATER SUPPLY OF IBADAN METROPOLIS (2010)

Months	Asejire scheme (m^3)	Eleyele scheme (m^3)	Total (m^3)	Water demand (m^3)
January	1,153,213	192,830	1,346,403	16,136,000
February	723,396	127,797	851,193	14,576,115
March	1,157,579	123,321	1,280,900	16,136,000
April	955,930	136,003	1,091,933	15,615,484
May	854,061	23,115	877,176	16,136,000
June	664,695	33,986	698,681	15,615,484
July	988,998	126,540	1,115,538	16,136,000
August	761,336	94,839	856,175	16,136,000
September	422,252	-	422,252	15,615,484
October	408,486	-	408,486	16,136,000
November	665,776	-	665,776	15,615,484
December	1,168,450	-	1,168,450	16,136,000

Source: [43]

TABLE 4

MONTHLY VOLUME OF RAINWATER HARVESTED IN IBADAN CITY (2009)

Month	Mean roof area per dwelling (m^2)	Number of dwellings supplied with potable water	Total roof area (m^2)	Rainfall (m)	Volume of rainwater (m^3/month)	Water demand (m^3/month)	Potential for potable water savings (%)
January	150	454,466	68,169,900	0.001	61,353	15,588,832	0.39
February	150	384,357	57,653,550	0.1381	7,165,760	14,080,235	50.89
March	150	456,490	68,473,500	0.0804	4,954,742	15,588,832	31.78
April	150	513,570	77,035,500	0.2037	14,122,918	15,085,966	93.62
May	150	317,462	47,619,300	0.1299	5,567,172	15,588,832	35.71
June	150	452,799	67,919,850	0.2174	13,289,198	15,085,966	88.09
July	150	408,507	61,276,050	0.2056	11,338,520	15,588,832	72.73
August	150	396,562	59,484,300	0.098	5,246,515	15,588,832	33.66
September	150	352,556	52,883,400	0.3285	15,634,977	15,085,966	103.64
October	150	496,465	74,469,750	0.2505	16,769,098	15,588,832	107.57
November	150	315,687	47,353,050	0.0491	2,092,531	15,085,966	13.87
December	150	418,822	62,823,300	0	0	15,588,832	0

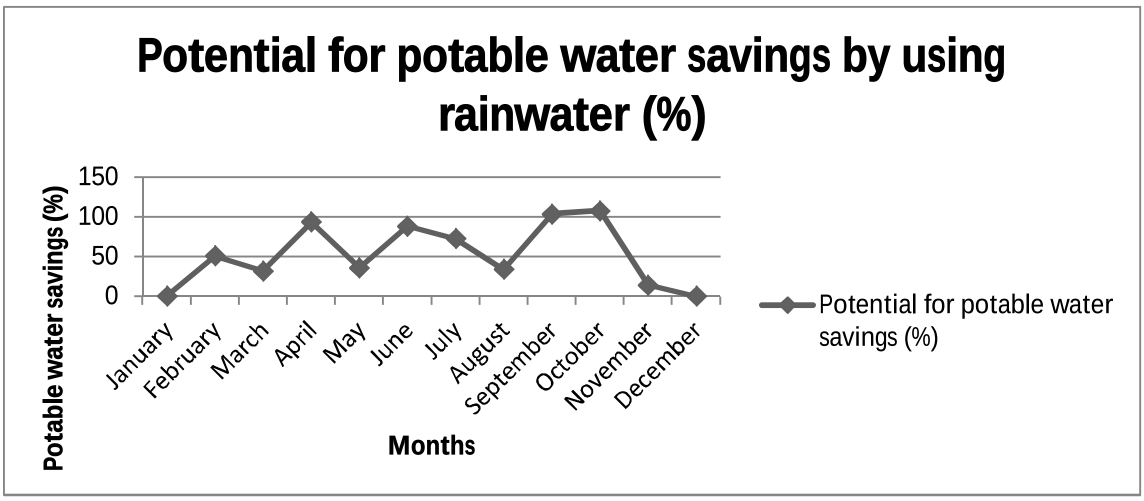

Figure 5. Pattern for potable water savings by using rainwater in Ibadan

5.6 Storage tank capacity

Figure 6 shows the amount of harvestable water (RWH) and the demand for each month (horizontal line). The figure shows a single rainy season from March-October. The months when collected rainfall meets demand are April-October. Hence, adequate storage is to be provided for the dry period from November-February.

Figure 7 shows cumulative monthly run-off and cumulative water use, which is an estimate of storage requirement. The cumulative inflow and outflow from the storage tank, and tank capacity are calculated as the greatest excess of water over and above consumption (greatest difference between the two lines). This occurs in October, with a storage capacity of 60.65 m^3. All this water will have to be stored to cover the dry season shortfall.

6. DISCUSSION

Results indicate that water demand in the residential sector of Ibadan City is ~131 litres per capita per day and that there is a mean annual rainfall of ~1350 mm. The mean potential for potable water savings is 52.7%, ranging from 0.39-107.57%, depending on potable water demand. Such a potential is significant, as rainwater could be used for potable purposes only.

The estimated annual water supply for a family of five based on RWH is 182,250 litres/yr, while demand is 146,913 litres/year. This reveals that the harvested water is adequate for all-purpose water supply. However, the mean capacity of the storage tank and the catchment area required for all-purpose water supply system based on RWH are 146,913 litres/year and 150 m^2, respectively.

In terms of runoff volumes, a 150 m^2 roof can collect 182,250 litres a year. This means 499 litres a day, assuming constant withdrawal throughout the year. For a family of five, this means 99.86 litres/head/day, which represents a substantial amount of water in urban areas, provided there is sufficient storage. Ibadan is indeed a very well watered City, with substantial amounts of rainfall available each year. Clearly, the greater the annual rainfall the larger the tank size that is required. Figure 6 shows that maximum storage is required in October, with a storage capacity of 60,650 m^3.

7. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

RWH is technically feasible for Ibadan, based on prevailing rainfall patterns. Over 90% of households have rooftops constructed from technically appropriate materials. The mean potential for potable water savings is 52.7%, depending on potable water demand. Such a potential is notable, as rainwater could be used for potable purposes only. An average roof of 150 m^2 in Ibadan will collect 182,250 litres/year (99.86 litres/head/day) for a family of five, which is about the water demand for drinking and cooking purposes. However, the required capacity of the storage tank required for an all-purpose water supply system based on RWH is quite large (182,250 litres). These can be reduced to affordable sizes, by collecting and storing water for cooking and drinking only, while non-potable uses are supplemented by water from other sources. However, it must be highlighted that due to the type of roofing material, rainwater should go through proper treatment in order to be used for potable purposes. The analysis reported in this paper reveals that Ibadan has a considerable rainwater harvesting potential. This is part of an on-going study and further work will be conducted on water quality assessment of harvested water from corrugated iron sheet roofs and effective cost analysis of treatment processes and storage tanks. In addition, it is envisaged that this work will develop a framework for an improved and sustainable RWH regime in Nigeria.

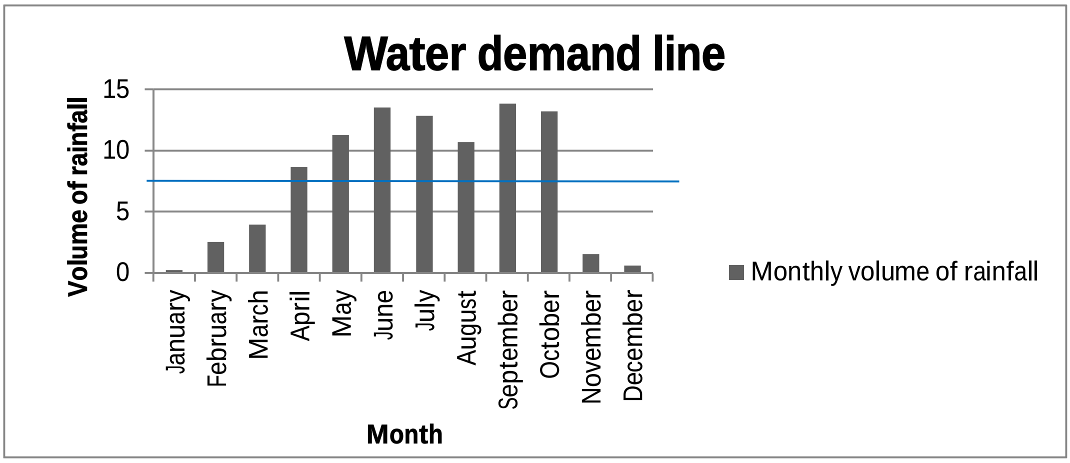

Figure 6. Mean monthly run-off and mean demand in Ibadan.

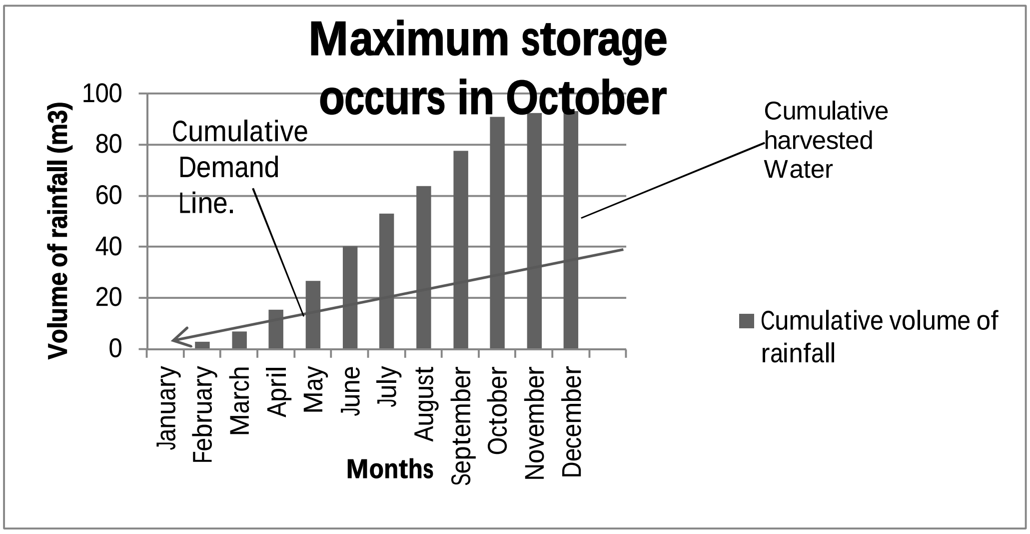

Figure 7. Cumulative monthly roof run-off and cumulative water use

(Estimate of storage requirement)

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