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Cost Analysis of Rainwater Cistern Systems: A Case Study of Ibadan, Nigeria

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Abstract In Nigeria, inadequate supply of pipe borne water is a major concern; hence, many homes depend on groundwater for household uses. However, this supplemental effort is inadequate to meet the demand of the increasing population as the water table declines resulting in a low yield especially during the dry season. Ibadan is the most populous city south of the Sahara with water supply problems and flooding concerns. There is also the associate issue of contamination from septic tanks. Thus, an alternative water supply source in the form of roof-collected rainwater stored in tanks is viable to further supplement the domestic water supply system. However, the economic feasibility of rainwater cistern system is an important factor in its acceptance in the scheme of water resources planning and development. Hence, a hydrological analysis was carried out using 30 years rainfall data from two meteorological stations in Ibadan, a Southwestern city in Nigeria. Since a rainwater-harvesting system (RWHS) is site specific, the volume of water to be harvested and stored per person was determined from three different case studies using the mass balance method. An estimate of the construction cost was carried out based on the prevailing cost of materials in the study area. This article concentrates on the cost analysis of a rainwater cistern system; as compared with the cost of water provision through the existing public water supply system (PWSS). The results revealed that the cost incurred on PWSS is quite low compared to the higher cost of installing a RWHS. However, the RWHS meets the demand of users by providing water in adequate quantity and quality and overcome the risk of contamination and contracting water borne diseases through the consumption of ground water in the study area. The cost analysis of a rainwater cistern in the study area suggests that the system is recommendable for Ibadan and other areas without or with inadequate PWSS. The study also reveals that Ibadan has a very good potential for RWH but some issues will need further research in this regard in the attempt to provide a sustainable solution.

Index Terms —Cost analysis, Ibadan, rainwater cistern system, sustainability

1 INTRODUCTION

Water is an essential element for all life and is used in various ways – for domestic and industrial purposes. It is also a part of the larger ecosystems on which biodiversity depend. The amount of precipitation converted to soil and groundwater accessible to vegetation and people is a dominant precondition for biomass production and social development in dry lands.

The water available is equivalent to the water moving through the landscape and fluctuates through the wet and dry periods. However, water scarcity is not only in arid and drought prone areas but also in regions with abundance of rainfall: water scarcity concerns the quality of the water and the quantity of resource available because degraded water resources become unavailable for more stringent requirements [1].

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Water is a key resource whose unavailability, will lead to non-sustainability of other resources, human and natural. However, climate change and a steady increased in industrial and agricultural activities have revealed that water, as a resource is no longer available on an ad-lib basis [2]. In most urban areas, population is increasing rapidly and the issue of supplying adequate water to meet societal needs and to ensure equity of access to water is one of the most urgent and significant challenges. It has been noted that as human population increases and people seek for better standard of living; as economic activities continue to grow in scale and diversity, the demand for fresh water resources will continue to grow [3].

Water scarcity is a pressing problem in the 21st century. It is estimated that by 2025, 2.7 billion people will face water scarcity [4]. There is a growing alarmism of 'water wars' and the emerging water crises is given several global agencies, national governments and NGOs a great concern [4]. At present, more than 1 billion people lack access to save drinking water [5], which means one in every six people lacks access to safe drinking water. An attractive solution for resolving water scarcity in various parts of the world is water-harvesting systems for runoff water collection and storage [6], [7].

Rainwater is a major source of fresh water and the activity of collecting rainwater directly for beneficial use or recharging it into the ground to improve groundwater storage in the aquifer is known as rainwater harvesting. Dependence on groundwater to meet the growing demands has increased tremendously [8]. When there is a gross misbalance between the natural recharge and extraction of water over a period, the decline of water table becomes significant with reduction of yield [9]. The only option available for the present day society is to improve the recharge over and above the natural processes. Rainwater harvesting (RWH) and recharge is one such promising option that has artificial recharge methods. It is estimated that with prudent artificial recharge schemes and wastewater recycling, *circa* 25% of India's water requirements in 2050 can be met [9].

RWH is simple and appropriate method of water supply and it is growing in importance due to increased potential catchment surfaces and failure of the conventional methods to meet the challenges of providing "clean water for all". Polluted groundwater has made the population yearn for much easier option with good quality water. RWH projects generally are practiced at the local level and of a small scale which do not include water treatment and conveyance over long distances [10].

A research is being carried out to assess the potential of RWH in Ibadan. This paper addresses the economic feasibility of rainwater cistern system by conducting a market survey in the study area to estimate the cost of constructing a rainwater cistern - this is with the aim of addressing the shortage of water in Ibadan.

2. Methodology

2.1 Study area

Nigeria is the most populous country in Africa with a land area of 923,768km^2 and a population of over 150million. Figure 1 shows a map of Nigeria indicating the location of Ibadan city in Oyo state. Ibadan is the capital of Oyo state with an estimated population of 2,559,853 [11] and a projected population of 7,656,646 in 2015. Ibadan is located between longitude 3^0 45^1 and 4^0 00^{1}E and latitude 7^0 15^{1}N and 7^0 30^1 and is reputed to be the largest indigenous city in Africa, South of Sahara. It is the second largest city in Nigeria consisting of eleven Local government areas (Fig.2) Ibadan was chosen because it is a residential area and groundwater pollution rate is high. The cost of developing surface water is very prohibitive due to poor management of wastes, which are usually dumped into streams and other surface water.

Urban water supply in Ibadan is based on groundwater and surface water [11] due to water availability in adequate quantities in shallow aquifers. Over 41.4% of the urban population are serviced with tube well water [12]. At present, however, the success achieved in hand tube well based urban water supply is on the verge of collapse due to the high pollution level of groundwater caused by poor waste management in the city and the fact that these wells go dry during the dry season [13]. These result in lack of access to adequate water supply to meet the societal need and users need to walk about 2miles to get water from rivers. Water borne disease is on the increase in the City [12]. However, the protection of health and well-being of the urban population living in high pollution rate areas is also of paramount importance as waterborne disease is one of the leading causes of death worldwide especially in children under the age of five. In addition, at any given time patients suffering from water borne diseases occupy half of the world's hospital beds [14]. Hence, provision of pollution free water is needed, especially in Ibadan, to mitigate the unwanted consequences of water shortage.

In Nigeria, the main rain occurs between April and October with an average rainfall ranging from 2,497mm at Port Harcourt in the Niger Delta to 869mm at Kano in the North [15]. Rainwater is abundant in the southern region of Nigeria. The city receives heavy rainfall during the rainy season with an average rainfall of 1350mm per year. Figure 3 shows rainfall data for Ibadan for the period 1980-2009, indicating that there is plenty of rainwater in the city. Rainwater harvesting (RWH) is not yet a common practice in the city. Currently, 9.4% of the population of Ibadan depends on pipe-borne water, 20.5% on boreholes, 41.4% on wells, 22.9% on streams and 5.8% on springs [12]. Figure 4 shows the percentage contribution of different sources of water in the city. The ponds replenished by rainwater each year are major sources of water supply in the rural areas. However, poor waste management and unhygienic practices are increasingly polluting the ponds, streams and groundwater [13]. Hence attention and effort are needed by all and sundry, to address these unhygienic practices, as they deplete the valuable sources of water supply. In addition to these, more sources of potable water supply are needed to augment the current under-supply. In the present context, therefore, RWH is being considered as an alternative option for increasing water supply in the city.

In the light of the above, there is a need to study the RWH potential of the area, so that it can be used to complement the existing supply and to lay a proper framework for future development of this resource in the area.

Figure 1 Map of Nigeria showing the study area

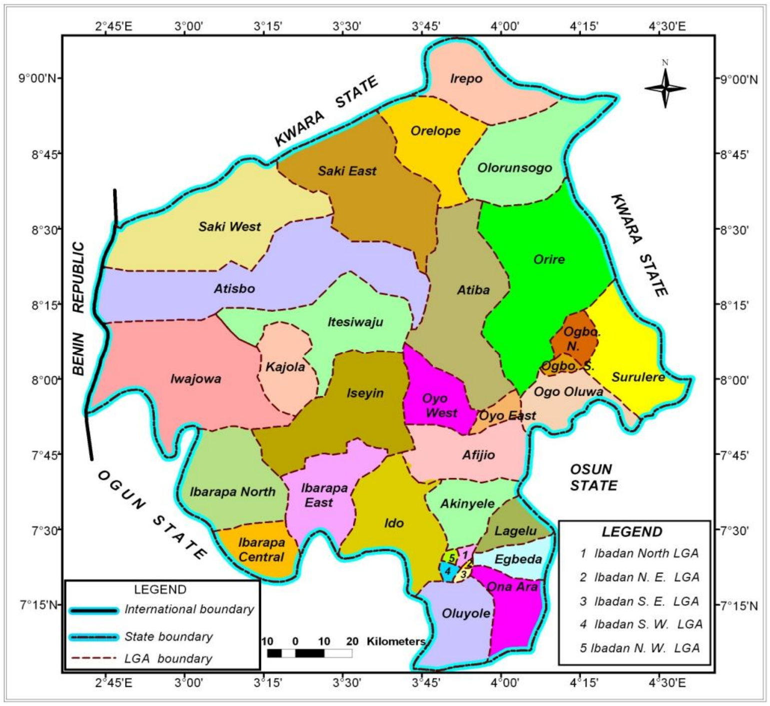

Figure 2 Map of Oyo state showing the 11 local government areas in Ibadan
Source: Department of Geography, University of Ibadan

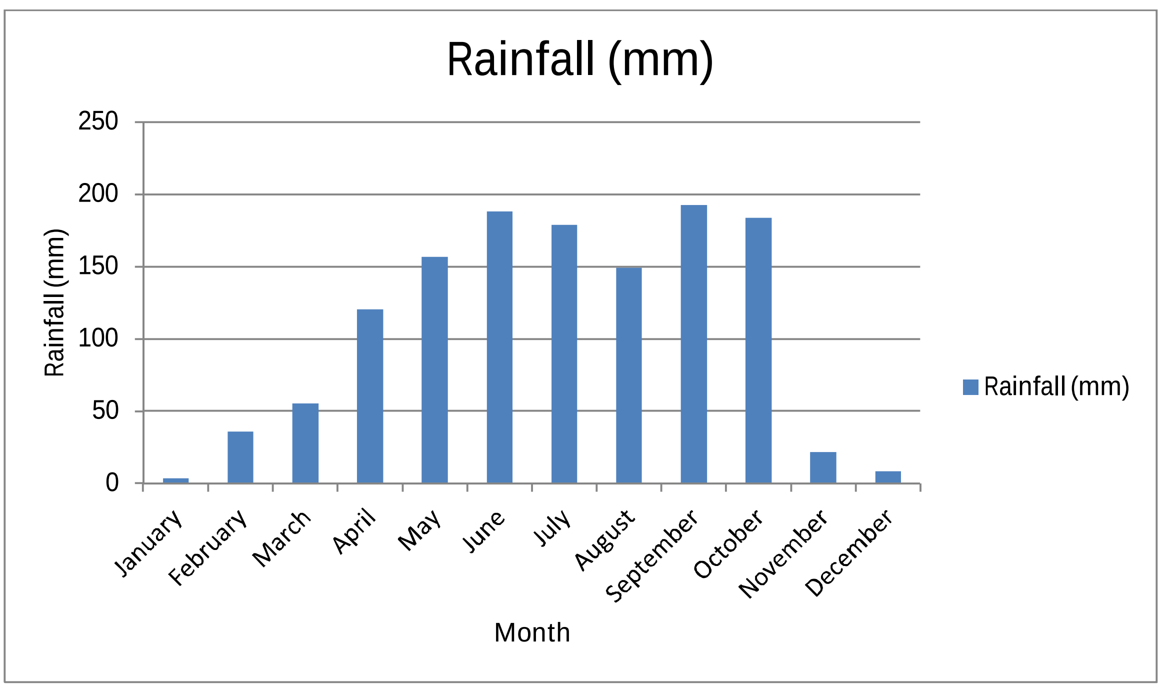

Figure 3 Average rainfall for Ibadan City for the period 1980-2009
Source: [16]

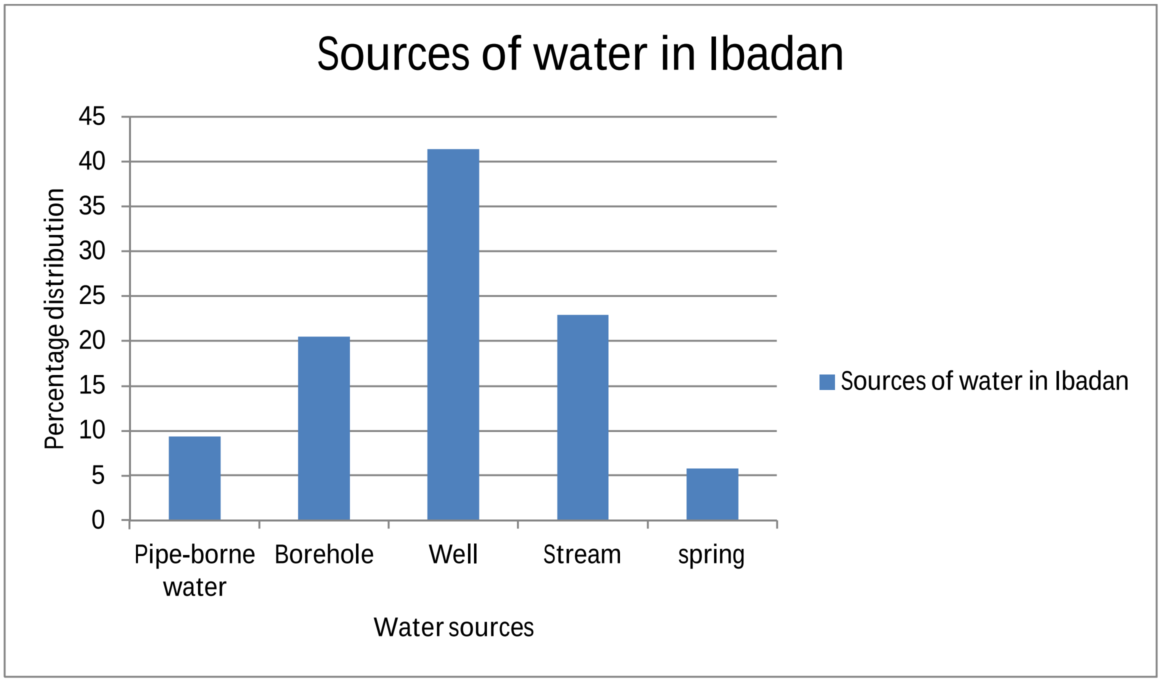

Figure 4 Sources of water in Ibadan city
Source: [12]

2.2 Methods

A desk study was conducted in order to review existing literature on the advances and experiences in RWH and to appraise the various RWH technologies available locally, regionally and globally. This was done to ascertain existing designs and technologies that are appropriate and can be adopted for Ibadan city, and Nigeria as a whole. A hydrological analysis was also carried out to describe the relationship between seasonal patterns and availability and establish a relationship between climate and rainfall variability, hence reliability of rainwater.

To accomplish the objective specified above it was necessary to obtain data on rainfall, household size, roofing material, roofing size and storage tank capacity based on mass curve analysis method.

2.2.1 Rainfall patterns

Daily rainfall data was obtained [16]. The data were processed in order to obtain the average monthly rainfall for the city. Figure 3 shows the monthly rainfall distribution of Ibadan city based on rainfall data 1980-2009. The figure shows that heavy rainfall is concentrated from April to October. The precipitation received from November to March is not adequate to meet the demand during this period. Hence, rainwater has to be stored during rainy season for the rest of the year.

2.2.2 Roofing materials

The roofing materials used in Ibadan include brick, grass, wood bamboo, iron sheets, cement concrete and roofing tiles. Over 91.2% have iron sheets as roofing materials while 0.8% have roofing tiles [17]. These roofing materials are suitable as rainwater catchment for collecting water for potable as well as non-potable purposes. However, the harvested water collected should be subjected to filtration and little treatment.

2.2.3 Roofing size

Since a RWH system is site specific, the volume of water to be harvested and stored per person was determined from three different case studies using the mass balance method. The roof area was determined from the roof plan using Equation (1)

$$RA = L \times B \qquad (1)$$

where

RA is the roof area

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L = is the length of building in (m)

B = Breadth of building in (m)

2.2.4 Water Demand Determination

The average daily water requirement of household per capita used for this study is as follows:

Drinking = 2 litres

Cooking = 10 litres

Toilet flushing = 20 litres

Washing and bathing = 40litres

Outdoor use = 8 litres

This gives a total demand of 80litres/head/day

2.2.5 Catchment Surface

Runoff = CiA

where C is the coefficient of runoff

i is the rainfall intensity

A is the roof area

The runoff coefficient of various rooftops is shown in Table 1

Table 1 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 [18]

2.2.6 Storage tank capacity

Daily rainfall data for 30 years was obtained [16]. The average monthly rainfall was determined and multiplied by an average roof area and a runoff coefficient of 0.9 in order to obtain monthly volumes of runoff in litres.

Case study 1: A household of twelve members

Figure 5 shows case study 1 (a household of twelve members).

For an average daily water demand of 80.5litres/day [19]

Total water consumption = 12 x 80.5litres/day x365days

= 352590litres/yr

= 352.59m^3/yr

However, only 117.53 m^3 will be stored because only 120 days of the year will be completely dry.

Effective annual rainfall = 1350mm

Roof area = 18.38 x 10.65

= 195.69 m^2

Runoff = 0.9 x 1.35 x 195.69

= 237.76 m^3

Hence, the roof will be adequate to collect the required volume of 117.53 m^3

Case study 2: an office block of 100staff

Figure 6 shows case study 2 (an office block of 100 staff-academic and non-academic staff)

For an average daily water demand of 40litres/head/day (for toilet flushing) [20]

Working days = 245 days

Saturdays = 52 days

Sundays = 52 days

Holidays = 16 days

Total demand = 1.8m^3/day [20]

Total water consumption = 1.8 m^3/day x 365days

= 657m^3/yr

However, only 216 m^3 will be stored because only 120days in the year may be completely dry.

Effective annual rainfall = 1350mm

Built area = 32.8m x 22.14m (roof plan)

= 726.32m^2

Void area = 19.13m x 8.36m (roof plan)

= 159.93m^2

Roof area = (Built -Void) area

= 566.39 m^2

Runoff = 0.9 x 1.35 x 566.39 m^3

= 688.16m^3

Hence, the roof will be adequate to collect the required volume of 216 m^3

Case study 3: A hospital of about 203 people (both patients and nurses)

Figure 7 shows case study 3 (a hospital block of 203 people-patients and nurses)

For an average daily water demand of 80.5litres/day [19]

Total water consumption

= 203 x 80.5 x 365litres/yr

= 594647.5litres/yr

= 5964.65 m^3 /yr

However, only 1960.98 m^3 will be stored because only 120 days in the year may be completely dry.

Effective annual rainfall = 1350mm

Roof area = 108.8m x 74.75m

= 8132.8 m^2

Runoff = 0.9 x 1.35 x 8132.8 m^3

= 9881.35 m^3

Hence, the roof will be adequate to collect the required volume of 1960.98 m^3

2.2.7 Private Cisterns in Ibadan

According to the price list obtained from three different tank suppliers in August 2012, the cost of a plastic water tank of 2330 diameter and 2920 height with a conical cover is $1,150; transportation cost is $500. A cost list of other tank sizes are presented in Table 2 while Table 3 shows the estimated cost for five comparable storage cisterns (for case study 1-3).

In addition, it should be clearly stated that the above analysis is purely in terms of economic feasibility. The private rainwater cistern system is not 100% reliable, it depends on climate conditions such as rainfall pattern and roof catchment; hence, certain factors should be included in the cost analysis. These and other factors need to be considered in order to assess the real benefit of the cistern system.

2.2.8 Public water supply in Ibadan

According to the Water Corporation of Oyo state report, water supply charges range from $0.36/m^3 to $0.83/m^3 depending on the location and purpose of use (domestic or commercial). An average family of six in Ibadan pays about $106 per year for their water supply. A cost list of water supply for domestic and commercial purposes is presented in Table 4.

Figure 5 A semi-detached twin bungalows at Akobo, Ibadan

Figure 6 Dr Egbogah's building (Department of Civil Engineering, University of Ibadan)

Figure 7 Otunba-tunwase Children Outpatient Ward, University College Hospital, Ibadan

TABLE 2. Cost of various sizes of plastic tanks

Diameter x height (mm x mm)	Capacity Litres	Price ($)	Cost/litre
1000 x 1000	750	80	0.11
1040 x 1200	1000	95	0.10
1200 x 1200	1200	100	0.08
1200 x 1330	1500	120	0.08
1200 x 1750	2000	150	0.08
1560 x 1900	3000	210	0.07
1640 x 1900	4000	320	0.08
1900 x 1960	5000	400	0.08
1950 x 2400	7500	870	0.12
2060 x 2560	8500	1000	0.18
2330 x 2920	10000	1150	0.16

Source: Authors Market survey in Ibadan 2012

TABLE 3. Size and cost of RCC and plastic water tanks; surface reservoirs and groundwater recharge pits for the three case studies

Capacity (m^3)	Aboveground RCC tanks ($)	Underground RCC tanks ($)	Plastic tanks ($)	Surface reservoirs ($)	Groundwater recharge pits ($)
120	32,989	89,236	21,192	6,230	11,469
220	60,479	163,599	38,852	11,421	21,026
1970	166,958	511,904	347,902	104,310	199,576

Source: Authors Bill of Engineering Measurement 2012

TABLE 4 Public main water supply cost in Ibadan

	Domestic supply		Commercial supply	
Capacity (Litres)	Cost ($)	Cost/litre ($)	Cost ($)	Cost/litre ($)
750	0.45	$6x10^{-4}$	0.63	$8.3x10^{-4}$
1000	0.6	$6x10^{-4}$	0.83	$8.3x10^{-4}$
1200	0.72	$6x10^{-4}$	1.0	$8.3x10^{-4}$
1500	0.9	$6x10^{-4}$	1.25	$8.3x10^{-4}$
2000	1.2	$6x10^{-4}$	1.66	$8.3x10^{-4}$
3000	1.8	$6x10^{-4}$	2.49	$8.3x10^{-4}$
4000	2.4	$6x10^{-4}$	3.32	$8.3x10^{-4}$
5000	3.0	$6x10^{-4}$	4.15	$8.3x10^{-4}$
7500	4.5	$6x10^{-4}$	6.23	$8.3x10^{-4}$
8500	5.1	$6x10^{-4}$	7.06	$8.3x10^{-4}$
10000	6.0	$6x10^{-4}$	8.3	$8.3x10^{-4}$

Source: [21]

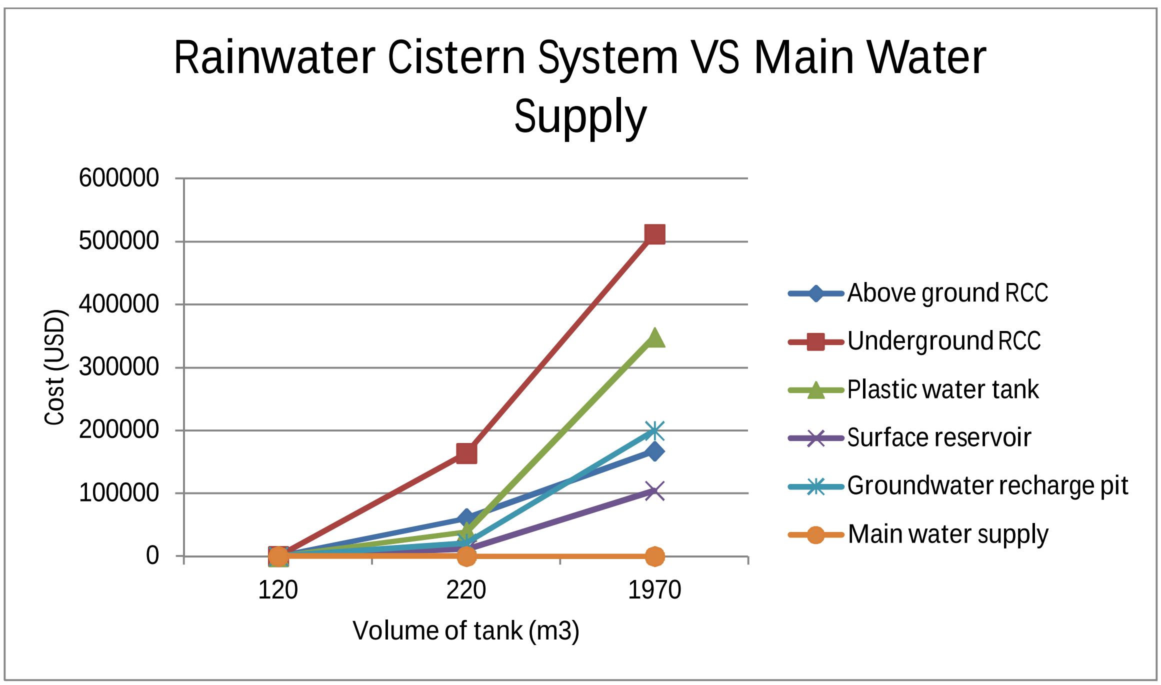

Figure 8 Graph of Cost of private rainwater cistern system versus public water supply system

3. RESULTS AND DISCUSSION

This paper has presented the cost analysis of rainwater cistern system. This is a complex concept because economic scenarios vary between countries. Thus, this paper also includes a cost analysis based on the economic feasibility for adapting rainwater cisterns as an alternative to public water supply systems reported from Nigeria. Figure 8 includes the cost of various cisterns made of different materials; exchange rate of One U.S. dollar to 150 Nigerian naira; the cost of Reinforced Concrete (RC) tanks (aboveground and underground), plastic water tanks, surface reservoir and ground water recharge pits. The figure shows that the cost of an underground RC tanks is the highest, the plastic water tanks is slightly less than the underground RC tanks; the aboveground RC tanks and the surface reservoir are within the low cost category; while the public main water supply is the cheapest.

4. CONCLUDING REMARKS AND FUTURE WORK

The cost analysis of rainwater cistern systems has been presented. In Ibadan, Nigeria, we have found that the public water supply is not economically comparable. However, the choice between the different systems will depend on the rainfall pattern of the area and the individual risk preference. The results revealed that the cost incurred on public water supply system (PWSS) is quite low compared to the higher cost of installing a rainwater harvesting system (RWHS).

However, the RWHS meets the demand of users by providing water in adequate quantity and quality and saves from the risk of water borne diseases through consumption of contaminated ground water in the study area. The cost analysis of a rainwater cistern in the study area suggests that the system is recommendable for Ibadan and other areas without or with inadequate PWSS. The study reveals that Ibadan has a very good potential for RWH. Further work will now be carried out to evaluate the various RWH techniques using Multi-Attribute utility theory in order to identify the most suitable option for meeting the daily water demand of Ibadan.

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