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Development of rainwater harvesting technology for securing domestic water supply in Ibadan, Nigeria

Shittu O.I[1], *Okareh O. T[2] and Coker A.O[3]

[1,3]Department of Civil Engineering, Faculty of Engineering, University of Ibadan, Ibadan, Oyo State, Nigeria
[2]Department of Environmental Health Sciences, Faculty of Public Health, University of Ibadan, Ibadan, Oyo State, Nigeria

Abstract

In both rural and urban areas, supplying adequate water to meet increasing population water demand is a major challenge faced by decision-makers in developing countries like Nigeria. This is as a result of the failure of conventional or municipal water supply systems to meet the challenges of providing clean water for the populace. People result to digging shallow and deep wells indiscriminately to supplement their daily water needs. As a result, the groundwater table would have been falling, causing hydrological imbalance. Domestic Roof-water Harvesting (DRWH) and groundwater recharge provide innovative solution to the inadequate water supply. In this study, a complete RWH technology was designed and constructed for a household, where public water system was non-existent. The RWH technology was incorporated into the existing shallow well water system. Water samples from the RWH system and shallow well were analysed using standard methods. With roof area of 70 m^2, 21 m^3 reservoirs was required for dry period. The Hardness, Alkalinity, Chloride, Iron and Nitrate of the harvested water showed values of 20.0, 21.0, 15.0, 0.2 and 2.0 mg/l respectively while pH was 6.8. The values were below WHO guideline limits for drinking water. Safety measures were taken to ensure that the harvested rainwater was of good quality. The study revealed that RWH technology is a viable and reliable water supply option in both urban and rural areas for domestic purposes.

Keywords: Rain harvesting, ground water recharge, hydrological imbalance, roof water

INTRODUCTION

Water is a renewable but finite resource, in the sense that the global hydrological cycle turns endlessly through the dynamics of evaporation, condensation, and runoff. The hydrological cycle ensures that there is the same amount of water now as existed when the Earth was formed. However, with population growth and ever-increasing demand for the same amount of water, pressures are seriously mounting. The global population has tripled in 70 years while water use has grown in six-fold. In the next 25 years, one-third of the world's population will experience severe water scarcity. More than 1 billion people lack access to safe drinking water (UNESCO 2000, UNFPA 2001). This means one in every six people lacks access to safe drinking water.

The inaccessibility to safe drinking water, led to the pledge by world stakeholders to reduce by half the proportion of people without safe drinking water in the Millennium Development Goals (MDG). It is a fact that water has no substitute. Unlike other scarce and diminishing resources, water cannot be replaced by the invention or discovery of some liberating alternative. Over 70% of our Earth's surface is covered by water. Although this means an abundant availability of water, but the issue of concern is the amount of fresh water available. About 97.5% of all water on Earth is salt water, leaving only 2.5% as fresh water (Encarta 2004).

Water scarcity thus becomes a serious problem throughout the world for both urban and rural communities (Coker, 2001, Edward 2005). More and more water is required for domestic, construction and industrial use. It was revealed by the United Nations (UN) that by the year 2025, two thirds of humanity will face a shortage of water. One third of the global population is facing water stress (Zalewski 2002). The associated problem is simply that in many developing countries, majority have no access to clean drinking water, while those that do, often spend considerable time walking and queuing to collect it (Sridhar et al, 2001). Many water management experts are thus becoming worried about the increasing problems of finding and improving water sources, while some existing water sources are now becoming depleted or polluted (Olusegun 2012).

The main source of water is precipitation in form of rain and when it rains, only a fraction of the water percolates, while the major part of the rainfall drains out as run-off and goes unused into the ocean (Sivanappan, 2006). In essence, the largest percentage of the rainfall is un-used and amount to waste, which constitutes erosion both in urban and rural communities. The problem of water shortage and the waste incurred in the rainwater can be reduced, if there is a well packaged programme of harnessing the naturally endowed rainwater resources (Andrew 1990, Aladenola and Adeboye 2010). Among the various alternative technologies to augment freshwater resources, rainwater harvesting is a decentralized, environmentally sound solution, which can avoid many environmental problems, associated with centralized, conventional, large-scale project approaches (Andrew, 2003). RWH is often overlooked by planners, engineers and builders because of lack of information – both technically and otherwise (Janette and Tim, 2006).

Therefore, this study is aimed at developing (designing and constructing) rainwater harvesting technology for securing domestic water supply in Ibadan, Nigeria with a view to reducing the water shortage problem.

METHODS AND MATERIALS

The study area

This study was carried out at Ibadan, Nigeria. Ibadan is a city in the south-west Nigeria and the capital of Oyo State. Ibadan around $7^0$23’47”N $3^0$55’0”E coordinates has an estimated 1,731,000 inhabitants (2000 estimate). The Mean annual precipitation in the city is about 1,250mm. Nigeria, the most populous country in Africa, has an area of 923,768 km^2 and a population of over 150 million people.

In Nigeria, the main rains occur between April and October; average rainfall ranges from 2,497 mm at Port Harcourt on the Niger Delta to 869 mm at Kano in the north (Encarta, 2004).

METHODOLOGY

A building roofed with galvanised iron was used for this study. Rainfall data and water demand per capita of the household were collected. Quantitative and qualitative analysis were carried out. The first stage of the research consisted of planning a research approach in order to develop an idea of rainwater harvesting systems and the methods being adopted in the collection, storage, and usage. Primary and secondary data were collected from relevant sources.

Rainfall data for a period of ten (10) years between the periods 1995 – 2004 was obtained from the Agro-climatology, Department of the International Institute of Tropical Agriculture IITA Ibadan. Rainfall is the most unpredictable variable in roof catchment system as there could be considerable variation from one year to the next. The Rainwater Harvesting System used composed of six basic components: Roof Catchment; Gutters and Downspout; Leaf Screen and Roof-washers; Storage Tanks; Conveying and Water Treatment. A measure to compliment the rain water harvest system with existing shallow well water system was considered an option.

The Design and Construction Indicators:

(i) Water Demand Determination

The average daily requirement of the household per capita used in this study is as follows (Lee et. al 2000).
Cooking (10 litres); Flushing of Toilet (20 litres); Washing and bathing (50 litres) and other needs (10 litres).This gives a total water demand of 80 litres per person / day. The number of persons in the household studied is seven (7) and the calculated daily water requirement for the household equals: 80 x 7 = 560 litres.

(ii) Runoff Coefficient

A runoff coefficient of 0.8 was adopted to account for losses due to spillage, leakages, infiltration, roof surface wetting and evaporation which would reduce the amount of rainwater which actually entered the storage tanks (Lee et. al 2000).

(iii) Roof Catchment Area

The approximate size of the existing roof catchment area is 200 m^2 (20 m x 10 m) as measured in the house plan. The catchment area was divided into three (3) sections. Section one has area of 21 m^2, section two has 25 m^2 while section three has 24 m^2. However, only 70 m^2 of the roof is used.

(iv) Potential Rainwater Supply from the Roof Catchment

An estimate of the mean annual runoff from the roof area was obtained using the following equations: $C = R \times A \times C$ Where: S = Mean Rainwater (m^3); R = Mean Annual Rainfall (m/yr); A = Roof Catchment Area (m^2); C = Runoff Coefficient
Supply, S = Rainfall x Area x Coefficient (runoff)
Mean annual rainfall, R for 10yrs = 1130mm/yr = 1.13m/yr. Area, A = 200m^2
Coefficient, C = 0.8. Hence, Supply, S = 1.13 x 200 x 0. = 180.8m^3/yr = 180,800 litres/yr = 495 litre/day. However, not all the catchment area was guttered, only 70m^2 of the roof was used. This amounts to 35% of the total capacity. Therefore, to obtain Actual Supply = 0.35 x 495 = 173 litres /day

(v) Water Demand

Since the catchment area is fixed and the amount of rainfall cannot be changed, the only variable that can be used to influence the available rainwater supply is the volume of the storage tank. The total household water demand is estimated at 560 litres / day.

(vi) Water Supply

Roof Area = 70m^2; Runoff Coefficient = 0.8; Average Annual Rainfall = 1130mm/yr
Therefore, Annual available water (assuming all is collected) = 70 x 1.13 x 0.8 = 63.28m^3
Daily Supply = 63.28 ÷ 365 = 0.173m^3/day = 173 litres / day
Assuming a four month (120days) dry period for storage (November to February), storage requirement is 173 x 120 = 20.76m^3 ≈ 21m^3

(vii) Gutters and Downspouts

For the three guttered sections of the roof catchment area, a gauge seven (7) aluminium sheet (section 150mm x 150mm) gutter was used; the largest roof catchment section area being 25m^2. The gutters were hung firmly in position with metal hangers fixed to the fascia board.

(viii) Roof washers

Roof washing is of particular importance since the first flush picks up most of the dirt, debris and contaminants that have collected on the roof and in the gutters during dry season. The downspout was extended down with a Tee joint to serve as Roof-washer. Below the Tee was a valve that could be opened or closed to flush out the dirt without getting into the cistern.

(ix) Storage Tanks

The storage tanks used for the projects were 3,000 litres capacity and 2,000 litres-capacity plastic tanks. The tanks were placed about half a metre above ground. A tight-fitting covered was provided for each tank to prevent evaporation, mosquito breeding and to keep insects, birds, lizards from entering the tanks. There were two outlets in the tanks; one outlet was connected to the pipe network and finally to the pump, while the other fitted with a tap.

(x) Water Conveyance

Considering the topography of the project site, water from the storage tanks could not flow by gravity to the house where it would be used. Therefore, a small 0.5 horse power electric pump was fitted to convey water from the storage tanks to the 1200 litre-elevated tank placed on the roof. The schematic diagram of the Rainwater Harvesting System's Storage and Conveyance Components is as shown in figure 1.

Laboratory Tests

Samples of water were taken from the galvanised roof, directly from the atmosphere and ground water. The samples were tested for pH, Alkalinity, Hardness, Nitrate, Chloride, and Iron. The tests were carried out using American Public Health Association (APHA, 1992) standard methods.

Harvested Rainwater Quality

To ensure good quality of the harvested rainwater, the tanks were air tight, screened and collection of water from the tanks were either through pumping or taps fitted to the tanks. Maintenance of the household roof catchment systems was limited to regular cleaning of the tanks, inspection of the gutters and downpipes, including removal of dirt accumulated on the screen. Cleaning of the roof catchment surface was done by opening the first flush valves to wash the roof and allow the dirty water to flow out during the first major downpour. Taps and pipes fitted to the tanks were about 10 cm above the tank floor to allow any debris entering the tank to settle on the bottom, so as not to affect the water quality.

However, to improve the quality, a solution of 1.0% sodium hypochlorite ppm 10,000 was added to the

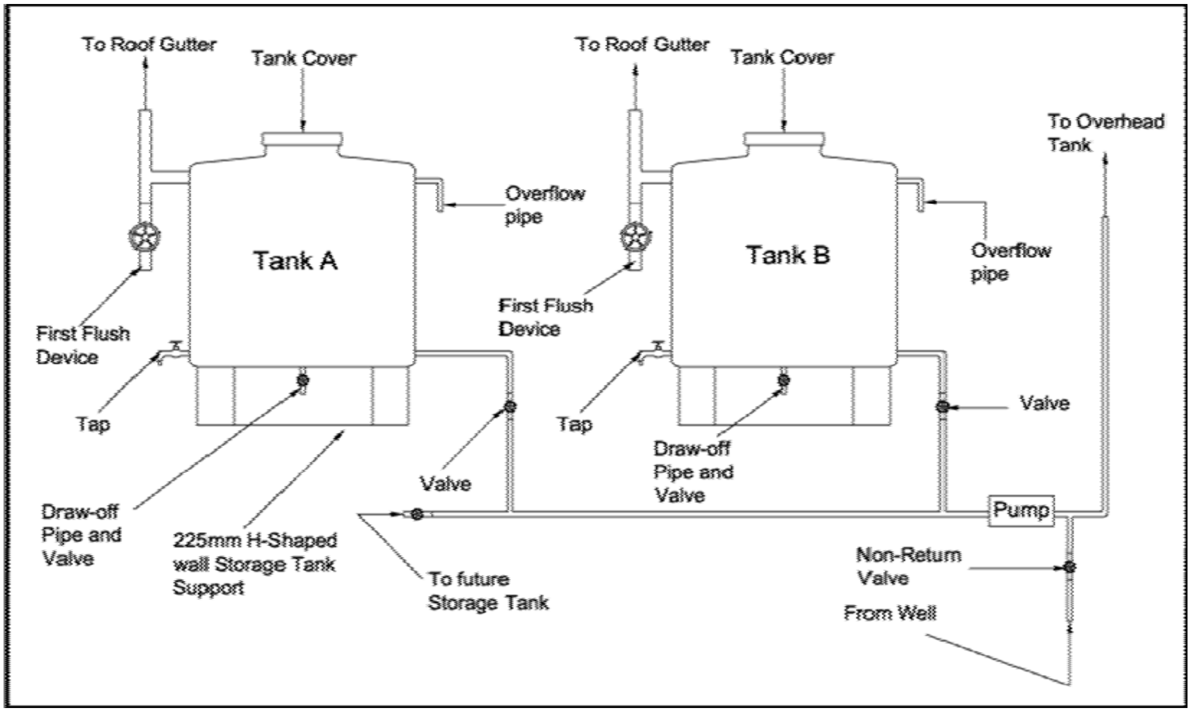

Figure 1: Schematic Diagram of the Rainwater Harvesting Technology's Storage and Conveyance Components

Table 1: Physico-chemical characteristics of the water samples

Parameter	Values Recorded from Various water Samples				W H O
	Direct from Atmosphere	Galvanised Roofing Sheet	Test Well	Control Well	
pH	6.6	6.8	7.4	7.6	6.8-7.3
Hardness, mg/l	0.0	20.0	25.0	27.0	40
Alkalinity, mg/l	19.0	21.0	85.0	86.0	40
Chloride, mg/l	10.0	15.0	60.0	60.0	200-300
Iron, mg/l	0.0	0.2	1.0	1.1	0.3
Nitrate, mg/l	0.0	2.0	0.8	0.8	50

harvested water in the tanks at the rate of 5 ml per 25 litres of water. This performs the function of disinfecting the water to improve the quality.

RESULTS AND DISCUSSION

The result of the tests conducted at the Laboratory of the Department of Agronomy, University of Ibadan is as shown in Table 1. The result showed that the harvested rainwater contains no dissolved minerals and salts and is near distilled water quality. The pH values are within the acceptable limits of WHO drinking water. The dissolved carbon dioxide in the atmosphere as the rain fall contributes to the slightly acidic nature of the water (Thomas and Martinson, 2003). Any trace of Nitrates or Sulphates dissolved in the air would further reduce the pH (WHO, 2006).

It was observed that harvesting all the roof catchment areas would have produced about 495 litres of water per day for the household. The required reservoir for the household for the dry period would be 60 m^3. With the present utilized roof area of 70 m^2, 21 m^3 reservoirs would be needed for dry period. Plate 1, 2, 3 and 4 shows conveyance system, gutters with mesh and downpipes connected to tank. With the current 5 m^3 (a 2000 litres and a 3000 litres capacity) tanks and provision for another plastic tank, a 13 m^3 underground tank would be required to meet up the gap. Although this would not meet the household water demand, water from the well

Plate 1: Tank with Pipe

Plate 2: Gutter with Mesh

Plate 3: Tank with Pipe and Tap

Plate 4: Tank Support with Valve

will augment the shortage. Rationing and economic use of water at the peak of the dry season should also be strictly observed. A large underground reservoir could be constructed if there is available land space to accommodate the harvesting of the entire roof area. This would provide the required water for the household throughout the dry period, thereby arresting the perennial water shortage at household level as commonly experienced in Ibadan city.

With the absence of public water in the study area, rooftop Rainwater Harvesting System will go a long way in providing water for individual households in the areas with provision of adequate storage facilities. The average roof area of the household is sufficient to provide the required water especially during the dry period. Since the rain was not harvested from the entire roof area, the incorporation of the rain water harvesting system with the existing shallow well water system for the household use brought appreciable relief from water scarcity. This was achieved by rationing water demand during the dry season. The quality of harvested water is good after taking adequate safety precautions. With the exception of alkalinity, all other water quality parameters assessed were below WHO guideline limits for drinking water. The high alkalinity value could be due to neutralization of the acidity by soil dust components like Ca and Mg (Umesh et al, 2001). In the absence of dust atmosphere, the pH of rainwater has been reported to be acidic (Umesh et al, 2001). In Nigeria, dry and early days of rainy seasons are usually associated with dusty atmosphere, which may contain substances such as Ca and Mg of carbonate, bicarbonate and sulphate. The dissolution of these components by rainwater may result in high levels of alkalinity in harvested rainwater. Apart from saving the households a lot of time usually spent on fetching water from other sources, Rainwater Harvesting also reduces runoff and erosion in the household. A lot of money was saved in buying water in the household during the dry season.

Rainwater Harvesting technology seems capital intensive, but operating costs are negligible.
Nevertheless, using underground tank creates economy of space as the reinforced concrete on top of the tank can be used for other purposes like sitting arena or parking of vehicles.

CONCLUSION

Rainwater harvest system has proven to be an effective intervention for the perennial water shortage at household level in Ibadan city.

Therefore, advocacy for its adoption will lead to drastic reduction in water-shortage / water related diseases and improve standard of living of the people. Government support will help in reducing the cost and create enabling environment for the adoption of the technology.

RECOMMENDATIONS

From the results obtained the followings are therefore recommended:
a) Rainwater Harvesting should be seen as a viable and reliable water supply option in Nigeria with abundant rainfall potentials.
b) Government should recognize and adopt rainwater harvesting technology in National Water Policy by undertaken initiative that will facilitate its use as it is commonly done in some other developing countries.
c) Instead of individual households, community participatory programme should be encouraged in RWH to make it more economical and affordable.
d) Since RWH can be available for dry season in Nigeria, institutions, public and corporate organizations should adopt RWH in non-potable use like toilet flushing and fire fighting. This will be an easy access to water which is a relatively cheap and convenience system.

RECOMMENDATIONS FOR FURTHER STUDIES

Detail research should be carried out on artificial water recharge to provide guidelines on their effectiveness and sustainability. In addition, this will make possible, not only an efficient usage of the Nigeria's water resources being wasted on flood and erosion, but also promote the country's economic growth through technological breakthrough.

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