Assessing the Potential and Identifying Suitable Sites for Rainwater Harvesting in Abuja, Nigeria

Ohiambe Eseoghene, Patrick G Home, Coker Wale, Joseph Sang

Abstract: ***Water scarcity is vastly becoming a serious Environmental problem in the world and in Nigeria, it is increasingly severe and very frequent. In Abuja, water scarcity is one of the major environmental problems. Nigeria is most likely one of the 25 African countries that will experience water scarcity or stress by 2025 as predicted by FAO. The problem of water scarcity in Abuja is unique because Abuja was not regarded as an ASAL region some years in the past, but its population has increased immensely within a short period. The rate of water consumption, urbanization and industrialization has exceeded the rate at which the available water supplies are replenished. This problem of water scarcity can be mitigated with detailed study of the area and the water resources available. Rainwater harvesting is one of the means with which water scarcity can be stopped or prevented. Though rainwater harvesting has been in existence for over 4000 years, its full potential to meet the water needs of millions of people has never been reached. Assessing and mapping Rainwater harvesting potential in Abuja would make it easier to estimate the total quantity of harvestable rainwater. In this study, the rainwater harvesting potential of Abuja was assessed using the Geographical Information System (GIS) integrated with Multi-criteria Decision Analysis (MCDA). Some of the factors considered during this analysis are annual rainfall, landuse/landcover, population, slope and soil type/runoff coefficient. The spatial multi-criteria analysis was used to classify and rank the suitable locations for rainwater harvesting while the analytical hierarchy process (AHP) method was used to compute the priority weight of each criterion. Using AHP, the percentages derived from the factors were Rainfall 28%, Slope 24.7%, Soil 19.9%, Land Use 17.1% and population 10.3%. At the end of the study, maps of different rainwater harvesting techniques were generated showing their individual potential in the study area. The result showed that Abuja has a very high potential for rainwater harvesting as the amount of rainwater harvestable can be used to eradicate water scarcity in the state.***

Keywords: Rainwater Harvesting Potential, Water Scarcity, Geographical information system, Analytical Hierarchy Process, Abuja

I. INTRODUCTION

Water and the scarcity of it has been found to be one of the major problems the world is facing, to be more precise, water was significantly noted by the Secretary General as one of the five "WEHAB" specific areas (Water, energy, Health, Agriculture and Biodiversity) in which specific results are both essential and achievable.

A common environmental problem in Nigeria is water scarcity which is said to occur when the available or tapped into water sources of an area is unable to meet the water demands.

Nigeria is facing water supply shortages in both urban and rural areas despite the abundant water resources available in various climatic zones. The rate of water consumption, urbanization and industrialization has exceeded the rate at which the available water supplies are replenished. This has led to water scarcity (Marcus King). Water scarcity is a very devastating environmental problem as it reduces the performance of people in addition to causing substantial impacts to the environment. Water scarcity in Nigeria is becoming an increasingly sever and frequent problem. That water is a necessity in achieving solution to all the other problems cannot be over emphasized (Maimbo et al., 2005). An important component towards meeting the African Water Vision is the need for managing rainwater resources and rainwater harvesting and storage has been recognized as one way of achieving that (Desta et al, 2005). Rainwater Harvesting (RWH) is an ancient practice that can be traced back 4000 thousand years and in many different countries of the world. New interests in rainwater harvesting centers around the use of the technology for domestic drinking water supply in urban and rural settings. Generally, rainwater harvesting can be described as any human practice that deliberately collects and conserves or stores rainwater to be used in the future for all purposes. It is the precise and deliberate collection of rainwater from any surface known as catchment area and storage of the same in physical structures or within the soils profile. Rainwater may be harvested from roof tops, ground surfaces and from ephemeral watercourses. It can serve as an affordable water source for household use, agriculture, environmental flows and prevention of flood damage. Rainwater harvesting provides natural soft water which can serve non-potable indoor usages.

Abuja is situated in the North Central zone, of the Geopolitical Zones of Nigeria. It is in the center of Nigeria just north of the confluence of the Niger River and Benue River. It is bordered by the states of Niger to the West and North, Kaduna to the Northea st, Nasarawa to the east and south, and Kogi to the southwest. Lying between coordinates: $8^0$50'N $7^0$10'E/ 8.833^{0}N 7.167^{0}E. It has a total land mass of 7,315km^2 (2,824 sq mi). Abuja lies at 1,180 feet (360m) above sea level and has a cooler climate and less humidity than is found in Lagos. Abuja experiences three weather conditions annually, a warm humid rainy season, a short period of harmattan and extremely hot dry season.

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Rainfall in Abuja reflects its location on the windward side of the Jos Pleateau and the zone of rising air masses. The annual total rainfall is in the region of 1100mm to 1600mm, its population has grown from 107,069 in 1991 to 3,564,100 in 2016. Abuja is made up of six local councils, Abuja municipal, Abaji, Bwari, Gwagwalada, Kuje and Kwali (Mbua, 2013). Like every state, Abuja has its own rural areas where farming of all sort is done.

1.1 Scope of Study

Abuja is the first planned city in Nigeria and has brought a change in the economy with the creation of jobs and educational institutions. It however was not prepared for the kind of growth in population that it has experienced since its inception, this growth has led to its very quick expansion and over exploitation of natural resources. The massive growth of the population has had impacts on tapped water resources of the area in the form of a rapidly growing need for water, the expansion of residential settlements which is a strain on the existing water distribution systems. Water scarcity is a major environmental problem affecting the lives of thousands in Abuja, especially those who cannot afford the cost of water from the water distribution service due to the high standard of living in the city or those too far from the city where the distribution systems are yet to cover. This study is focused on reducing the strain on distribution agencies while making sure water is provided to every individual with the easiest RWH technologies possible thereby eradicating this environmental problem.

II. DATA SOURCE

The data utilized for this study were mainly secondary, apart from Secondary Data sourced from journals, published books, government reports, unpublished reports, newsletters, the study also sourced secondary data from the following sources:

i. Rainfall Data

Rainfall data was used for this research, to assess the rainfall variability over the study area for the period 1991-2016, with more emphasis on 2016. The daily data were collected from the ground-observed station of the Nigeria Meteorological Agency (NIMET) stationed at the Abuja international airport, while the satellite-observed data were obtained from the Tropical Rainfall Measuring Mission (TRMM) and the Climate Hazard Group Infrared Precipitation (CHIRPS) for comparison purpose.

ii. SRTM 30m DEM

The shuttle Radar Topography Mission (SRTM) 30m DEM of the study area was obtained from United State Geological Survey/National Aeronautics and Space Administration/Shuttle Radar Topography Mission (USGS/NASA SRTM) via the USGS Earth explorer website www.usgsearthexplorer.org. the data were then projected to the Universal Transverse Mercator system of coordinate.

iii. Landsat Data

In this study the Landsat imagery was used to create the Land use/Land cover map for the study area. The spatial resolution of Landsat imagery is adequate for vegetative analysis particularly, to identify all kinds of vegetative cover. Three scenes of Landsat images from the Landsat5, Landsat7 and Landsat8 were acquired for the years 1987, 2001 and 2016 respectively. These were all obtained online from the data archive of Global Land Cover Facility (GLCF) under the United States Geological Survey (USGS). The images acquired for the use of this study are all cloud free; these were modified and projected using Universal Transverse Mercator UTM 32N. WGS 1984 Coordinate system of earth model by GLCF. Table 1 shows a list of Landsat images acquired and their dates.

Landsat images are generally known to be efficient, simple and first choice when it comes to mapping on GIS, three Landsat Imageries were downloaded from USGS and one from Google Earth.

Table 1: Summary of Landsat Images Acquired for the Research

Sensor	Reference System/ Path/Row	Spatial Resolution	Acquisition Date	Sources
Landsat 5 TM	WRS/189/054	30m	28-01-1987	http://earthexplorer.usgs.gov/
Landsat7ETM+	WRS/189/054	28.5m	18-12-2001	http://earthexplorer.usgs.gov/
Landsat 8 OLI and TIRS	WRS/189/054	30m	22-12-2016	http://earthexplorer.usgs.gov/
Google Earth Satellite Maps	Nil	2m	2016	http://earth.google.com

iv. Study Population

The estimated population for Abuja which is the study area is about 3649100 according to the 2015 population census.

v. Soil Data

The soil data for Abuja was extracted from Harmonised World Soil Database. There are five major soil types in the study area which are Loam, sand, loamy sand, sandy clay and Sandy loam as illustrated in Table 2 below. The area classified as no data are areas covered by water bodies. The loam was ranked highest because the content of clay in this soil type is 21% while the sandy loam soil type in the area has 14% of clay content, therefore, it has a lower ranking. It is clay content in soil that does not allow infiltration of water through the soil thereby causing surface runoff which is the harvestable rainwater.

The soil type with more percentage of sand allows infiltration therefore has less runoff.

Table 2: Relative Runoff Coefficient for Different Soil Types, Slope and Land Use

Land use	Slope (%)	Sand	Loamy sand	Sandy loam	Loam	Silt loam	Silt	Sandy clay loam	Clay loam	Silty clay loam	Sandy clay	Silty Clay	Clay
Forest	<0,5	0.03	0.07	0.10	0.13	0.17	0.20	0.23	0.27	0.30	0.33	0.37	0.40
	0,5–5	0.07	0.11	0.14	0.17	0.21	0.24	0.27	0.31	0.34	0.37	0.41	0.44
	5–10	0.13	0.17	0.20	0.23	0.27	0.30	0.33	0.37	0.40	0.43	0.47	0.50
	>10	0.25	0.29	0.32	0.35	0.39	0.42	0.45	0.49	0.52	0.55	0.59	0.62
Grass	<0,5	0.13	0.17	0.20	0.23	0.27	0.30	0.33	0.37	0.40	0.43	0.47	0.50
	0,5–5	0.17	0.21	0.24	0.27	0.31	0.34	0.37	0.41	0.44	0.47	0.51	0.54
	5–10	0.23	0.27	0.30	0.33	0.37	0.40	0.43	0.47	0.50	0.53	0.57	0.60
	>10	0.35	0.39	0.42	0.45	0.49	0.52	0.55	0.59	0.62	0.65	0.69	0.72
Crop	<0,5	0.23	0.27	0.30	0.33	0.37	0.40	0.43	0.47	0.50	0.53	0.57	0.60
	0,5–5	0.27	0.31	0.34	0.37	0.41	0.44	0.47	0.51	0.54	0.57	0.61	0.64
	5–10	0.33	0.37	0.40	0.43	0.47	0.50	0.53	0.57	0.60	0.63	0.67	0.70
	>10	0.45	0.49	0.52	0.55	0.59	0.62	0.65	0.69	0.72	0.75	0.79	0.82
Bare soil	<0,5	0.33	0.37	0.40	0.43	0.47	0.50	0.53	0.57	0.60	0.63	0.67	0.70
	0,5–5	0.37	0.41	0.44	0.47	0.51	0.54	0.57	0.61	0.64	0.67	0.71	0.74
	5–10	0.43	0.47	0.50	0.53	0.57	0.60	0.63	0.67	0.70	0.73	0.77	0.80
	>10	0.55	0.59	0.62	0.65	0.69	0.72	0.75	0.79	0.82	0.85	0.89	0.92
IMP		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

From the table above, the composite runoff coefficient was estimated using the formular

$$C = \frac{C_1A_1 + C_2A_2 + \cdots C_nA_n}{A_{total}}$$

Where C is the composite runoff coefficient

C_1 *to* C_n are the corresponding runoff coefficients for different landuses, soil type or slope

A_1 *to* A_n are corresponding areas of different landuses, soil types or slopes

A_{total} is the sum of the areas considered from A_1 to An

2.1. Summary of Data Sources and Description

All data collected, their sources, description and scale/resolutions are summarized in the Table 3;

Table 3: Data Sources and Description

SN	DATA	Acquisition Date(s)	DATA FORMAT	Scale/Resolution	DATA SOURCES	DESCRIPTION
1	GPS coordinates	2016	Numerical		Field Survey	The coordinates was used to locate the positions of landmarks
2	Topographic map	(1967)	Digital	1:50,000	OSGOF	The streams, rivers and lake in the Study Area were digitized from it.
3	Landsat	(1987-2016)	Digital	30m	www.glovis.org	Image Classification; LULC analysis
7	ASTER (GTMv2)	2011	Digital	30m	www.usgs.org	Digital Terrain Analysis
8	SPOT	2005	Digital	5m	NASRDA	Change detection Analysis
9	Soil Texture Map	2008	Analogue	1:250,000	NGDI/HWSD	Soil texture & classification
10	Shapefile	1994	Digital Map		NASRDA	To delineate the extent of the study area
11	SRTM (DEM)	2014	Digital Map	30m	Digital web	The Digital Elevation was derived from it.

12	CHIRPS		Numerical		www.badc.ac.uk	Rainfall & Runoff Analysis
13	Population	1991-2016	Numerical		NBS	Population density, dynamics & Projection

III. METHODS

i. Image Pre-Processing

Image pre-processing consists of those operations that prepared the data set for subsequent analysis. One of the analysis deals with compensating for systematic errors, which are errors that come as a result of the effects of numerous atmospheric and radiometric factors, such as sensor spectral properties, atmospheric scattering, and change in illumination. These parameters can cause difficulty in comparing more than one image of the same scene which are taken under different conditions (Schott *et al.* 1988). Removal of these effects from the digital data leads to the restoration of the images to their correct or original condition. Image restoration can be broken down into two; radiometric restoration and geometric restoration.

ii. Imagine Processing

The images were loaded into Erdas Imagine 2014 interface and a false colour composite was formed using bands 4, 3, 2 that is, the infrared, red and blue bands respectively. The supervised image classification of the images was carried out using the maximum Likelihood algorithm. This was based on the data obtained for the ―training areas in the ground truthing. The classification of the image provided the aerial extent of each land cover type which was used to assess the changes in land cover over the 30-year period (1987-2016).

iii. Analysis of Land Use Land Cover of the Study Area

On a global and even local scale, the various factors of rainwater harvesting (environmental and socio-economic conditions) vary in both space and time. This study therefore tried to represent all by Presentation of GIS maps that showed the distribution and aerial extents of land use systems and classes, to show the great advantage of the satellite remote sensing and GIS technologies over the conventional land use survey techniques. Each land use feature was identified and mapped using supervised classification method as described in Table 4.

Table 4: Description of Land-Use/Land-Cover

	Land-Use / Land-Cover	Descriptions based on Author
1	Built-Up	Residential, industrial and commercial units, road and railway networks and other associated lands
2	Vegetation	Natural and manmade forests, natural grasslands, woodland, shrubs, sparsely planted trees
3	Bare Surface	All vacant spaces, sands
4	Water Body	Streams, rivers, dams and ponds
5	Rock	Rocky Areas

iv. Digital Elevation Model

The DEM image data were extracted and imported into the ArcGIS 10.3 where the elevation values were converted to points. The points were treated as spot heights, which were then interpolated. Deterministic interpolation techniques were used to create surfaces from the measured points, based on the extent of similarity (Inverse Distance Weighted). The deterministic interpolation technique used was the local interpolator which calculated predictions from the measured points within neighborhoods', which have similar spatial areas within the larger study area.

The slopes help to identify the maximum rate of change in surface value over a specific distance and they are expressed in degrees or percentage. In actualizing the slope map from the DEM required for the final thesis analysis, the spatial analyst tool in ArcMap 9.3 was used in the slope map calculation. Calculating slope is one function of many in spatial analyst tool and this function was used to derive the slope map from the DEM.

v. Reclassification of Slope Map

The slope map was reclassified into a relative friction cost of 10 classes in order to have a common value. The slope map classification was achieved using symbology under the diagram properties in the model. The reclassification of the slope map helped in differentiating the different slopes between the different slope classes during criteria evaluation and as such provided a proximity surface on the best area rainwater harvesting technologies.

➢ *Lists of Methods Used in the Research Study*

There were five major methods of data analysis adopted in this study.

1. Land Use Land Cover classification
2. Proximity and Overlay Operations
3. Maximum Likelihood method of supervised image classification.
4. Interpolated Distance Weighted method for Rainfall Analysis
5. Multi-criteria Evaluation (MCE) using the Analytical Hierarchical Process (AHP)

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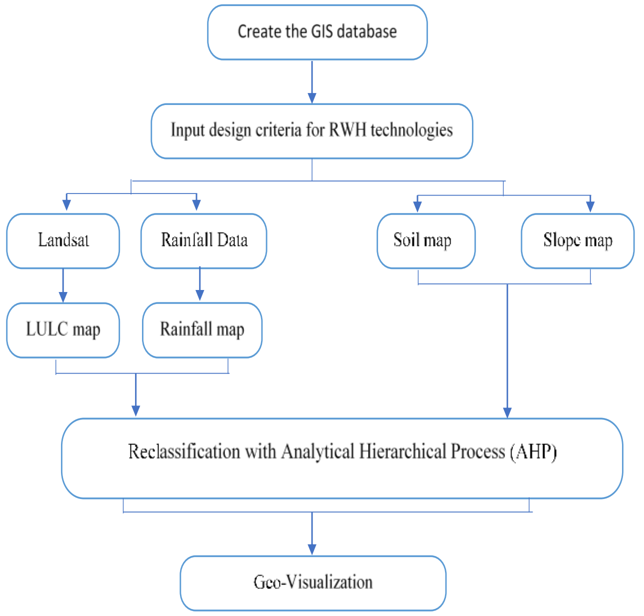

Figure 1. Methodology Flow Chart

IV. RESULTS AND DISCUSSIONS

a. The most important factor in rainwater harvesting is rainfall. The quantity of rain expected in Abuja will determine its potential for rainwater harvesting. During the rains, the ground becomes saturated and the soil can no longer store water leading to increased surface runoff. At this point all other rainwater becomes a waste or the cause of some other environmental problems like flooding, erosion, gullies if not carefully collected and stored for future use. The ground and remotely sensed satellite derived precipitation data for Abuja were acquired and the average annual precipitation was calculated. The average rainfall for Abuja for this study after considering 16 stations as shown in Figure 2 and Table 6 below ranged from 1171.4mm to 1465.9mm per annum.

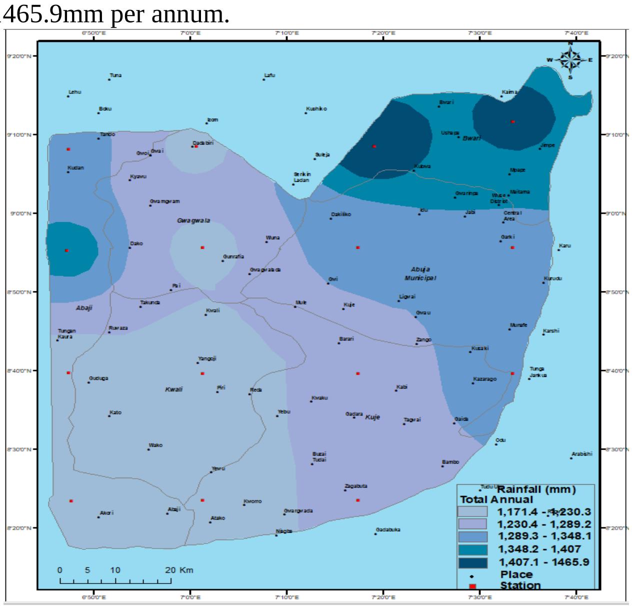

Figure 2: Rainfall Map

The results of the rainfall map shows that Abuja actually experiences high rainfall according to the classifications and ranking done by (Maimbo et al., 2005). Their criteria for all kinds of rainwater harvesting stated that any rainfall more than 1200mm is considered high and their classification was divided into just three categories. Low being the least ranging from 200mm-400mm, Medium ranging from 400mm-1200mm and High which is above 1200mm. It can therefore be concluded that Abuja experiences a high rainfall.

b. Slope Analysis

Slope map was generated from Digital Elevation Model (DEM) using the Shuttle Radar Topography Mission (SRTM) imagery. The slope distribution for the study area ranges from 0 – 71.86° as show in Figure 3. Areas with higher slope degree would allow water flow along the path while water would gather at areas with smaller slope degrees.

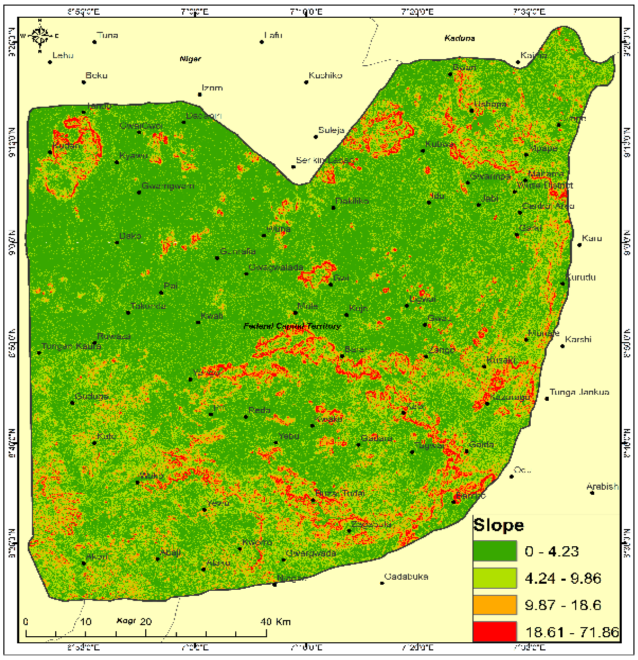

Figure 3: Slope Map

The slope maps were classified from 0 – 4.23, 4.24 – 9.86, 9.87 – 18.6 and 18.61 – 71.86 as shown in Figure 4 above, reason because this classification made it easier to understand the landuse landcover pattern as well as in the determination of sites for both in-situ and surface rainwater harvesting technologies in the study area and so it was adopted for his study.

c. Soil Type

The soil data for Abuja was extracted from Harmonised World Soil Database. There are five major soil types in the study area which are Loam, sand, loamy sand, sandy clay and Sandy loam as shown in Figure 4 below. The area classified as no data are areas covered by water bodies. The loam was ranked highest because the content of clay in this soil type is 21% while the sandy loam soil type in the area has 14% of clay content, Therefore, it has a lower ranking. It is clay content in soil that does not allow infiltration of water through the soil thereby causing surface runoff which is the harvestable rainwater.

The soil type with more percentage of sand allows infiltration therefore has less runoff.

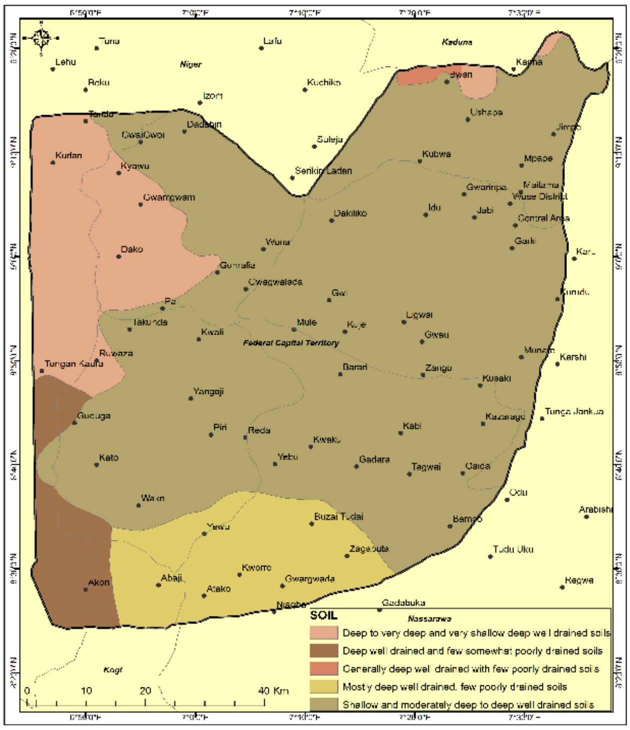

Figure 4: Soil Map

d. Land Use Analysis

The land use of Abuja was generated from Landsat 8 imagery for 2016 covering the area. The image was classified into nine land use types; Built up, Dense Vegetation, Sparse Vegetation, wetlands, cultivated lands, Forested areas, bare surfaces, Rocks Outcrops and Water Bodies as represented in Figure 5. The land use was then reclassified according to their level of importance for different rainwater harvesting technologies.

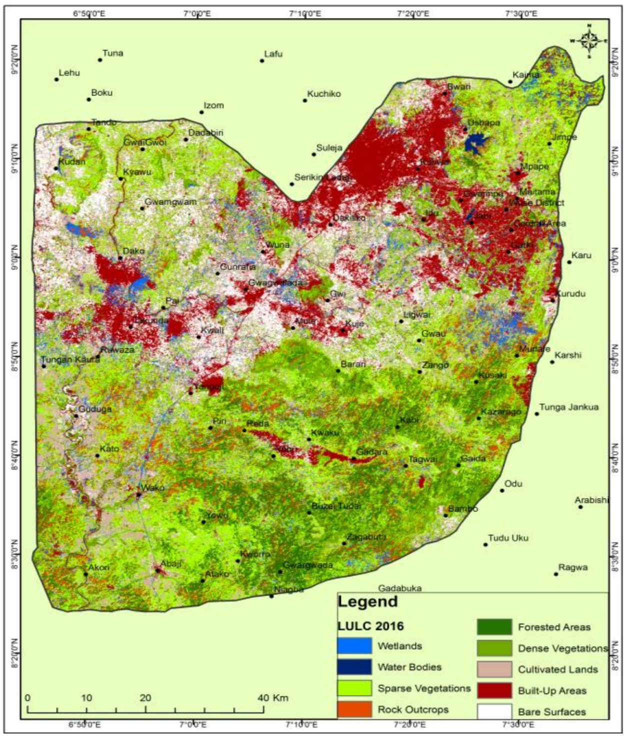

Figure 5: Landuse/landcover Map

e. Population Data

The last population census was carried out in 2015 and the percentage growth rate was estimated to be +13.91/year. With which the 2016 population of Abuja was estimated to be 3,564,100 using the same growth rate. Although this was for the whole state, the census is usually carried out with respect to local government (districts) areas before they are compiled. The population of each local government area was obtained from the records of the National Bureau of Statistics (NBS) and represented in Figure 6.

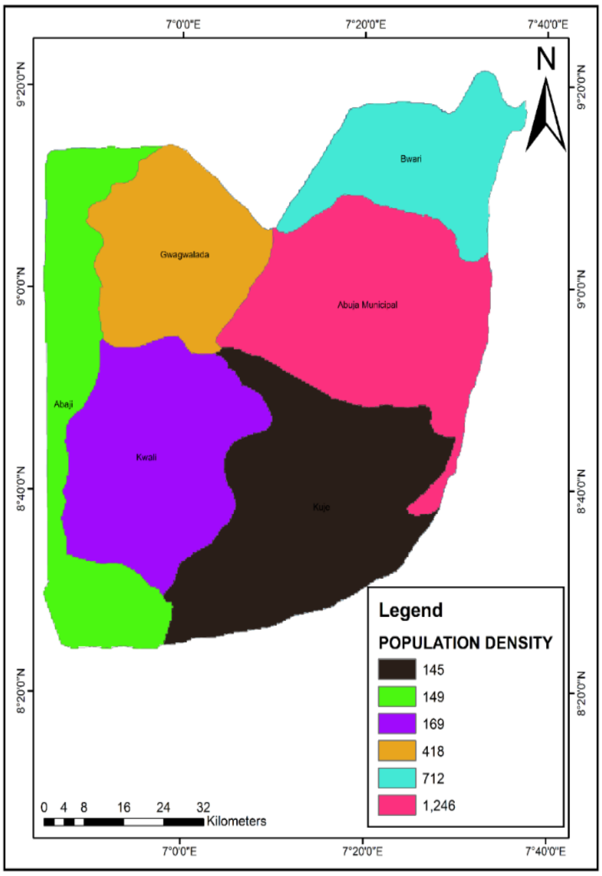

Figure 6: Population Map

f. Rooftop Rainwater Harvesting Potential

Rooftop RWH can only be possible in built-up areas since the presence of a roof is the requirement for the necessary catchments and most especially in scattered settlements where water pipe networks installations would not be economically viable. Maimbo et al. (2007), stated that areas receiving at least 200mm of annual rainfall are potential locations for rooftop RWH. Abuja receives an average of 1,171.4 – 1,465.9mm of rainfall annually. Thus, settlements in Abuja have the required rainfall capacity for rooftop RWH. The rooftop RWH uses two criteria which include rainfall and the landuse/landcover. The built-up area in the landuse/landcover was ranked highest considering the expected rainfall and the estimated runoff coefficient of 0.8. Table below shows the ranking of each criteria. Figure 7 shows the potentiality map for rooftop RWH.

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Table 5: Ranking Criteria for Rooftop RWH

Criteria	Values	Ranking
Rainfall	1,171.4 – 1,230.3 1,230.4 – 1,289.2 1,289.3 – 1,348.1 1,348.2 – 1,407 1,407.1 – 1,465.9	5 5 5 5 5
Land use/cover	Wetlands Water Bodies Sparse Vegetations Rock Outcrops Dense Vegetations Cultivated Lands Built-Up Areas Bare Surfaces	1 1 1 1 1 1 5 1
Population density	1 – 145 146 – 149 150 – 169 170 – 418 419 – 712 713 – 1,246 (average household size in Abuja consists of 4.5 persons) Requiring about 90 lit/day	5 5 5 5 5 5

The ranking of the landuse/landcover as show in table 8 above was done based on the consideration that for rooftop rainwater harvesting to be implemented, there must be a roof catchment. Therefore only built-up area was considered. The landuse/landcover map was reclassified into built-up area and others. The population ranking is all 5 since its assumed that every person lives under a roof, however small it maybe.

Though the built-up area from the landuse/landcover map seemed small as shown in figure 7, the population data was used to determine the rainwater harvesting potential by estimating an average roof size for the study area using googleearth and considering the average household size to be 4.5 persons/household, each district average roof area was estimated as shown in tables 9 and 10 below.

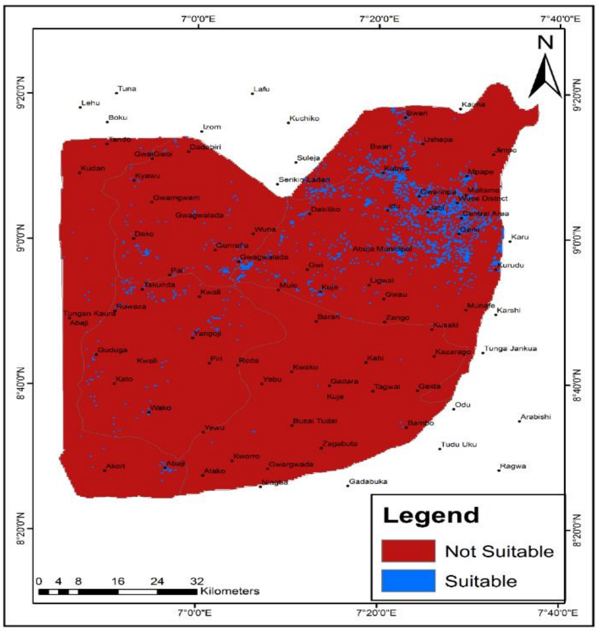

Figure 7: Rooftop Rainwater Harvesting Sites

Table 6: Ranking Criteria for Rooftop RWH based on Population

Criteria	Values	Ranking
Rainfall	1,171.4 – 1,230.3 1,230.4 – 1,289.2 1,289.3 – 1,348.1 1,348.2 – 1,407 1,407.1 – 1,465.9	5 5 5 5 5
Population density	1 – 145 146 – 149 150 – 169 170 – 418 419 – 712 713 – 1,246 Average household size in Abuja consists of 4.5 persons (NBS Annual abstract of Statistics) Average roof area per household is 180square meter (Google Earth estimation) Average quantity of water is 20lit/person/day	5 5 5 5 5 5

Table 7: Quantity of Rainwater Harvestable Based on Population

Districts	Household Size	2016 Population	No of Estimated households	Total roof area (Km^2)	RO coefficient	rainfall min (m)	rainfall max (m^3)	volume min (m^3)	volume max (m^3)
Abaji	4.5	148623	33027	5945	0.8	1.2	1.5	5707	7134
AMAC	4.5	1967383	437196	78695	0.8	1.2	1.5	75548	94434
Bwari	4.5	580948	129100	23238	0.8	1.2	1.5	22308	27886
Gwagwalada	4.5	402743	89499	16110	0.8	1.2	1.5	15465	19332
Kuje	4.5	245923	54650	9837	0.8	1.2	1.5	9443	11804
Kwali	4.5	218479	48551	8739	0.8	1.2	1.5	8390	10487
TOTAL								136861	171077

The ranking for the population of each district was still found to be high because they each have a population which implies they have roofs. However, from the calculation done in table 7 above and figure 8 below, different districts had different average roof sizes due to their individual population and therefore resulted to the classification in the figure 8 below. The districts with low rainwater harvesting potential which are Abaji, Kwali and Kuje were estimated to harvest less than 10,000m^3 and less than 12,000m^3 of water which is only about 10x10^{6}lit to 12x10^{6}lit of water.

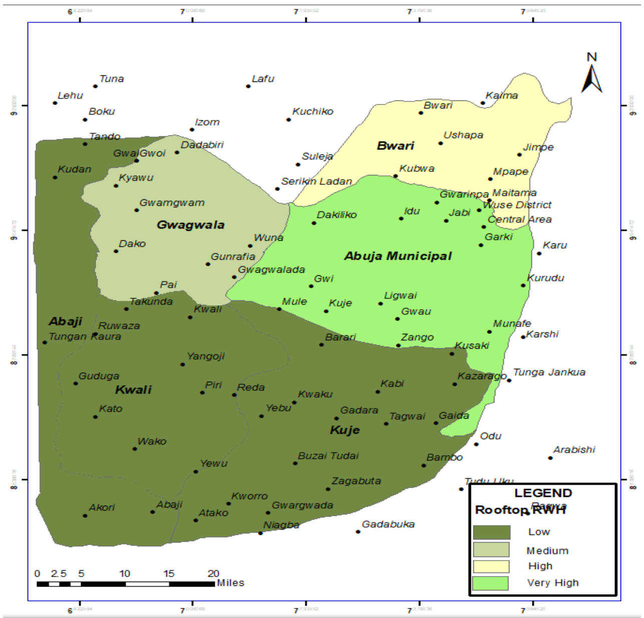

Figure 8: Rooftop RWH for Population

g. Surface Rainwater Harvesting System

Surface RWH refers to the collection of runoff from surfaces such as roads, pavements, hillsides, bear lands and water bodies into ponds, drainages and collection pans. Water tend to flow from steep slopes to flat areas. However, very steep slopes are not favourable for surface RWH. Fairly or moderately steep slopes are preferable as water gathers in these areas. The study area, Abuja has some areas with moderately steep slopes and a high amount of rainfall for surface runoff to be stored. Water could be stored in Wetlands, water bodies and open bare surfaces for irrigation and domestic purposes. Surface rainwater harvesting also requires soil types will help determine the the infiltration properties as well as the runoff coefficient. For surface RWH, the soil should be able to hold water above the surface not allowing infiltration into the soil profile. Impermeable surfaces like concrete pavements also support runoff storage for surface RWH. Table 8 shows the ranking for each criterion. Figure below shows the potentiality for surface RWH.

Table 8: Ranking Criteria for Surface RWH

Criteria	Values	Ranking
Rainfall	1,171.4 – 1,230.3 1,230.4 – 1,289.2 1,289.3 – 1,348.1 1,348.2 – 1,407 1,407.1 – 1,465.9	5 5 5 5 5
Land use/cover	Wetlands Water Bodies Sparse Vegetations Rock Outcrops Dense Vegetations Cultivated Lands Built-Up Areas Bare Surfaces	1 1 5 5 3 5 3 5
Soil	Deep to very deep and very shallow deep well drained soil	3
	Deep well drained and few somewhat poorly drained soil	5
	Generally deep well drained with few poorly drained soil	5
	Mostly deep well drained few poorly drained soil	3
	Shallow and Moderately deep to deep well drained soil	5
Slope	0 – 4.23 4.24 – 9.86 9.87 – 18.6 18.61 -71.86	3 3 5 5

The ranking of the landuse/landcover in table 9 above was done considering areas that are suitable for runoff harvesting. The wetlands and waterbodies don't allow for surface RWH except in rear cases of flood so they were ranked low. Built up area since it was previously strictly considered for rooftoprainwater harvesting, most of it was assumed to be going for that. But there is still places like the coumpounds, paved srfaces like roads etc. dense vegetation was also considered medium along side built-up areas. The others were considered highly suitable for surface RWH.

The ranking of both soil and slope were done considering the dept, texture and runoff coefficient of each soil type as well as slope percentages as classified. The resulting map in figure 9 below shows the result for surface RWH.

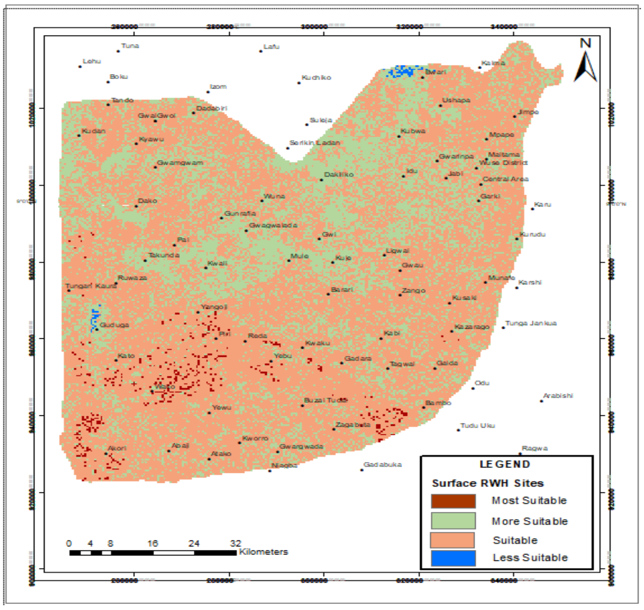

Figure 9: Surface RWH Sites

The suitability ranking in the map displayed in figure 9 above shows areas less suitable and most suitable for surface rainwater harvesting. This was done based on the landuse/landcover, slope, soil type and rainfall data as shown in table 11 above. The areas which were found to be most suitable are areas with sparse vegetations and rock outcrops steep slopes, shallow well drained soils and of cause a minimum rainfall of 1171.4mm. The more suitable areas included bare surfaces, built-up and some rock outcrops, having deep well drained soils, medium to steep slope and rainfall. The suitable includes areas of dense vegetation, forested lands, medium slopes, mostly deep poorly drained soils and rainfall. The less suitable included wetlands and waterbodies which educes its suitability for surface RWH.

h. In-situ Rainwater harvesting System

In-situ RWH refers to all the individual farm methods used to collect rainwater directly into the soil profile on farmlands for the sole purpose of plant/crop growth. In this case, rainwater is harvested to enhance soil moisture for crop production. The average rainfall in the study area meets the requirement for in-situ RWH Maimbo et al. 2007. Areas that need soil moisture replenishment are given priority, well-drained soils were also prioritised as they would allow water infiltrate into the soil and store within the soil profile. Figure 10 shows the potentiality for in-situ RWH. Table 5 shows the ranking of each criteria.

Table 9: Ranking criteria for In-Situ RWH

Criteria	Values	Ranking
Rainfall	1,171.4 – 1,230.3	5
	1,230.4 – 1,289.2	5
	1,289.3 – 1,348.1	5
	1,348.2 – 1,407	5
	1,407.1 – 1,465.9	5
Land use/cover	Wetlands	1
	Water Bodies	3
	Sparse Vegetations	5
	Rock Outcrops	5
	Dense Vegetations	3
	Cultivated Lands	5
	Built-Up Areas	1
	Bare Surfaces	5
Soil	Deep to very deep and very shallow deep well drained soil	3
	Deep well drained and few somewhat poorly drained soil	5
	Generally deep well drained with few poorly drained soil	5
	Mostly deep well drained few poorly drained soil	3
	Shallow and Moderately deep to deep well drained soil	5
Slope	0 – 4.23	3
	4.24 – 9.86	3
	9.87 – 18.6	5
	18.61 -71.86	5

The ranking of landuse/landcover was done considering areas best for harvesting rainwater solely for the purpose of crop production which included considering the distance from the land, quantity of water needed, the slopes to avoid erosion etc. therefore, cultivated lands, sparse vegetations, bare surfaces and rock outcrops were ranked highest, built-up areas and wetlands ranked low while the others were ranked medium.

The ranking of both soil and slope were also done considering the dept, texture and runoff coefficient of each soil type as well as slope percentages as classified.

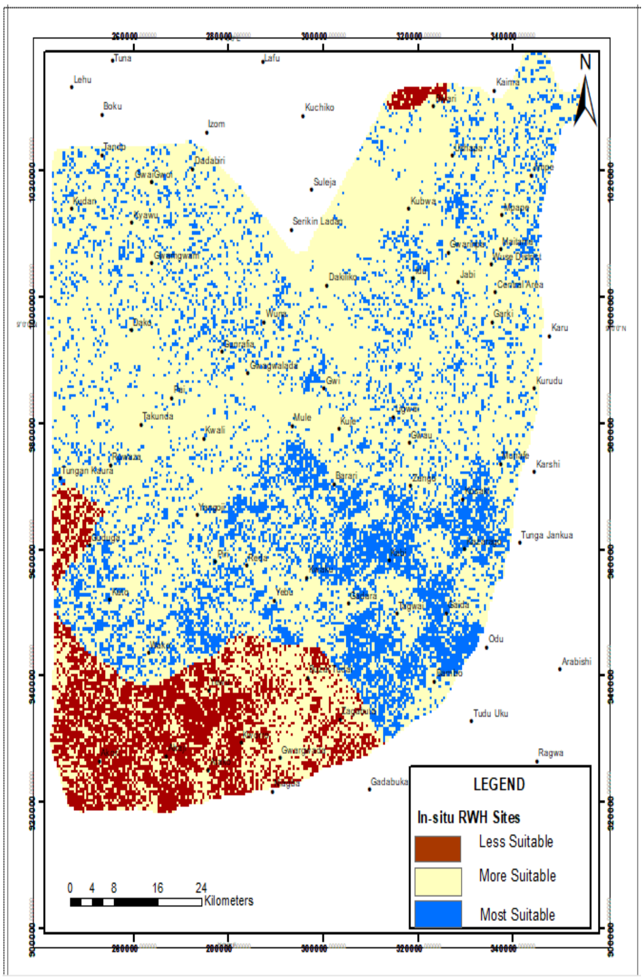

Figure 10: In-Situ RWH Sites

The suitability ranking as show in figure 10 above was done after the overlay of the considered map. This map shows less suitable, these are areas with very steep slopes, deep to certainly deep poorly drained soils, water bodies and wetlands, some rock out crops, and a minimum rainfall. When compared to the other areas, they were found less suitable. The more suitable areas included moderate slopes, very high rainfall, cultivated lands, sparse vegetation, bare surfaces, built-up areas and deep moderately drained soil types. The most suitable included medium to steep slopes, sparse and dense vegetation, forested area, rock outcrops and cultivated lands. It has the shallow to deep well drained soil and high rainfall thus it was considered the most suitable for In-Situ RWH.

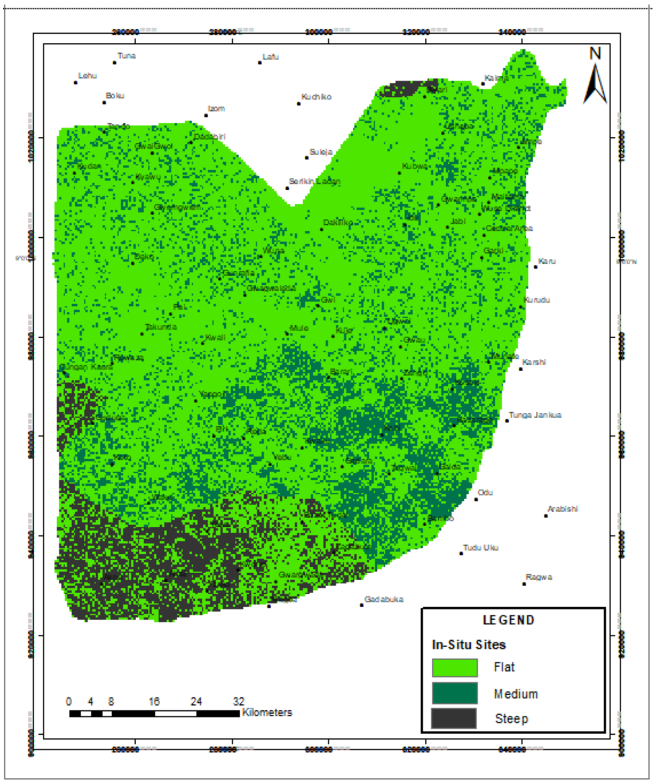

Figure 11: Sites for In-Situ RWH Technologies

This classification as illustrated in figure 10 above was strictly based on slope and of cause landuse/landcover after having considered rainwater to be more than enough for crop production. The different classifications of slope, flat, medium and steep help to determine what areas area are best suited with some RWH technologies. The technologies considered for the slope classes are illustrated in table 10.

Table 10: RWH Technologies and Appropriate Slope

Slope	RWH Technology
Flat	Negarims Trapezoidal bunds Grass Strips Broad Bed and Furrow
Medium	Fanya juu terraces Flood Water Harvesting Contour Stone Bunds Bench Terraces
Steep	Ngolo Pits Rock Catchment Tower Garden

V. SUMMARY

The rainwater harvesting potential for Abuja, considering the general means of harvesting rainwater, the different uses of rainwater and the population is very high. Abuja has the potential to meet all water needs of the population in it by the available water sources it has, especially rainwater. From our study, we have been able to show that the potential for rainwater in Abuja is not just high, it is very high. The table below shows a compilation of the rainwater harvesting potential of Abuja for rooftop, surface and in-situ rainwater harvesting. From Table 6 below it was estimated that 0.395Km^3 volume of rainwater can be harvested from rooftops at the minimum expected rainfall while about 0.493Km^3 volume of rainwater is harvestable at maximum rainfall. The table also shows that Abuja has no low rainfall or medium rainfall. According to the classification of rainfall in Table 11 above, Abuja has a high rainfall and therefore its potential for RWH is high.

Table 11 Quantity of rainwater Harvestable in Abuja

Area of Abuja	Rooftop RWH	Surface RWH			In-situ RWH		
	Based on map	Less suitable	Suitable	More suitable	Most suitable	Suitable	More suitable	Most suitable
In Km	1624	72	31891	15768	435	4290	34854	9080
RO coefficient	0.8	0.24	0.53	0.62	0.65	0.4	0.5	0.52
Rainfall min (m)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Rainfall max (m)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Volume min (m^3)	1559	20.8	20282.7	11731.4	375.8	1956.2	27186.1	8281
Volume max (m^3)	1949.8	25.9	25353.3	14664.2	469.8	2445.3	33982.7	10351.2

The runoff coefficients used in the table above were the composite runoff coefficients for the different landuse/landcover, soil types and slopes as shown in table 2 above.

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VI. CONCLUSION

This research forms part of a larger project to show through a Geographic Information System (GIS) that Abuja has a huge and untapped potential for rainwater harvesting. This information is required for awareness creation and as a decision support tool for targeting RWH plans and investments for both individuals and governmental bodies in the position to see that the state and the country at large is secured from environmental problems like water scarcity along with its effect. GIS was selected precisely for this work because of the versatility of the tools in developing visual messages that cover large areas, it has been used for country-based studies as well as continental.

With regards to the results obtained from this research, some conclusions can be drawn; Abuja has a very high RWH potential and this RWH in Abuja can be done using several technologies ranging from Rooftop to in-situ and surface RWH technologies.

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