



# ASSESSMENT OF RAIN WATER HARVEST POTENTIAL IN SOKOTO BASIN, NIGERIA FOR IMPROVED WATER RESOURCE MANAGEMENT

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## Abstract

The Sokoto basin is part of north-western Nigeria; an area characterised by semi-arid condition largely due to high rainfall variability leading to frequent drought occurrence and water scarcity in the region. Rainwater harvesting can serve as an effective coping strategy in addressing the water deficit experienced by the people during the long dry season. This paper aimed to assess the rainwater harvest potential of Sokoto basin using variable landscape approach to improve water resource management. Simulations were run for 6 sequential rainfall years (2000-2005) to determine the distribution of rainfall input into output of runoff, actual evapotranspiration and groundwater outflow. The runoff and some groundwater outflow are considered as potential components for harvest and storage to be used after rainy season. The high potential areas for harvest were identified and classified using GIS and remote sensing techniques. The paper recommends a unified rational approach to water resources planning and development and suggests that small household water reservoirs and community earth dams should be built to capture excess runoff from rooftops and high runoff contributing landscapes for use during the dry season.

## Keywords

Sokoto Basin, Rainwater Harvest, Landscape Variability, Water Resource Management

## Introduction

Sokoto Basin is in Sub-Saharan Africa within the semi-arid part of the continent characterized by limited water resources and increased pressure of accessibility due to expanding urban, industrial and agricultural water requirements. WHO/UNICEF (2012) reported that globally, over 40% of all people who lack access to drinking water live in Sub-Saharan Africa. The problem persists more in the region because of slow and poor technological advancement, low incomes and institutional capacity to mitigate the problem (WHO, 2011, MacDonald, 2005, Kevin and Nicholas, 2010). Even though the potential impacts of climate change have long been recognised, there has been comparatively little research relating to its impact on water resources (IPCC, 2001). Today however, greenhouse warming associated with climate change continues to dominate the world's science and policy agenda on global change, and the fundamental concern is the impact of these changes on hydrology and water resources. The major concern is how the human society directly influences the state of the terrestrial water cycle in the visible presence of rapid population growth and economic development thus, altering the equilibrium to water quality, quantity and availability in many areas around the world (WaterAid, 2007).

Water is one of the critical factors that determine settlement and development of people in Sokoto basin. Even though the region is well endowed with water resources, and is well drained with a close network of rivers and streams (Ayoade and Bamwo, 2007), most of the smaller rivers are however, seasonal, especially in the upper catchment of the basin. The expanding population and the threat posed by climate change are putting the water resources under pressure and calling for new approaches for water resource planning and management. As water demand is increasing due to modern developments, changing life styles and population growth, the challenges of meeting the increasing demand became necessary for improving development and economic growth of the region.

Rainwater management, also known as harvesting, is receiving renewed attention as an alternative to or a means of augmenting water sources. Rainwater harvesting involves any human activity of collection and storage of rainwater in natural or artificial container for either immediate or future use before the onset of the next rainy season for domestic, agricultural, industrial and environmental use (Kun et al., 2004; Mati et al., 2005). Intercepting and collecting rainwater where it falls is a practice that extends back to pre-biblical times (Pereira et al., 2002). It was used 4,000 years ago in Palestine, Greece and South Asia over the last 8,000 years (Pandey et al., 2003). The ancient Romans use this

method in their residences where cisterns and paved courtyards captured rain to supplement the city's supply from aqueducts. The method had been extensively used in India to directly recharge groundwater at rates exceeding natural recharge conditions (Mahnot et al., 2003).

The advantages of the technique is its relatively low costs compared to other sources of water supply; it is modest; and that locally individual or community programmes can develop and manage the required facilities such as the collection devices, basins, storage tanks, surface or subsurface recharge structures or wells.

Larger rain harvesting schemes which involve intercepting runoff using low-height berms or spreading dikes to increase water infiltration into the soil can also be introduced especially at the upstream catchments where deforestation has decreased water availability (UNEP, 2005).

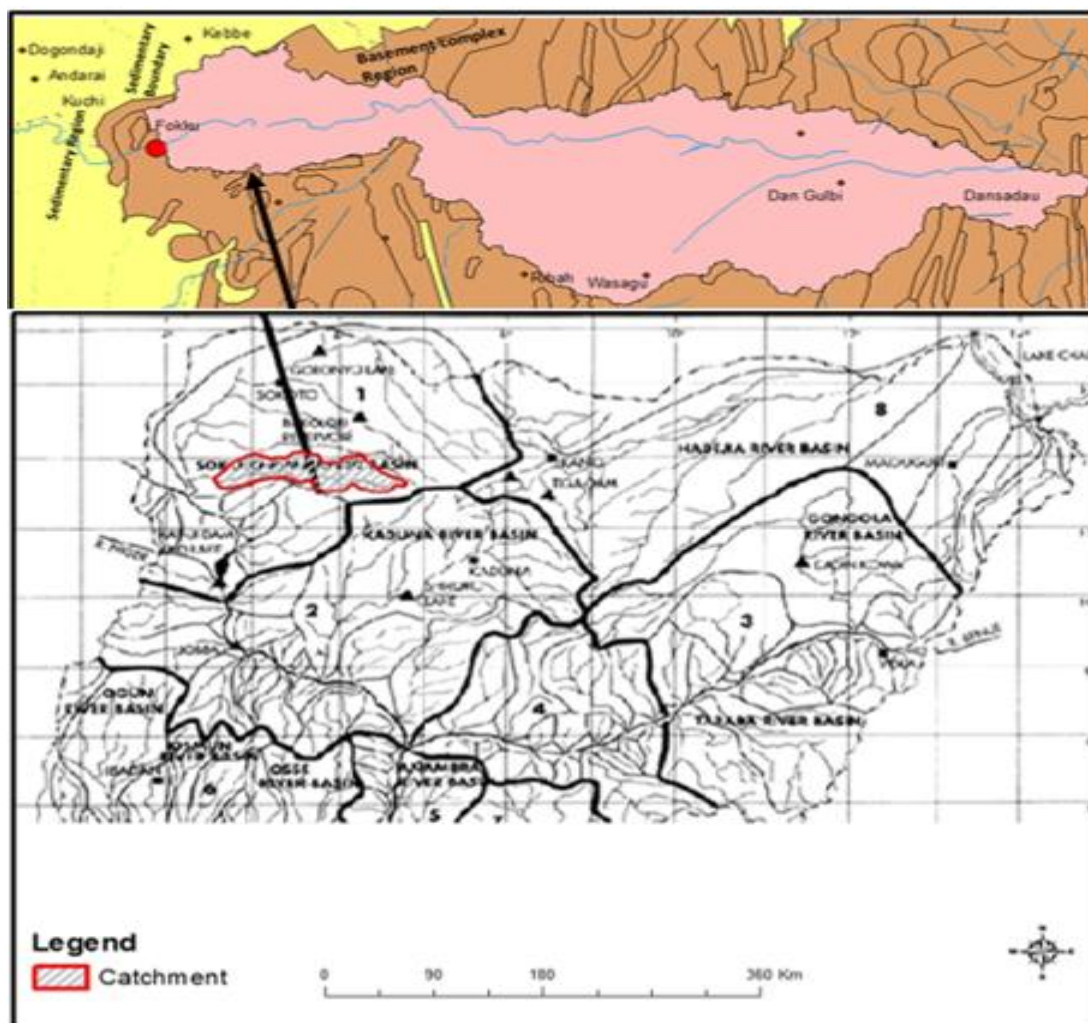
On a larger scale, there are water diversion programmes recently being adopted around the world (e.g. in China, India, Oman, Pakistan, Hungary, Germany, US etc.) in form of artificial storage and recovery (ASR) or managed aquifer recharge (MAR). This involved diverting surface water into nearby spreading basins, ditches, recharge pits or injection wells for recharge purposes into different types of aquifers. These techniques are used to regulate the natural variability in flow, reduce evaporation losses and improve water quality. The practice is more common in arid and semi-arid areas around the Middle East and Mediterranean regions. Runoff in 'Wadis' (dry riverbeds that only contain water during rainfall) is collected behind earthen berms instead of being allowed to run into the sea or evaporate. The water infiltrates into the underlying material (alluvium sand or gravel) and retained for longer period without being subjected to excessive evaporative losses that could have occurred from surface storage. In wetter areas, diversions into alluvium are used for filtration purposes to reduce the cost of treatment needed for water supplies.

### **The study area**

The study area is part of the basement complex area of the Sokoto basin located in the north-western part of Nigeria (**Error! Reference source not found.**) between the latitudes 11° 30" and 12° 00" N and longitudes 4° and 7° E. The region forms the major river basin of the riverine lowlands of the Rima valley. The area forms the catchment of the river Ka (also known as *Gulbin Ka*) at the southern end of the basement complex (**Error! Reference source not found.**). The river originates from the basement highlands around Dansadau in Zamfara State, it runs some 250 kilometers west into Kebbi State before joining the Sokoto

River and shortly afterwards, join the Niger River. The general elevation ranges between 190 m above sea level in the lowland *fadama* floodplains which range between 0.3 – 2 km in width along the river and its tributaries to 450 m above sea at the upper lands around Gusau and Dansadau. The catchment area above Fokku gauge was given as 15000 km<sup>2</sup> (Anderson and Ogilbee, 1973, JICA, 1990).

**Climate:** The climate within the Sokoto Basin is tropical continental dominated by two opposing air masses; the tropical maritime and tropical continental air masses. The position of their convergence is called the inter tropical discontinuity (ITD) and largely determines the onset and cessation of rainfall at a particular time of the year (Bello, 1997). The tropical maritime air mass is moist and blows from the Atlantic, while the tropical continental air mass is dry and blows from the Sahara Desert. The onset of rainfall in the region is usually from April, but properly commences by June to September, while the dry season takes over from October to March. The average annual rainfall ranges from 500 mm around the northern boundary with Niger Republic to 1200 mm towards the southern edge of the basin.



**Figure 1: River Ka catchment**

The highest temperatures occur towards the end of the dry season from March to April. The daily maximum and minimum temperatures similar to the precipitation vary from the northern part to the southern part of the basin (Ekpoh and Nsa, 2011). Temperatures range between a daily minimum temperature of 9 °C in the cold season (from early December to early February) to a daily maximum temperature of 45 °C from March to end of May. The low temperatures are associated with the Harmattan, a northeasterly dry and dusty West African trade wind which blows from the Sahara into the Gulf of Guinea from November to February.

**Geology:** The geology of the Sokoto basin has been described by Kogbe (1989), Anderson and Ogilbee (1973), and Offodile (2002), mostly focussing on the sedimentary part and giving a brief description of the basement complex part. Literature exists however, on the basement complex rocks elsewhere in Nigeria. Basement rocks dominate about 50 % of Nigeria's surface area while Cretaceous and Cenozoic sediments cover the other 50% (Adelana, 2003). According to Eduvie (2006) Hazell et al (1988), and Anderson and Ogilbee (1973), the basement complex of Nigeria lies within the Pan-African terrain with four broad lithological units as follows:

- A polycyclic basement of migmatites and gneisses together with relics of ancient metasediments of schist, phyllite, and quartzite.
- Younger low to medium grade metasediments and metavolcanics, which form distinct NNE-SSW trend within the migmatite-gneiss complex.
- Syntectonic to late tectonic Older Granite suite which intruded both the migmatitegneiss and the metasediments.
- Unmetamorphosed alkaline, calc-alkaline volcanic and hypabbysal rocks, which overlie or intrude the basement and sedimentary rocks.

These rocks have been greatly affected by repeated geo-movements which resulted in the Cretaceous plate separation with consequent development of steeply dipping joints followed by weathering. The depth of the weathered zone sometimes extends down to 50 m and the surfaces are often covered by laterites and Aeolian sands.

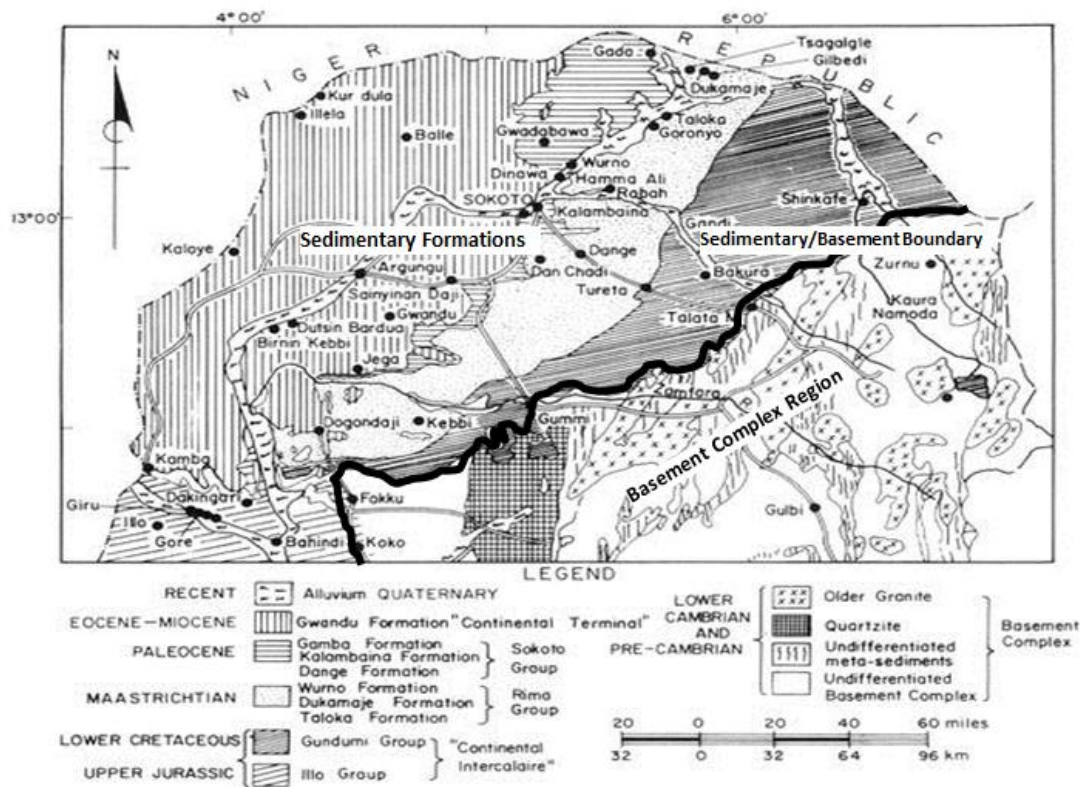


Figure 2: Geological map of the Sokoto Basin (Modified from Kogbe, 1981b)

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**Hydrogeology:** The first important exploratory study in Sokoto basin was done by Anderson and Ogilbee (1973), who give a general description of the hydrogeology during a project to explore the artesian aquifers in the sedimentary part of the basin. Since then, a number of studies focussing on the hydrogeological characteristics, Oteze, 1979, Offodile, 2002, Adelana et al., 2006, Ndubuisi, 2007) and groundwater development (SARDA / WADROP, 1988, JICA, 1990, Graham et al., 2006) of the basin have been carried out. Groundwater in the crystalline rocks is generally available in small quantities (Chandra et al., 2012, Robins et al., 2013) and occurs within fractures and weathered rocks (Holland, 2012, Wyns *et al.* 2004). The fractures are sometimes open up to a depth of 91 m, but even so, yields to boreholes are relatively low and cause high drawdowns (Adams, 2009). The availability of groundwater in the crystalline basement rocks depends on the development of thick soil overburden or the presence of fractures that are capable of holding water. The storage of groundwater is confined to fractures and fissures (JICA, 1990) in the weathered zone of igneous, metamorphic and volcanic rocks, the thickness of which range from <10-60 m in arid and humid rain forest (MacDonald et al., 1995, Chimphamba et al., 2009).

**Soils:** The available detailed soil maps for Sokoto basin only cover the fadama (UNDP-FAO, 1969) and sedimentary parts (Sambroek and Zonneveld, 1971) of the basin. Due to lack of available detailed soil mapping of the basement complex region of Sokoto basin, this section is informed by the Harmonised World Soil Database (HWSD, 2012) and Soil Atlas of Africa (2013). Broadly, the soils within the catchment area fall within four major groups in the HWSD and Soil Atlas of Africa classifications. The major soil classes identified are: Lithosols, Lixisols, Plinthosols and Gleysols.

**Landuse and vegetation:** The catchment falls within the Sudan Savannah zone with vegetation consisting of short grasses characterised by thorny species (Kaltho *et al.*, 1997) and a scatter of acacia species which are interspersed with herbaceous cover of annual grasses. A comparative analysis of vegetation density towards the northern part of Zamfara state (which includes the drier part of the study area) between 1962 and 1991 (ARCA, 1995) shows that increasing human pressures on land such as expansion of cropland, livestock overgrazing and cutting of trees for firewood has resulted in the loss of about 71 - 85 % of the natural vegetation (Hassan, 2000;).

### **Water supply situation**

When dry season is severe, most hand dug wells in the region dries up, leaving only deep hand dug wells to provide water at intermittent intervals for the rest of the year and at reduced yield. The only reliable source of water supply at this difficult time of the year is in the Fadama (wetland areas) where shallow hand dug wells provide water at low yields. The groundwater in the Fadama locations relatively easy to exploit and suitable for small scale development for domestic, livestock and irrigation, provided the rural population is small. However, the water in the fadama is being competed for between people and their livestock and as such, in some areas cannot be able to meet required demand. The water in the Fadama areas is also used for irrigation agriculture, with heavy manuring / application of chemical fertilizers to grow vegetables and other dry season cash crops. The quality of the water is therefore highly compromised and may not be potable. Recent studies also explained that possible global increases in temperature and changes in precipitation patterns over the years have greatly affected the quantity and quality of water resources.

### **Sources of Water**

The ultimate source of water on the earth's surface is precipitation, usually water resources of a given area depends on the amount of rainfall received over that area. In Sokoto state, the rates of water loss due to evapotranspiration are enormous because of the longer hours of bright sunshine and higher mean air temperatures in the state. During the dry season, the rainfall is always less than the water need and plants have to draw upon the soil moisture reserve, thus, creating a soil moisture deficit.

The surface water sources of the region mainly the river Rima and its tributaries; the Sokoto, Zamfara and Ka. The tributaries rise in the Basement Complex area of the east and southeast and flow radially towards the west. The flow of the Rima and its tributaries is seasonal at the upper catchments (Basement complex areas) and perennial at the lower catchment (lower part of the sedimentary areas) before meeting the river Niger. Other surface water sources are the lakes such as that of Kware, Kalmalo, and Bodinga, and storage dams at Goronyo, Lugu and Shagari.

The region is blessed with abundant groundwater resource that plays an important role in sustaining the flow of perennial rivers at lower catchment in the sedimentary areas. Groundwater water supply in the state can be divided into two hydrogeological provinces: Tertiary sedimentary area in the northwest, and cretaceous sedimentary area in the northeast



and southwest. In the tertiary area, the Gwandu and the Sokoto group formations (Dange and Kalambaina limestone) store a large quantity of water existing in the form of artesian wells that gives low-moderate yields. In the cretaceous area, the Gundumi/Illo and the Rima group formations (Wurno and Taloka formations) store large amount of water under water table and artesian condition that gives high-moderate yields.

### **Materials and methods**

The methodology employed for this research starts with the desk study (i.e. literature review and study area identification) and simulation set up. Daily rainfall and daily maximum and minimum temperature records of Gusau meteorological station was obtained for 5 year period (2006 – 2010). The station is located in the basement complex area of the Sokoto basin.

The overall study area (River Ka catchment) was estimated using the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) of Nigeria with 90 m resolution. Geological map including GIS layers is obtained from Nigerian Geological Survey Agency (NGSA), while the Harmonised World Soil Database (HWSD) was used to obtain the soil map, soil types and other soil hydrological characteristics for the study area. Topographic maps of Nigeria in addition to the geology and soil maps were used to identify the different landscape features and soil types at different locations within the catchment.

Based on the understanding of the complex geology of the basement complex areas in the study area, the hydrological processes of the basement complex region are considered to be spatially non-uniform. Individual landscapes respond differently from one another depending on the vegetation, soil types, topography, land use and other surface landscape features. The study area was therefore divided into landscape units to be subdivided into smaller areas or sub-units based on the heterogeneity which determines their hydrological responses.

In this research, six major landscapes, some of which are further sub-divided, are identified within the catchment. The landscapes are:

- Built-up areas landscape
- Cultivated landscape
- Bare surface landscapes
- Bare rock landscape
- Forest landscape
- Fadama landscape

After the landscape classification, simulations were run using the required parameters to represent the different variables identified on each landscape. For each of the major landscapes and sub-units, inputs were used to characterize their soil, regolith and landuse based on the features identified.

## Results and Discussion

The simulations have been run for 5 years (2006-2010), representing the results of wet and dry years to see the variations of landscapes hydrological behaviour under wet and dry conditions. The simple water balance assumption for this paper consists of a catchment with precipitation as the only input and runoff, evaporation/evapotranspiration, groundwater outflow and abstraction (integrated in the model simulation) as the outputs. This can be expressed using the following equation in the context of climate-landscape influences as:

$$\Delta S = P - E - R_o - G W_o \dots\dots\dots\text{eqn. 1}$$

Where  $\Delta S$  = change in storage,  $P$  = precipitation,  $E$  = evaporation/evapotranspiration,  $R_o$  = runoff, and  $G W_o$  = groundwater outflow

Table 1 represents the results of the water balance for five consecutive rainfall years

**Table 1: Landscape units water balance for five years**

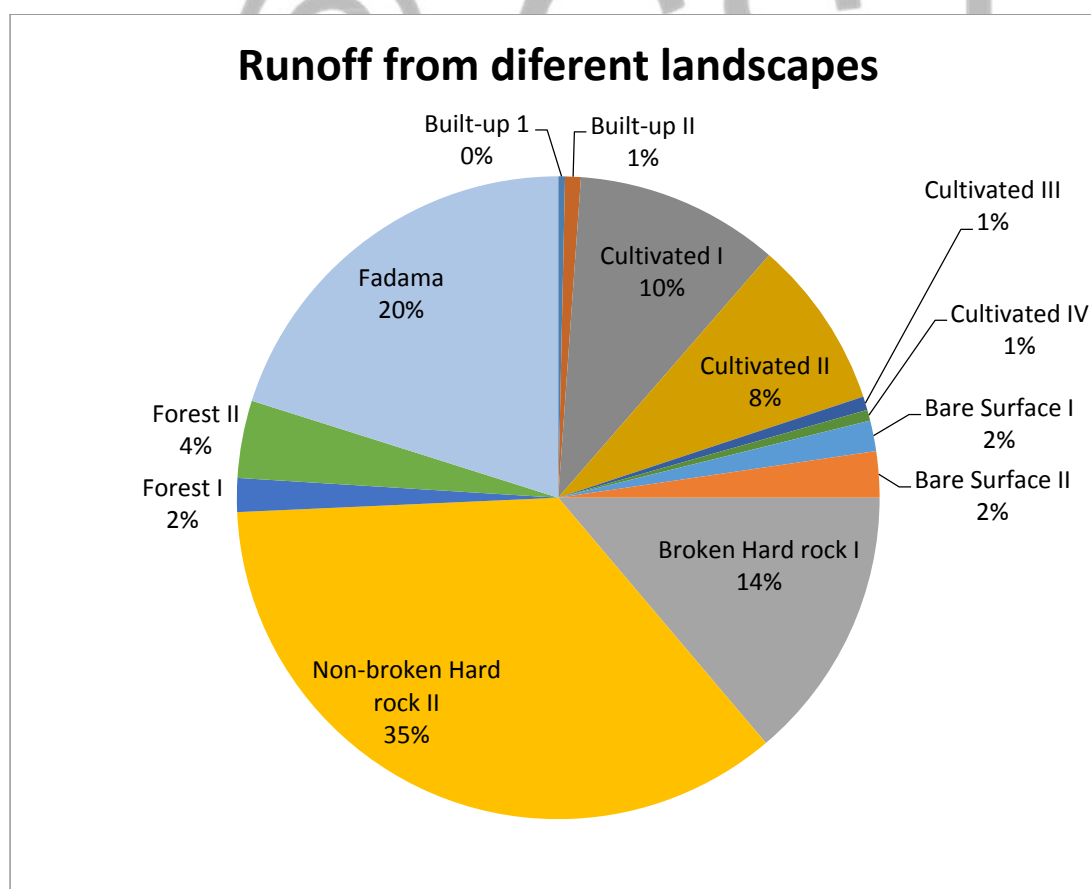
No	Conceptual Landscape	Total for Years (2006 – 2010)				
		Rain (mm)	Runoff (mm)	AET (mm)	Groundwater discharge / Outflow ( mm)	Change in Storage (mm)
1	Residential I	4918	1096	3699	87	36
2	Residential II	4918	1095	3705	110	8
3	Bare Surface I	4918	2491	2467	0	-40
4	Bare Surface II	4918	2501	2685	0	-268
5	Forest I	4918	131	4775	0	12
6	Forest II	4918	162	4719	0	37
7	Bare Rock I	4918	894	1304	2540	180
8	Bare Rock II	4918	3443	1304	0	171
9	Cultivated I	4918	664	3628	449	177
10	Cultivated II	6296	1102	4112	957	125
11	Cultivated III	4918	664	3597	480	177
12	Cultivated IV	6296	1065	4097	1006	128
13	Fadama	9639	1953	6255	1427	4

The summed contributions from the individual landscapes to the total water balance of the catchment over the 5 year period are recorded in **Table 1**, showing the total output of runoff, AET and groundwater outflow. The total catchment values are calculated by summing the area weighted contributions of individual landscapes as presented in **Error! Reference source not found**.

### Runoff contributions from different landscapes to the catchment-scale water balance

The results of total runoff contributed by each landscape for 5 years are given in **Table 1**. The depth of runoff from cultivated lands II and IV to the fadama and river is influenced by the run-on from the non-broken hard rocks added to the actual rainfall; also, the runoff from the fadama to the river is influenced by the run-on from all the five landscapes added to the actual rainfall.

Figure 3 shows the area weighted runoff totals recorded in **Table 1**, which are expressed as a depth over the entire catchment (rather than over the landscape unit).



**Figure 3: Percentage 5 year runoff contribution from individual landscape unit**

In Figure 3, the non-broken rocks has the largest runoff contribution equalling about 35 % of the total runoff generated. This is not unexpected in view of the fact that the non-broken hard rocks occupy about 15 % of the total land area. In contrast, the broken hard rocks contribute only about 14 % of the total runoff in the 5 year water balance despite much runoff generated from this landscape due to lack of infiltration.

The fadama has the second highest individual landscape contribution of runoff in the water balance having about 20 % of the total runoff. The fadama receives large amount of run-on from other landscapes, some with three times bigger land area. The fadama area is smaller than some of the contributing landscapes in addition to the fact that it doesn't contribute flow to any landscape; this results in high runoff generated from the fadama.

Despite the large total runoff from the two sealed surface landscapes (**Error! Reference source not found.**), their relatively small size (5 % of total land area) compared to other landscapes shows that their weighted runoff contributions to the overall catchment water balance is small (2 % each) compared to for example, the four cultivated lands with total land area of 30 %, which together, contributes about 20 % runoff (**Error! Reference source not found.**) in terms of per unit area contribution.

The effect of variations in soil depth of different landscapes can also be seen in the results of cultivated lands I to IV in **Error! Reference source not found.**. Although the total per unit area runoff from cultivated II & IV is higher than that of cultivated I & III, the area weighted runoff however is lower for Cultivated I and III due to their larger areas than Cultivated II & IV, despite the latter having additional run-on from non-broken hard rock.

The total runoff contributions from residential landscapes to the river are very small (**Error! Reference source not found.**), equalling only about 1 % of total runoff. It was observed during the fieldwork that most towns within the catchment are located close to the fadama because it serves as their source of water supply for irrigation and domestic use especially in the dry season.

Even though, the total land area of forest landscapes is twice the size of built-up landscape, the contributions of runoff from the two forests to the river are also small equalling about 6 % of the total runoff generated (**Error! Reference source not found.**). The forest surface allows more water infiltration and consequently higher soil water storage which is later intercepted and utilized by plant roots for evapotranspiration.

## **Conclusion**

This paper assesses the rainwater harvest potential of basement complex areas of Sokoto basin due to the fact that the weathered basement rocks are known to provide avenues through which water can be developed for community water supply. What is needed is a unified rational approach to water resources planning and development that takes cognizance of actual hydrological behaviours of different landscape units.

The paper identifies the exposed non-broken rocks, fadama and bare surface landscapes as having the high potential for excess runoff generation.

To ensure a sustainable water supply throughout the year for the local people, the paper stresses the need to apply methods of water conservation during excess for future use in the dry season. This involves taking advantage of the high levels of runoff not captured by natural recharge during rainy season for augmentation of groundwater resources through artificial recharge of aquifers in the deep weathered zones; or capturing and storing surface runoff by building small earth dams.

Artificial recharge is a method being used extensively in areas with similar hydrological condition around the world e.g. the development of sand dams in Kenya, Ethiopia, Namibia, Burkina Faso and India. It provides the cheapest form of new safe water supply for towns and small communities

This research is suggesting that small earth dams should be built to capture excess runoff from the sealed surfaces and non-broken hard rocks for use during the dry season. This will help not only in preventing the occurrence of flash floods but also alleviate the water shortage problems faced by the local people in the dry season.

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