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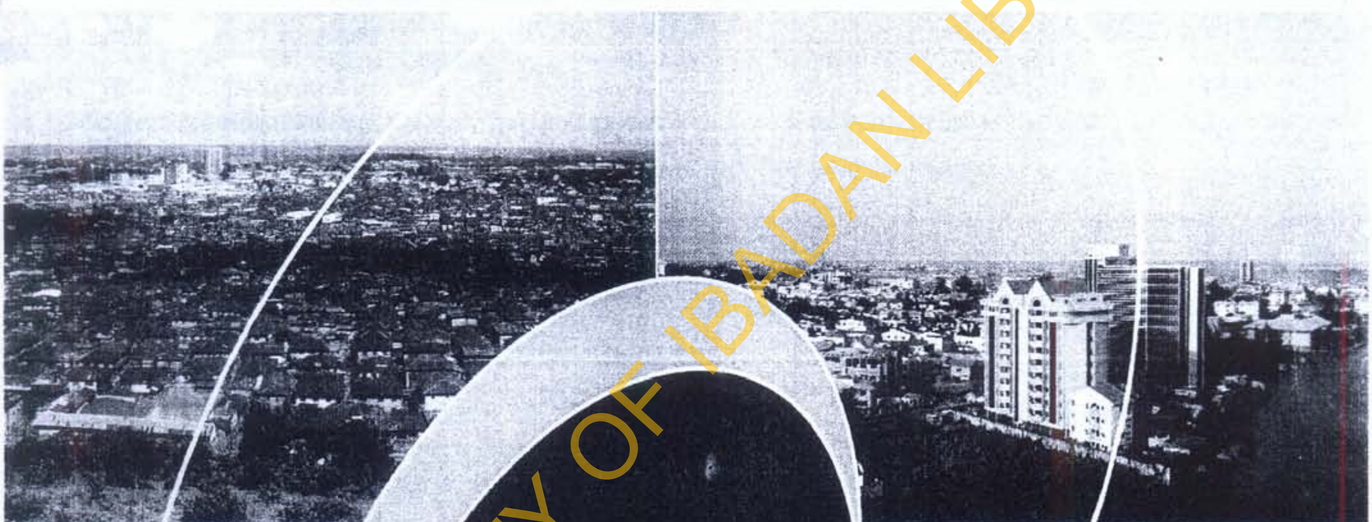

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Rainwater Harvesting: Harnessing Traditional Approach to Reduce Flash Floods in Ibadan Metropolis

*Wahab, B. and Ojolowo, S. K
Department of Urban and Regional Planning,
University of Ibadan
*Corresponding Author: *bolanle_wahab@yahoo.com*

Abstract

This paper presents an empirical case study of domestic rainwater harvesting (RWH) techniques that could be employed to reduce surface run-off. Equations were derived to calculate the potential amount of rainwater that could be harvested and the actual amount of rainwater harvested by 178 buildings with rainwater harvesting facilities at Coca-Cola Area on 26 August, 2011 when Ibadan metropolis was devastated by flash flood. The study found that, through rooftop catchment techniques, as much as 90 per cent of runoff water could be harvested and that 100 per cent is achievable if augmented with surface catchment techniques for open spaces within the metropolis. The paper concludes that incorporating indigenous and modern rainwater harvesting techniques into the management of flood in Ibadan metropolis will not only mitigate the risks associated with flood, but will also enable sustainable access to domestic water and promote urban agriculture and household food security.

Keywords: Flash floods, Indigenous Rainwater Harvesting Techniques, Runoff Coefficient, Integrated Water Resources Management, Coca-Cola Area, Ibadan.

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Introduction

The severity and frequency of flood across the globe affirmed that flood is the most frequent of all natural disasters (Glickman *et al.*, 1992; IFRCRS, 1998; UNDHA, 1997; Abhas, *et al.* 2012). Flood had ceased to be a coastal challenge as many landlocked countries have recently been ravaged leading to a colossal loss of lives and property. Floods are normal environmental phenomena that bring alluvial soil and water transportation in many parts of the world, but flooding at an unexpected scale and with excessive frequency (as being witnessed nowadays) causes damage to life, livelihoods and the environment. Flood losses reduce the asset base of households, communities and societies through the destruction of crops, buildings, infrastructure, machinery and dwellings, in addition to the tragic loss of life (Aletan *et al.*, 2011). The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) predicts that increase in frequency of heavy precipitation events will further augment flood risk.

Flooding arises from rainfall – when rainfall intensity exceeds the infiltration capacity of the soil, excess water is generated (Oni, 2003). Ayoade (2006) asserts that the impervious human-made surfaces that make up the urban fabric ensure that little of the falling rain infiltrates into the ground. When it rains, some of the water is supposed to be retained in ponds or soil, by vegetation and the rest in a normal environment flows on the land as surface run-off without destructive potential. The removal of these water retaining features due to urban development enhances excess run-off. Flooding in Ibadan arises from excess run-off resulting from impermeable surface occasioned by urban development (Agbola *et al.*, 2012), blocked hydraulic structures, siltation of water channels, deforestation, and failure to adhere to space standards for urban development.

In Ibadan metropolis, residents become apprehensive in thoughts and actions at the slightest atmospheric change signifying the approach of rainfall due to the devastation associated with flash flood in recent times. Therefore, it is rational to look inwards for techniques that will enable residents co-habit with flash flood in the city. One of such techniques is rain water harvesting. This is one of the indigenous water resources management strategies. It is the art and science of collecting and storing rainwater for domestic and agricultural purposes (Ferguson, 2012). The benefits of indigenous knowledge to disaster risk-reduction have been acknowledged and identified as the most sustainable response to water management (Mercer *et al.*, 2007). Therefore, the focus of this study is to showcase rainwater harvesting systems potential in reducing the amount of surface run-off resulting from impervious urban surface, as a strategy to reduce the risks of flood in Ibadan metropolis, as exemplified in Integrated Water Resources Management (IWRM).

Integrated Water Resources Management (IWRM)

The concept promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems as shown in Figure 1 (Global Water Partnership (GWP), 2000; Aletan *et al.*, 2011)). IWRM is also public participation-based and explicitly takes care of ecosystems (Rongchao *et al.*, 2004). Integrated water resources management secures water for drinking, food production, nature, industry and other uses. It creates employment, protecting vital ecosystems, deals with variability of water in time and space, and reduces risks associated with water. It also creates popular awareness and understanding that encourage collaboration across sectors and boundaries which eventually spur public participation in decision making on water. Application of IWRM model to manage water incorporates the collection of rain water for varying uses and reduces surface runoff leading to flash flood in various communities (Aletan *et al.*, 2011).

Integrated Water Resource Management remains a core approach for ensuring that communities subsisting on resources within

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a watershed continue to obtain benefits from and within their locality. One of the ways of developing policies and development actions for flood control and watershed management is through a better understanding of the traditional uses of rainwater, and its management and coping strategies to excessive rainfall in the communities. This is because traditional water management knowledge systems and practices are passed down from generation to generation. This approach provides a key input into progressive technical development and implementation of rainwater management, which includes harvesting, storage and utilization for flood management and sustainable management of watersheds.

The application of IWRM will facilitate ecological sustainability, whereby the capacity of the hydrosphere to meet the needs of the present generation will not be hindered, and also provide adequate aquatic resources for the future generations. Ecological sustainability is the belief that all humans must use resources wisely and efficiently to avert pollution and exhaustion; to achieve economic efficiency and, in the end, social equity and equality in access to water in both rural and urban environment.

Literature Review

Rainwater harvesting has been practised in civilizations around the world and appears to have originated in Asia and the Middle East several thousand years ago (Evenari *et al.*, 1961). Rainwater utilisation also has a long history in Sri Lanka, Nepal and Bangladesh where the use of rain harvesting systems are still common today (CAWST, 2011). Examples of traditional water collection for both domestic and agricultural uses dating back more than 4,000 years have been documented in India (CAWST, 2011). In the Negev desert in Israel, cisterns for storing run-off from hillsides, for both domestic and agricultural purposes, have

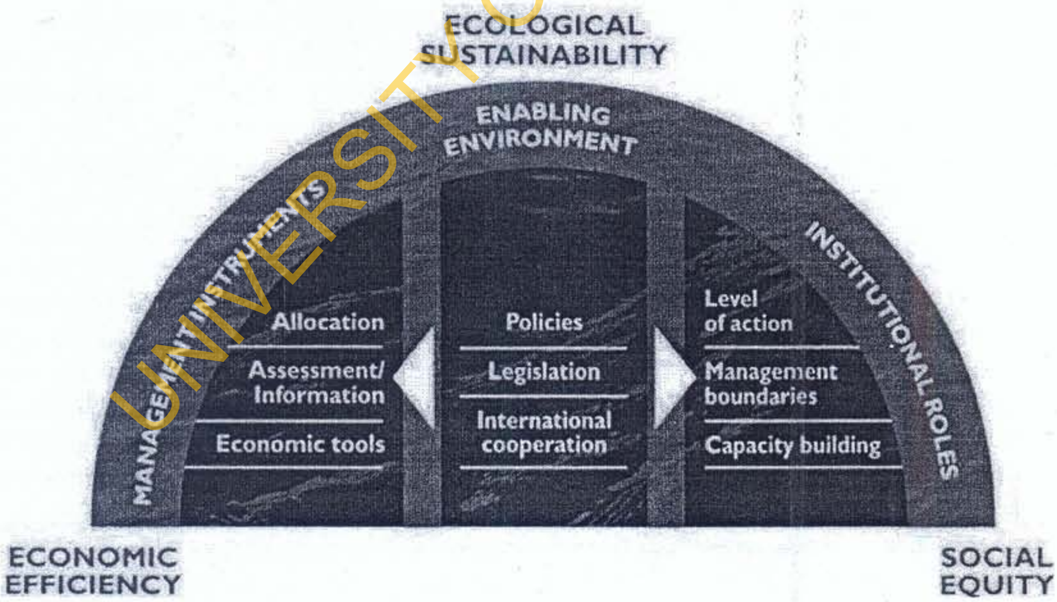

Figure 1: General framework for Integrated Water Resources Management
Source: GWP, 2000

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allowed habitation and cultivation in areas with as little as 100 mm of rain per year since 2,000 BC or earlier (Evenari *et al.*, 1961). The earliest known use of rainwater technology in Africa comes from Northern Egypt, where sub-surface cisterns with volumes ranging from 200 to 2,000 m^3 have been used for at least 2,000 years – some are still in use today (Shata, 1982, Arnold and Adrian 1996). In sub-Saharan Africa, the small-scale collection of rainwater into traditional jars and pots has been practised for millennia. Rainwater has been traditionally collected in Uganda from trees using banana leaves or stems as temporary gutters; up to 200 litres may be collected from a large tree in a single storm (Pacey and Cullis, 1986). In China, there have been bottle-shaped underground tanks, known locally as *shuijiao*, which are up to 30m^3 in volume, used for several centuries to store water for many households (CAWST, 2011). Conical dome shaped structures, known as *abanbars*, designed to house communal sub-surface rainwater cisterns, have been used in Iran for many centuries till date (Hassanizadeh, 1984 in CAWST, 2011). In 1979, United Nations Environment Programme (UNEP) commissioned a series of regional case studies in China, India, Mexico, the U.S., Africa, Australia, and the South Pacific into rain and storm water harvesting in rural areas (World Bank, 2010). The publication of the case studies was the first global comprehensive overviews of rainwater harvesting technologies. The first conference on the use of rainwater cisterns for domestic water supply was held in Honolulu, Hawaii in 1982. The next three conferences took place in the U.S. Virgin Islands (1984), Thailand (1987), and the Philippines (1989) at which point the scope of the conference series was broadened to include other forms of rainwater catchment systems such as rainwater harvesting for agriculture. At the 1989 conference in Manila, Philippines, there was an agreement to set up an association to oversee the conference series and endeavour to promote the technology worldwide. Subsequent conferences took place in Taiwan (1991), Kenya (1993), China (1995), Iran (1997), Brazil (1999) and Germany (2001) (UN-HABITAT, n.d). Similarly, the World Water Forum in Marseille, France in 2012 did not consider rainwater harvesting as an antidote to flash flood either, but a means of potable water supply for household consumption and irrigation.

Since the 1970s, a growing body of literature has emphasised the importance of incorporating local knowledge and practices into development and conservation projects (Mercer et al., 2007). Some of the disciplines where indigenous knowledge has been incorporated are: (a) Soils: Scott and Walter (1993), Sandor and Furbee (1996); Gray and Morant (2003), Payton et al. (2003), Gowing et al. (2004),(b) Fisheries: Mackinson (2001); (c) Natural resource management: ADPC and UNDP (2005), Moller et al. (2004), Rist and Dahdouh-Guebas (2006); (d) Forestry: Thapa et al. (1995), Walker et al. (1995), Walker (1999), Singhal (2000), Klooster (2002), Donovan and Puri (2004), Kaschula et al. (2005); (e) Land management: Gobin et al. (2000), Reed et al. (2007); (f) Health: Giles (2007); (g) Agricultural research: Rajasekaran et al. (1991); Rajasekaran (1993), Warren (1996), Zwahlen (1996); (h) Marine conservation: Drew (2005); (i) Climate: Stigter et al. (2005); (j) Desertification: Gaur and Gaur (2004); (k) Water: Roncoli et al. (2002), Osti (2005); and (l) Climate change: Dixit and Patil, (1996); Nyong et al., (2007); (m)

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management of land and cropping pattern (Tjitayi et al., 1979; Finkel et al., 1986); (n) land use strategies and house building techniques (Wahab, 1997) and (o) emergency situations (Burt and Keiru, 2009).

Similarly, the available literature on indigenous water harvesting technologies and its applications is encouraging. Small reservoirs were developed for rainfall-runoff harvesting for controlling erosion and sustaining upland agricultural development at Kali Garang watershed, Semarang, Indonesia, where yearly average rainfall is 4000 mm (Sumarjo Gatot *et al.*, 2001). They opined that the system could also control flood during the wet season, as well as drought during the dry season. Those works that considered rainwater harvesting as one of the solutions to the problem of water scarcity only, and not a means of reducing surface run-off to curb flooding were (Eletta and Oyeyipo, 2008; Ajayi and Ugwu, 2008; Burt and Keiru, 2009; Borthakur 2009; Manochon, 2010; Onoja *et al.*, 2010; Ehlert, 2010; Eruola *et al.*, 2010; Wahab 2010; Akintola and Sangodoyin, 2011; Victor, 2011; Magnus, 2011; Chukwuma *et al.*, 2012; Oti & Skinner, 2012; Ubuoh *et al.*, 2012; Lade *et al.*, 2013; Wahab 2013; Oyediran, 2014).

However, Shittu *et al.*(2012) suggested further studies in area of artificial water recharge in order to reduce runoff and subsequently curb flash flood and erosion. They designed Roofwater Harvesting (RWH) systems for domestic, industrial and agricultural purposes for both urban and rural areas in Ibadan and considered it the cheapest and most viable water supply option. Lade *et al.* (2013) conducted hydrological analysis of Ibadan city 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. They were of the opinion that Ibadan city has good potable water saving potential using rainwater; owing to the fact that the mean potential for potable water savings discovered was 52.7%. The study conducted by Eruola *et al.* (2010) at Oke-Lantoro community in Abeokuta, Southwest Nigeria revealed that harvested rainwater was suitable for domestic purposes. The results of the research conducted by Ubuoh *et al.* (2012) in Akwa Ibom State Nigeria indicated that mean monthly rainfall ranged between 18.39 - 378.63 mm and mean annual rainfall ranged between 145.6 – 440.7 mm and maximum rainwater harvested was 98.3m3 (983,000 litres), adequate for domestic consumption.

The Study Area

Ibadan city, the study area, is located in south-western Nigeria (Fig. 2). Ibadan lies approximately between latitude 7.28^0 and 7.29^{0}N and longitude 3.5^0 and 3.13^{0}E. It is the capital of Oyo State, and is reputed to be the largest indigenous city in Africa, south of the Sahara. Ibadan was the centre of administration of the old Western Region, Nigeria right from the days of the British colonial rule. It is 128 km inland northeast of Lagos and 530 km southwest of Abuja, the federal capital. It is a prominent transit point between the coastal region and the areas to the north. The city ranges in elevation from 150 m in the valley area, to 275 m above sea level on the major north-south ridge which crosses the central part of the city. The city's total area is 1,190 sq mi (3,080 km^2) (Lyold, 1967).

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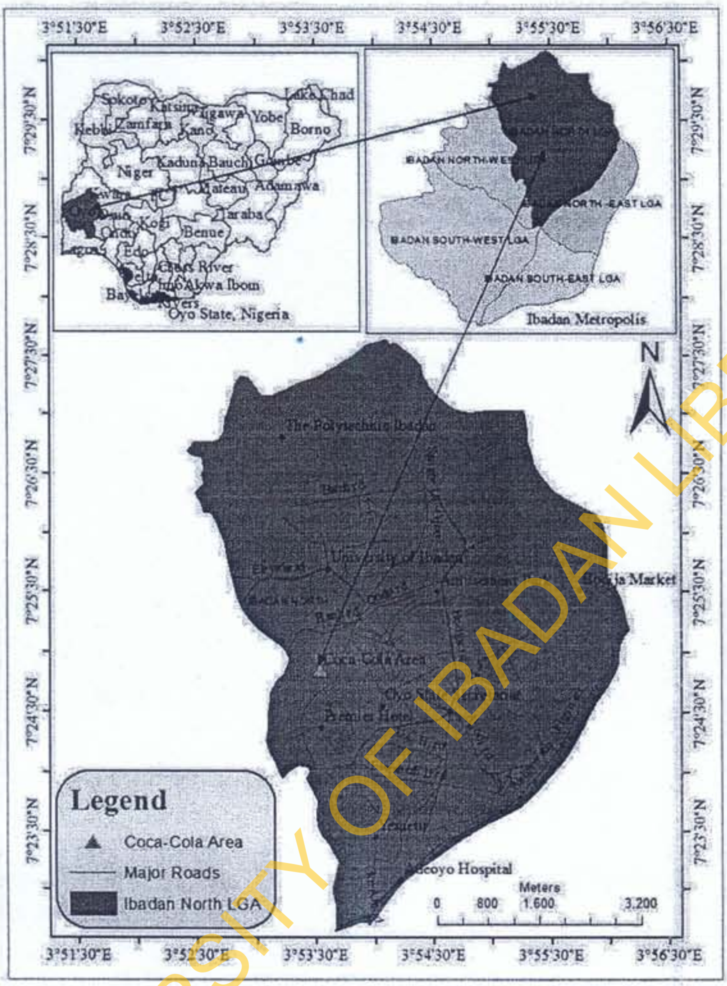

Figure 2: Coca-Cola Area, Ibadan North LGA, Oyo State, Nigeria
Source: Office of Surveyor General, Oyo State, Nigeria, 2012

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Spatio-temporal and Demographic Growth of Ibadan

Developed land of Ibadan increased from only 100 ha in 1830 to 12 km^2 in 1931 (Mabogunje, 1968). In 1952, it was estimated that the total area of the city was approximately 103.8 km^2 (Areola, 1994). The land area was 30 km^2 in 1963; 112 km^2 in 1973, 136 km^2 in 1981 and 214 km^2 in 1988 (Fourchard, 2003). By the year 2012, according to Oladosu (2013), the total percentage of land use of Ibadan was 72.5%, vegetation cover was 26.2% and water body was 1.4% (Fig. 3). Demographically, in 1856, the population of Ibadan was estimated at 60,000 and by 1890, it had increased to about 200,000 (Millson, 1891). In 1921, it was 238,094; 386,359 in 1931, and 459,000 in 1952 (Mabogunje, 1968). The population of Ibadan grew to 600,000 in 1963 (Lyold, 1967). The 1991 and 2006 census exercise put the population of Ibadan at 1,222,570 and 2,550,593 people, respectively (NPC 1991 and NPC 20010). With the population growth rate of 3.2%, the projected population of Ibadan for 2013 was 1,524,163 people.

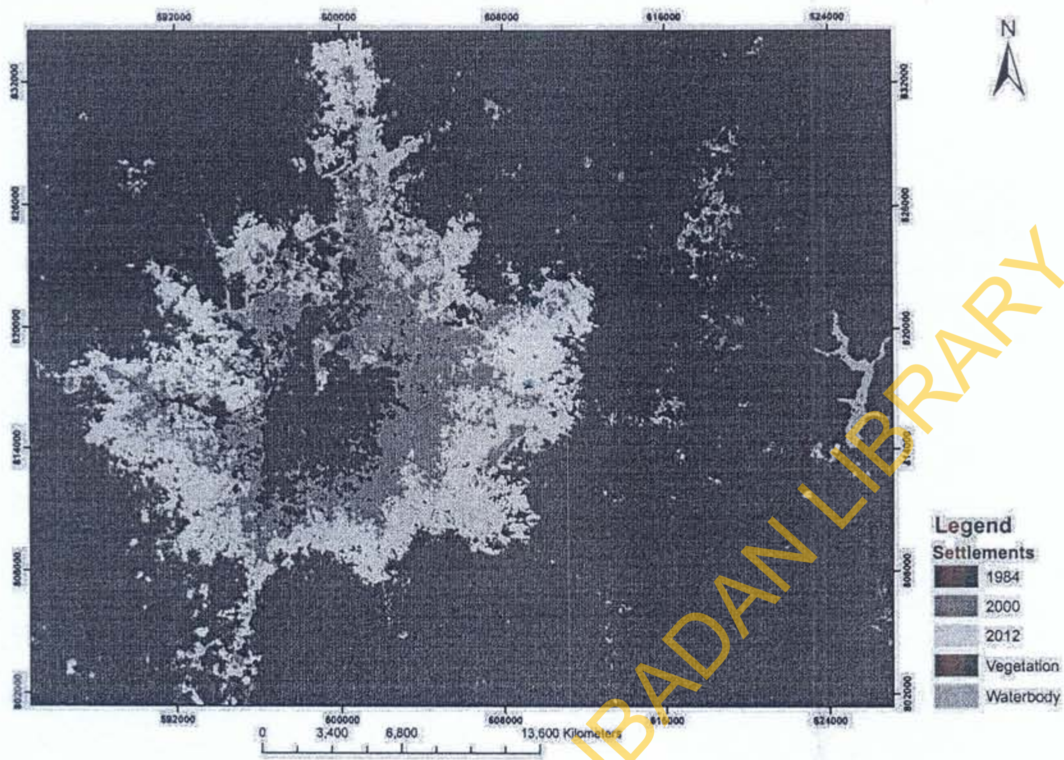

Figure 3: Super-Imposition of Land Use Land Cover Change of Ibadan (1984, 2000, 2012)
Source: Oladosu (2013)

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The Climatic Characteristics of Ibadan

The latitudinal location of Ibadan makes it to enjoy the West African Monsoonal climate marked by distinct seasonal shift in the wind pattern. Between March and October the city is under the influence of moist maritime southwest monsoon winds which blow from the Atlantic Ocean (Oguntoyinbo, 1982). There are on average 30 storms in a year accounting for over 70% of the total annual rainfall (Oguntoyinbo, 1982). The mean annual rainfall of Ibadan is 1258.9mm (Oguntoyinbo, 1978); the mean annual temperature is 26.6^{0}C. The mean maximum temperature of 28.8^{0}C occurs in February while the mean minimum temperature of 24.5^{0}C occurs in August when the cloud cover is dense. Relative humidity oscillates around 94 percent.

The Trend of Floods in Ibadan

The incidence of floods in Ibadan is not a recent phenomenon. The city had been suffering from varying degrees of flooding since 1955. Flooding occurred in several areas of the city whenever Ogunpa River overflowed its banks (Adegbola and Jolayemi, 2012). Flooding also occurred in 1960, 1961, 1963, 1969, 1978, 1980 and 2012 along the water shed of Ogunpa and Kudeti streams. The flooding of 1969 was unique because it resulted from a mere 25.4 mm rainfall (Akintola, 1981). An accurate assessment of the havoc caused by floods in Ibadan over the years is difficult to obtain (CBN, 1999). However, a number of official estimations have been made at different points. For instance, the losses arising from the flood disaster of August 1980 in Ibadan were estimated at N300 million then, while the number of lives lost was put at 500 people (Agbola *et al.*, 2012). Over 1 million naira was lost to flood in 2011 (Table 1); while about three lives were lost to flood on July 14 to 15 in 2012 (Plates 1&2).

Rainwater Harvesting Techniques: Systems and Components

Rainwater harvesting systems have three main parts namely: the catchment, the gutter/downpipe, and the storage tank (Fig. 4). The roof is usually the catchment for rainwater harvesting and an integral part of all buildings/structures; the catchment could also be the totality of the surface areas being drained into sub-surface storage tank, as shown in Figure 5. The gutter/downpipe is the part of the rainwater harvesting systems that convey harvested rainwater either from the roof or surface areas into the storage tanks; while the storage tanks are the devices that retain harvested rainwater for immediate and future use. Lee and Visscher (1990) classified rainwater harvesting techniques in Africa into three; rooftop, surface and runoff farming catchments systems.

Rooftop catchment systems consists of a rooftop catchment area (made of iron-sheet or slate but occasionally of thatch), connected by gutters and downpipe (made of bamboo, iron or plastic pipes or corrugated iron sheets) to one or more storage containers which range from clay-pot, rubber, plastic or ferroconcrete tanks of all sizes.

Surface catchment harvesting systems consist of four main types: rock catchments; earth dams and excavated reservoirs and sub-surface dams (Lee and Visscher, 1990). In each, water is collected and stored at strategic locations before it can rush away as floodwater or seep away out of reach into the ground. Also, surface run-off can be collected from artificial surface (see Fig. 5), such as the one found in

Table 1: Rainfall-induced Floods in the City of Ibadan, Nigeria (1951 and 2013)

S/N	Date	Rainfall (mm)	Estimated Damage to Property (Naira)	Estimated Loss of Lives
1	9-10 July 1951	161	Unknown	Unknown
2	16-17 June 1955	173	Unknown	Unknown
3	16-17 August 1960	178	Tens of thousands of naira	Unknown
4	27-28 August 1963	258	Tens of thousands of naira	At least 2 persons
5	14 May 1969	137	Tens of thousands of naira	At least 2 persons
6	1973 (undated)*	Unknown	More than 100,000	3 persons
7	20 April 1978	126	Over 2,000,000	At least 2 persons
8	31 August 1980	274	More than 300,000,000	More than 500
9	1982 (undated)*	Unknown	Unknown	Unknown
10	1984 (undated)*	Unknown	Unknown	Unknown
11	April 1986 (undated)*	Unknown	Unknown	Unknown
12	June/July 1987(undated)*	Unknown	Unknown	Unknown
13	April 1997 (undated)*	151	Unknown	Unknown
14	26 August 2011	187.5	Over 30 Million	Over 100
15	14-15 July 2012**	Unknown	Unknown	3
16	23 September 2013***	Unknown	Unknown	At least 2 persons and 1 injured

Note: USD 1 = N156 (2011)

Sources: Nigerian Environmental Study Action/Team (NEST 1991: 107), National Water Resources Institute (2011: 10), *Akintola and Ikwuyatum (2012: 199), Agbola, *et al.* (2012: 208), ***Atoyebi (2013), **Authors' update.

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Plates 1&2: Scenes of Flood in Ibadan on July 14-15, 2012
Source: *Thisdaylive* from http://www.thisdaylive.com/articles/after-the-ibadan-flood-policeman-two-others-found-floating-in-river/120288/ 17/09/2013 21:15 Hrs

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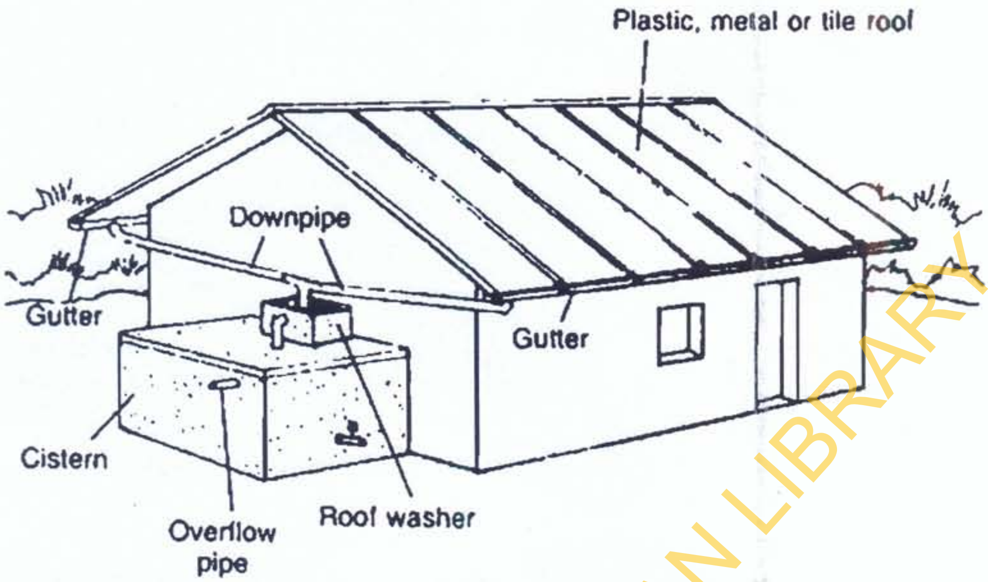

Figure 4: Simple Rainwater Harvesting System
Source: Owoade (1989)

urban environments. The collected run-off can be stored in reservoirs. Reservoirs could be of many different types and sizes, located on or below the surface of the ground (Figure 5 & Plate 3). Sub-surface tanks can be made from local materials using concrete, brick and traditional clay linings.

Runoff farming systems involves the management of surface runoff to increase direct infiltration into fields, promoting crop growth and boosting yields in otherwise unfavourable soil moisture conditions. The system contains micro-catchments and variously-sized check barriers combined with contour ploughing for retaining rainwater.

All rainwater-harvesting systems comprise six basic components irrespective of the size of the system:

(i) Catchment area/roof: this is the surface upon which the rain falls; the roof has to be appropriately sloped, preferably towards the direction of storage and recharge;

(ii) Gutters and downpipes: These are transport channels from catchment surface to storage. Gutters and/or downpipes have to be designed depending on site, rainfall characteristics and roof characteristics;

(iii) Leaf screens and roof washers: This constitutes the systems that remove contaminants and debris. A first rain separator has to be put in place to divert and manage the first 2.5 mm of rain, so as to collect seemingly contaminated rainwater separately;

(iv) Cisterns or storage tanks: These are sumps and tanks where collected rain-water is safely stored or recharging the ground water through open wells, bore wells or percolation pits;

(v) Conveying: The delivery system for the treated rainwater, either by gravity or pump;

(vi) Water treatment: Filters to remove solids and organic material and equipment, and additives to settle, filter, and disinfect. Briefly explained, the rainwater harvesting system involves collecting water that falls on roof of a house made of zinc, asbestos

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Figure: 5. A hypothetical Simple Run-off Rainwater Harvesting System (underground storage tank)
Source: ITDG Technical Brief (undated)

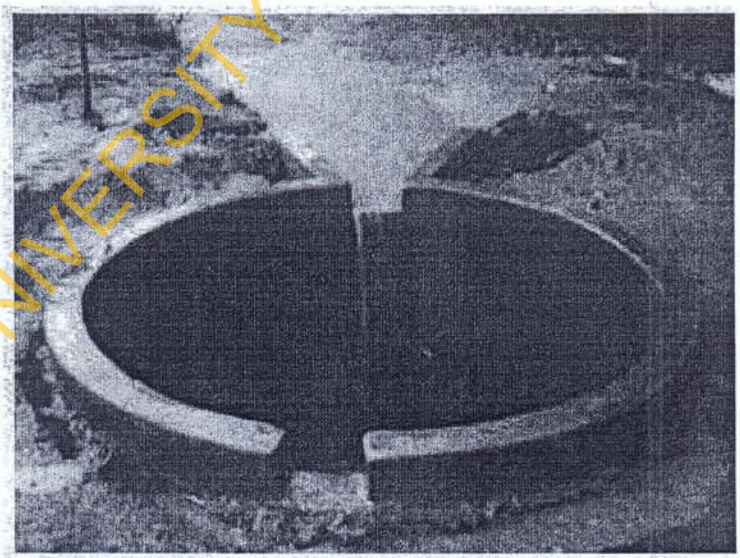

Plate 3: Run-off Rainwater Harvesting (surface storage tank) in Sigiriya, Sri Lanka
Source: ITDG Technical Brief (undated)

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or other materials during rain storms, and conveying it by an aluminium, polyvinyl chloride (PVC), wood, plastic or any other local material, including bamboo drain or collector, to a nearby covered storage unit or cistern.

This section presents in pictures, different rainwater harvesting systems used by residents in Coca-Cola area of Ibadan and characteristics of components

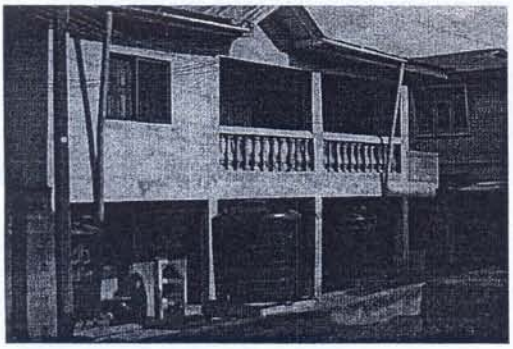

Plate 4: Two-storey residential buildings installed with a RWH system of 3 x 3000 litres of black plastic tanks at Ifelodun Street, Coca-Cola, Ibadan.

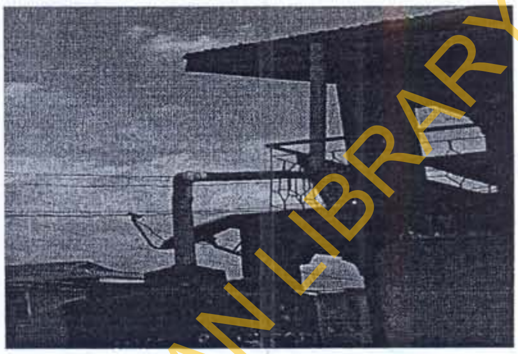

Plate 5: Two-storey residential buildings installed with a RWH system of 2000 litres of black plastic tanks at Ifelodun Street, Coca-Cola, Ibadan.

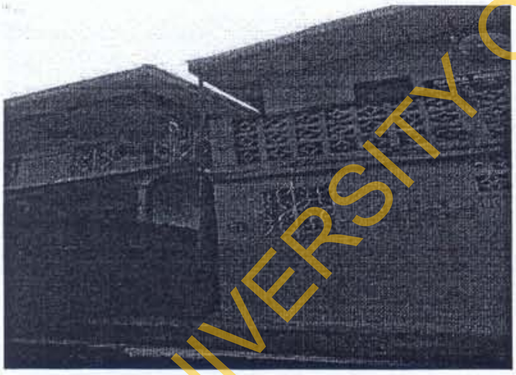

Plate 6: A mosque installed with a RWH System of 1000 litre blue plastic tank at Ifelodun Street, Coca-Cola, Ibadan.

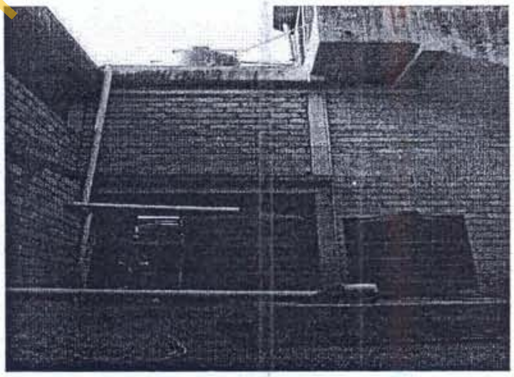

Plate 7: An art theatre with residential apartments at the rear air-space featuring a combination of surface and underground tanks for RWH at New Cultural Centre, Oremeji Area, Adegoke Street, Coca-Cola, Ibadan.

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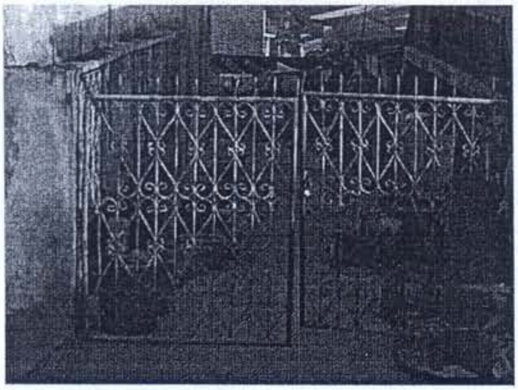

Plate 8: Buckets of all sizes positioned for collecting rainwater at Ajegunle Street, Coca-Cola, Ibadan.

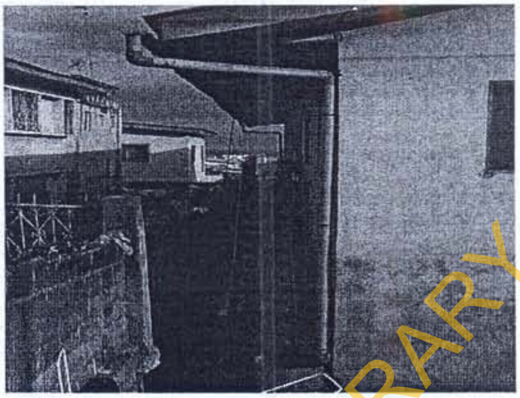

Plate 9: A block of four flats with 20-litre RWH systems at Ajegunle Street, Coca-Cola, Ibadan.

Source: Authors' Fieldwork (2013)

Research Methods

Primary and secondary data were collected from relevant sources. The primary data obtained during the fieldwork included 178 buildings with rain water harvesting facility (RHF) at Coca-Cola Area, Ibadan. Rain water harvesting facility includes roof of a house, collector or gutter and storage unit for collecting and storing rainwater. Measurements of the roofs of buildings with RHF were taken with 50m tape and a range of 135.4 square metres to 196.5 square metres obtained. Similarly, records of the volume of tanks used for storing rainwater in the buildings were taken and 1000 litres to 2000 litres were recorded. The models used to arrive at these formulae are presented in Sub-section 5.2.1 to 5.2.6. The main secondary information was the mean rainfall data recorded to have caused flooding in Ibadan on 26 August, 2011 by the National Water Resources Institute (NWRI). The rainfall data is presented in Table 1.

The area of roof was determined during the fieldwork by measuring and recording the breath and length of the land area covered by the roof with equation 1.

$$AR = L*B \qquad (1)$$

Where:

RA = the area of roof
L = the length of building in (metres)
B = Breadth of building in (metres)

The capacity of rainwater storage tanks in each building with RHF in Coca-Cola area of Ibadan ranged from 1000 to 2000 litres depending on the number of both surface and underground tanks attached.

A typical run-off coefficient for various rooftops is shown in Table 2. Based on the flat roof with smooth surface common in the study area, a run-off coefficient of 0.5 was adopted to account for losses due to spillage, leakages, roof surface wetting and evaporation which would reduce the amount of rainwater that actually entered the storage tanks. Below are the run-off coefficients for various rooftops as given by Legget *et al.* (2001).

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Table 2: Run-off Coefficients for Various Roof Types

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

Source: Legget *et al.* (2001)

The volume of rainwater that could be harvested during rainfall in Coca-Cola area was determined using mean size of rainfall of 187.5mm^3/0.1875m^3 obtained from National Water Resources Institute (2011) (in respect of the August 2011 rainfall in Ibadan that flooded the city), the total area of roof, and a run-off coefficient of 0.5. Thus, the volume of rainwater that could be harvested in the area was determined using equation 2.

$$\mathbf{PRH=\sum TAR*R*C*1000} \quad (2)$$

Where:

PRH is the amount of rainwater that could be harvested in the study area (m^3/rainfall),

TAR is the total area of roof (m^2),

R is the amount of rainfall in Ibadan that caused flooding (mm/m^2 rainfall),

C is the run-off coefficient (non-dimensional), and 1000 is the conversion factor from m^3 to litres.

The actual amount of rainwater harvested (ARH) was obtained with equation 3:

$$\mathbf{ARH=\sum VT*NB} \quad (3)$$

Where:

ARH = Actual volume of rainwater harvested
VT = Volume of tank (litres)
NB = Number of building

The percentage of actual amount of rainwater harvested to the potential rainwater that could be harvested in Coca-Cola area of Ibadan was derived using equation 4.

$$\mathbf{P(\%)=100*\frac{ARH}{PRH}} \quad (4)$$

Where:

P is the percentage (%), **ARH** is the actual rainwater harvested (m^3/flood day), **PRH** is the potential amount of rainwater that could be harvested (m^3/flood day).

Discussion of Results

The study found out that the area of roofs in Coca-Cola area of Ibadan raged from 135.4m^2 to 196.5m^2. Table 3 presents the frequency of the areas of roofs of buildings with RHF as observed at Coca-Cola in Ibadan during the field survey in August 2013. Equation 1 was used to arrive at 27783.0m^2 as Total Area of Roof (TAR) of 178 buildings with RHF (see equation 1 in section 6.2.1).

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As presented in Table 3, buildings with RHF had different number of tanks attached to the systems; even buildings with the same area of roof had different capacity of tanks. For instance, 21 buildings with area of roof of $135.4m^2$ had only one-1000L tank each attached, while the remaining seven had two-1000L. Some other buildings have two-2000L, three-2000L etc, while only one building shown in Plate 7 had 2000L underground tank with a three-2000L and one-1000L surface tanks. The Total Volume of Tank (TVT) derived for the sampled buildings was 496000L (see Table 3). This also represents the ARH.

Equation 2 was applied (see section 6.2.4) to obtain the potential amount of rainwater (PRH) that would fall on the roofs of all the 178 buildings with RHF. For instance, the 21 buildings with $135.4m^2$ that produced a total area of roof of $2,843.4m^2$ could harvest 266,568.8 litres of rainwater as presented in Table 3. The same formula was applied to obtain the PRH on 26 August, 2011 by 178 buildings. Therefore, the roofs of 178 buildings with rainwater harvesting facilities had the potentials to collect a total of 2,604,656.3 litres of rainwater on August 26, 2011.

Equation 3 was employed to determine the actual volume of rainwater harvested (ARH), that is, the amount of rainwater that the storage facility accommodated on August 26, 2011 when Ibadan metropolis was flooded. The total actual volume of rainwater harvested was 496000 litres as presented in Table 3 with various volumes of tanks attached to RHF in each building sampled.

Equation 4 was applied to obtain the percentage of actual rainwater harvested as against the potential amount that could have been harvested if all buildings in Coca-cola area of Ibadan metropolis had rainwater harvesting facilities.

$$P(\%) = 100* \frac{ARH}{PRH}$$

$$= 100* \frac{496000}{2,604,656.3} = 19.04\%$$

It can be deduced from the study that the potential amount of rainwater that could have been harvested by 178 buildings with RHF at Coca-Cola Area alone in Ibadan on 26 August, 2011 to avert excessive run-off that caused flash flood was 2604656.3 litres; the actual amount harvested based on sizes of storage tanks was 496000 litres, which was 19.04 per cent of 2604656.3 litres. This shows that an average of 2786.52 litres of rainwater was harvested by each building with RHF. The remaining 80.6 per cent would have been taken off the run-off either by increasing the volume of storage tanks or if about 883 buildings had rainwater harvesting facilities.

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Table 3: Analysis of Actual Rainwater Harvested as Percentage of Potential Amount of Rain that could be Harvested on August 26, 2011 in Coca-Cola Area, Ibadan

S/N	Area of roof (m^2) per sampled building (a)	Number of Buildings (NB) with RHF at Coca-Cola (b)	Total area of roof (m^2) (TAR) (a)*(b) =(c)	Volume of Tank per building (VT) (L) (d)	Total volume of tank (TVT) / Actual Rainwater Harvested (ARH) (Litres) (b)*(d) =(e)	Potential amount of rainwater that could be harvested (Litres) (PRH) (see Sec. 7.3) (f)
1	135.4	21	2843.4	1000	21000	266568.8
2	135.4	7	947.8	2000	14000	88856.3
3	138.7	12	1664.4	2000	24000	156037.5
4	138.7	6	832.2	3000	18000	78018.8
5	142.8	10	1428.0	2000	20000	133875.0
6	142.8	4	571.2	3000	12000	53550.0
7	142.8	3	428.4	1000	3000	40162.5
8	146.8	2	293.6	2000	4000	27525.0
9	146.8	11	1614.8	3000	33000	151387.5
10	146.8	2	293.6	2000	4000	27525.0
11	147.6	8	1180.8	5000	40000	110700.0
12	147.6	2	295.2	2000	4000	27675.0
13	147.6	1	147.6	3000	3000	13837.5
14	152.5	1	152.5	4000	4000	14296.9
15	152.5	3	457.5	3000	9000	42890.6
16	152.5	6	915.0	2000	12000	85781.3
17	152.5	3	457.5	1000	3000	42890.6
18	156.7	8	1253.6	2000	16000	117525.0
19	156.7	2	313.4	4000	8000	29381.3
20	156.7	2	313.4	3000	6000	29381.3
21	163.7	7	1145.9	3000	21000	107428.1
22	163.7	6	982.2	2000	12000	92081.3
23	167.9	1	167.9	1000	1000	15740.6
24	167.9	3	503.7	3000	9000	47221.9
25	167.9	1	167.9	4000	4000	15740.6
26	171.6	6	1029.6	3000	18000	96525.0
27	171.6	5	858.0	2000	10000	80437.5
28	174.6	2	349.2	4000	8000	32737.5
29	174.6	5	873.0	3000	15000	81843.8
30	175.8	4	703.2	4000	16000	65925.0
31	175.8	1	175.8	3000	3000	16481.3
32	182.7	1	182.7	4000	4000	17128.1
33	182.7	2	365.4	5000	10000	34256.3
34	187.5	2	375.0	5000	10000	35156.3
35	187.5	2	375.0	4000	8000	35156.3
36	193.7	4	774.8	5000	20000	72637.5
37	193.7	1	193.7	6000	6000	18159.4
38	195.6	2	391.2	6000	12000	36675.0
39	195.6	3	586.8	5000	15000	55012.5
40	195.6	1	195.6	4000	4000	18337.5
41	196.5	1	196.5	5000	5000	18421.9
42	196.5	3	589.5	6000	18000	55265.6
43	196.5	1	196.5	9000	9000	18421.9
	Total	**178**	**27783.0**	**146000**	**496000**	**2604656.3**

Source: Authors' Field Survey, 2013

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From the result of this study, we could conclude statistically, as shown in Table 3, that the flood events in Ibadan on 23 September, 2013; 14-15 July, 2012; 26 August, 2011; April, 1997, 31 August, 1980; 14 May, 1969; 27 to 28 August, 1963; 16 to 17 August, 1960; and 16 and 17 June, 1955 could have been averted if almost all houses in Ibadan had rainwater harvesting facilities capable of reducing the excessive run-off causing flooding.

Conclusion and Recommendations

The potential of rainwater harvesting to reduce surface run-off is evident in this study. This approach could be employed to augment other forms of flood control and prevention, such as sanitary disposal of solid waste, regular maintenance of storm water channels, adherence to urban development guidelines, and development of adequate drainage facilities. This study is of the opinion that the past flash floods and their associated risks in Ibadan could have been controlled and prevented if simple indigenous rainwater harvesting systems had been applied. Simple rainwater harvesting facility should be made one of the prerequisites before approval is granted for building development of any type – residential, commercial, industrial, educational, and public - by urban and regional planning authority. The integration of rainwater harvesting into urban development planning in Ibadan and other similar urban centres in Nigeria will facilitate sustainable flood management.

Incorporating indigenous and modern rainwater harvesting techniques in the management of flash floods in Ibadan metropolis will not only mitigate the risks of flash floods, but also enable sustainable access to drinkable water and promote urban agriculture to attain household food security.

Rainwater harvesting systems intercept, divert, store and release rainfall for future use. Construction, operation, and maintenance of rainwater harvesting facilities are neither labour intensive nor capital intensive. Similarly, rainwater harvesting is fitted into any existing strategies of flash flood management– either structural or non-structural, as it also has the propensity to hold water and eventually reduce the quantity of surface run-off at community, city and regional levels.

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