© 2016, ISSN 2180-2491

Geografia Malaysian Journal of Society and Space

The Osun Drainage Basin in the Western Lithoral Hydrological Zone of Nigeria: A morphometric study

Ashaolu Eniola Damilola[1]

[1]Department of Geography and Environmental Management, Faculty of Social Sciences, University of Ilorin, PMB 1515, Ilorin, Nigeria

Correspondence: Ashaolu Eniola Damilola (email: damash007@yahoo.com)

Abstract

The importance of drainage basin as a planning unit for water resources development and management cannot be overemphasized and this requires accurate characterization of the drainage basin. This study takes a closer look at the Osun drainage basin with a view to updating the existing records, estimate the morphometric features and make hydrological inferences. The data used in this study include a 30m resolution Digital Elevation Model (DEM) acquired from the United State Geological Survey (USGS), geology map of Nigeria acquired from Nigeria Geological Survey Agency (NGSA), Harmonized World Soil Database (HWSD) prepared by the Food and Agricultural Organization (FAO), and the 1991 locality population data of Nigeria acquired from National Population Commission (NPC). Remote sensing and GIS techniques were adopted in the analysis of the data using ArcGIS 10.2. The acquired DEM was used to delineate Osun drainage basin and 21 morphometric parameters were estimated. The results revealed that Osun drainage basin is a 4th order drainage basin, with an area of 9926.22km ^{2} , and a length of 213.08km. The area covered by the two geology types and the four soil types were quantified and it revealed that 93.28% of the basin is underlain by the Basement Complex rocks, while 50.89% of the basin is covered by sandy clay loam soil. All these will influence the basin discharge rate, chances of flood occurrence, peak flow, infiltration rate and recharging of the Osun basin groundwater system among others. Based on these results, this study serves as a scientific database for further detailed hydrological investigation of Osun drainage basin while benefiting the sustainable drainage basin management and development programmes of the Ogun-Osun Rivers Basins Development Authority.

Keywords: drainage basin, GIS, hydrological zones, morphometric features, Nigeria, Osun River, water resources management

Introduction

The disparity in the coordinates (location and position) of Osun drainage basin reported by different researchers (Awokola and Martins, 2001; Ifabiyi, 2005; Adeboye and Alatise, 2008) in Nigeria aroused the curiosity for this research, coupled with none or scanty information on the morphometric properties of the basin such as area, length, number of stream, stream order, drainage density and texture, bifurcation ratio among others. It was also noticed that a quite number of researchers (Odusote, 1989; Oke et al., 2013; JICA, 2014; Oke et al., 2015) lumped up the description of the basin with Ogun basin as "Ogun-Osun" drainage basin, basically because the two basins are the major drainage basins in the western lithoral hydrological zone of Nigeria, under the management of the Ogun-Osun River Basin Development Authority. From the foregoing, it becomes pertinent to carry out the research of this nature to beam a light on Osun drainage basin, so that the outcome can serve as a scientific data base for further detailed hydrological investigation of the basin.

Drainage morphometric analysis is usually carried out to have an insight on the prevailing geological variation, topographic information and structural setting of a basin and their interrelationship (Singh et al., 2014). The development of the nature and type of drainage network pattern is dependent on the bed rock lithology and its associated geological structures which can be better understood through quantitative morphometric analysis (Nag and Chakraborti, 2003; Rama, 2014). Thus, drainage analysis based on morphometric parameters is essential for drainage basin planning, as it provides information on the characteristics of the drainage basin such as slope, topography, soil condition, runoff characteristics, surface and groundwater potential among others (Rama, 2014).

In the past, drainage morphometric parameters were extracted from the topographical maps or field surveys, which can give rise to a lot of inaccuracies and discrepancies as the case of Osun drainage basin. However, in over two decades, digital elevation model (DEM) which is a digital topographical information has been used extensively for drainage basin morphometric analysis, because it is fast, precise, updated and inexpensive way of drainage basin morphometric analysis (Moore et al., 1991; Maathius, 2006; Singh et al., 2014). Assessment of drainage basin through the adoption of remote sensing and GIS has been carried out by a number of researchers in different environments and it has proven to be an accurate scientific tool for drainage basin characterization (Chopra et al., 2005; Jeved et al., 2009; Pankaj & Kumar, 2009; Hajam et al., 2013; Rama, 2014; Singh et al., 2014). Thus, with the powerful advantage of remote sensing and GIS techniques over the conventional method of characterizing drainage basin which have provided inaccurate information on some of the drainage basins in Nigeria. This present study adopted the remote sensing and GIS techniques to correct the trend of misinformation on drainage basins in Nigeria. Therefore, the aim of this study is to beam a light on Osun drainage basin, with a view to updating the existing information on Osun drainage basin, estimate the morphometric features and make hydrological inferences for water resources management.

Study area

The Osun River drainage system rises in Oke-Mesi ridge, about 5 km North of Effon Alaiye and flows North via Itawure gap to latitude 7°53″ before winding westwards via Osogbo and Ede, then southwards to flow into Lagos lagoon about 8 km east of Epe (Oke et al., 2013). The basin has a tropical continental climate of Koppen Aw type humid tropical rainforest climate (Ifabiyi, 2005; Adediji & Ajibade, 2008). The mean annual rainfall ranges between 1500 mm to 1,800 mm, with the rainy season covering about eight months (April to November). The rainy season in the basin is normally characterized by two maxima rainfall with peaks in July and September/October (Adediji & Ajibade, 2008). Temperatures are generally high and almost uniform throughout the year, about 30°C (Ifabiyi, 2005; Adediji & Ajibade, 2008). Many of the rivers in the basin including the dominant Osun River have their sources in the northern part of the basin. The Osun River is perennial and its volume fluctuates with seasons. The river flows through a narrow valley throughout its course across Basement Complex rocks (Ifabiyi, 2005).

The land surface is generally undulating with high altitude in the northern part and low altitude in the southern parts of the basin. The northern part is characterised by numerous domed hills and occasional flat topped ridges, the more prominent hills in this region, are found at llesa, lgbajo, Okemesi, Elu and Oba. (Ifabiyi, 2005). The basin is underlain by metamorphic rocks of Precambrian Basement Complex, with outcrop in various parts. The crystalline rocks of the Basement Complex, consisting mainly of folded gneiss, schist and quartzite complexes, which belong to the older intrusive series. The great majority of this Basement rocks are very ancient in age and they showed great variations in grain size and in mineral composition (Oke et al., 2013). Sedimentary rocks of cretaceous and latter deposits are found in the southern sections of the Osun basin (Ifabiyi, 2005; Oke et al., 2013). The soils belong to the highly ferruginous tropical red soils associated with Basement Complex rocks. As a result of the dense humid forest cover in the area, the soils are generally deep and of two types, namely, deep clayey soils formed on low smooth hill crests and upper slopes; and the more-sandy hill wash soils on the lower slopes (Ifabiyi, 2005).

The basin is covered by secondary forest and in the northern part, the derived Savannah mosaic predominates. Originally, virtually all parts of the basin had a natural lowland tropical rain forest vegetation; but this has given way to secondary forest regrowth as a consequence of years of human occupation (Ifabiyi, 2005). Hence, the vegetation of the area can be described as derived savannah characterized by gallery of forest along stream sides and tall grasses with scattered perennial. The land use pattern within the drainage basin includes land use for residential/settlements, built up areas, bare rocks and soils surfaces, farmlands, vegetation and water bodies (Ifabiyi, 2005). The basin have fourteen water supply schemes such as Esa Odo Water Scheme, Ilesa Water Works, Ede Booster Station, Iwo, Eko ende, Ila Orangun, Mokuro water works, Ife wara water works, Ikeji Ile water works and Ikire among others. However, potable water supply in more than half of the drainage basin is supplied by Ede-Oshogbo water scheme serving several towns and villages. T Dams and weirs are found on the major river system within the basin, such as Osun, Erinle, Otin and Ayiba Rivers. Weirs are found at Inisa, Okuku and Oyan (Ifabiyi, 2005).

Materials and methods

Materials

The data used in this study include: (i) 30m resolution Digital Elevation Model (DEM) of the basin extracted from the Shuttle Radar Topographic Mission (SRTM) downloaded from the US Geological Survey Website, (ii) The geology map of Nigeria that covered the part of the country where the basin is located acquired from the Nigeria Geological Survey Agency (NGSA), (iii) The Harmonized World Soil Database (HWSD) version 1.2 (2012) prepared by the Food and Agriculture Organization of the United Nation (FAO), and (iv) The 1991 locality population data collected from the National Population Census (NPC).

Methods

The Osun drainage basin was delineated from the SRTM DEM using the Archydro tool in ArcGIS 10.2, while the spatial analyst tool was employed to prepare topographic map of the basin. The delineated basin from the DEM was later converted to shape file. Basin parameters, such as basin area, basin perimeter, basin length, stream order and stream length were calculated directly from the DEM using ArcGIS 10.2. These parameters were used to determine other influencing factors, such as bifurcation ratio, stream frequency, drainage density, drainage texture, total relief, relief ratio, elongation ratio, circulatory ratio, form factor, length of overland flow, leminiscate ratio among others. The methodologies adopted for the computation of all the morphometric parameters are presented in Table 1.The Geology map of Nigeria that covered the study area was georeferenced to WGS 1984 zone 31 and digitized. The delineated basin shape file was overlaid on the digitized geological map to extract the geology of the basin.

The HWSD OLE DB file was loaded through ArcCatalog and the ArcMap was launched to add the raster .bil file of the HWSD. The raster soil map was projected to WGS 1984 and the soil attribute was joined using the join command. The new raster map with the associated table was exported and save, then the reclass tool in spatial analysis tool was used to reclassed and exported the new rater using the soil texture in the attribute table. The drainage basin shape file was overlaid on the new raster that contain the soil texture to extract the soil of the study area. The soil will be discussed in terms of the basic infiltration rate for various soil type as well as its influence on overland flow. The Minnesota storm water manual (prepared based on the review of thirty guidance manuals and over 150 published articles on infiltration rate) on soil infiltration rate was adopted for this study. The soil infiltration rate suggested in the manual are as follows: clay - 1.524mm/hour, sandy clay loam - 5.08mm/hour, sandy loam - 20.32mm/hour and loamy sand - 20.32/mm (Minnesota storm water, 2014).

© 2016, ISSN 2180-2491

The drainage basin shape file was also overlaid on the local government map of Nigeria to extract the local government area that fall within the basin. However, the whole area of some local government did not fall within the basin, thus, the locality within such local government area that fall within the basin were identified and used for the basin population estimation. The 1991 locality population data of the basin was later used to estimate the population of the drainage basin for the year 2015, using the 3.2% national growth rate. The reason for adopting the 1991 locality population data for the study was because the last population census in 2006 do not published the locality data for the country.

Table1. Methods adopted in the computation of morphometric parameters

SN	Features	Parameters	Formulae	References
1.	Areal Features	Basin Area	Area from which water drains to a common stream and boundary determined by opposite ridges.	Strahler (1964)
2.		Basin Perimeter	Outer boundary of drainage basin measured in kilometers	Schumm (1956)
3.		Basin Length	The straight line from the mouth of the basin to the farthest point on the basin perimeter.	Schumm (1956)
4.		Form Factor	$F_r = A / L^2$ F_r = Form factor, A = Basin area, L = Basin length	Boyce and Clark, (1964), Horton (1945)
5.		Elongation Ratio	$R_e = 2\sqrt{A/\pi}/L$ R_e = Elongation ratio, A= Basin area, L= Basin length, π =3.142	Schumm (1956)
6.		Circulatory Ratio	$R_c = 4\pi A / P^2$ Where, A=Area of basin, π = 3.14, P = Perimeter of basin	Miller (1953)
7.		Drainage Density	$D_d = L / A$ Where, L=Total length of stream, A=Area of the basin.	Horton (1945)
8.		Stream Frequency	$F_s = N_u / A$ Where F_s = Stream frequency, N_u = Number of stream, A=Area of the basin	Horton (1945)
9.		Leminiscate Ratio	$K = L2 / 4A$ Where L = Length of the basin and A = Area of the basin	Schumm (1956)
10.		Constant Channel Maintenance	$C = 1/Dd$ Where Dd = Drainage Density	Horton (1945)
11.		Drainage Texture	$R_t = N_u / P$ R_t =Drainage texture, N_u = Number of stream, *P*= Drainage perimeter	Horton (1945), Smith (1950)
12.	Linear Features	Stream Order	Hierarchical rank	Strahler (1964)
13.		Total Stream Length	The total length of all the tributaries and the principal drainage	Schumm (1963)
14.		Mean Stream Length	Total stream length divide by total number of streams	Schumm (1963), Strahler (1964)
15.		Main Stream Length	The length of the principal drainage line	Schumm (1963)
16.		Bifurcation Ratio	$R_b = N_u / N_u + 1$ Where R_b = Bifurcation ratio, N_u = Number of streams in the order U and N_u + 1 = Number of streams in the next higher order	Gregory and Walling, (1973), Schumm (1956)
17.		Mean Bifurcation Ratio	Rb_m = average of bifurcation ratios of all order	Strahler (1957)
18.		Length of Overland Flow	$L_g = 1 / D_d \times 2$ Where =Length of overland flow, D_d = Drainage density	Horton (1945)
19.	Relief Features	Total Basin Relief	$R = H - h$ Where H= maximum height of the basin, h= minimum height at the basin mouth	Hadley and Schumm (1961)

20.		Relief Ratio	$R_r = R / L$ Where R_r = Relief ratio, R = Relief, L = Length of the basin	Schumm (1963)
21.		Ruggedness Number	$R_n = Bh \times Dd$ Where, Bh=Basin relief, Dd=Drainage density	Schumm (1956)

Results and discussion

Location, position and population

From the delineation of Osun drainage basin from the acquired DEM in ArcGIS 10.2 using ArcHydro 10.2 watershed tool and ground truthing exercise, it was discovered that Osun drainage basin is located between latitude 6°25´58.79´´and 8°21´3.6´´ North and longitude 3°47´34.8´´and 5°10´55.2´´ East in the western lithoral hydrological zone of Nigeria. It covers about 42 Local Government Areas (LGAs) which spread across the five states (Osun, Ekiti, Oyo, Lagos and Ogun) of the Southwestern Nigeria and some parts of the southern Kwara state. It is important to point out that 24 of the 42 LGAs are in Osun state, while 11 are in Oyo, 6 in Ekiti, 4 in Ogun, 4 in Kwara, and 2 in Lagos state. The estimated population of the basin as of 2015 using the 3.2% national growth rate of Nigeria was 6,341,159. The estimated population figure within the basin revealed the need for sustainable management of the basin for optimal water resources usage to meet the needs of the ever growing population in view of the challenges of climate change and increasing urbanization. The map showing the location and position of the Osun drainage basin, Nigeria is presented in Figure 1.

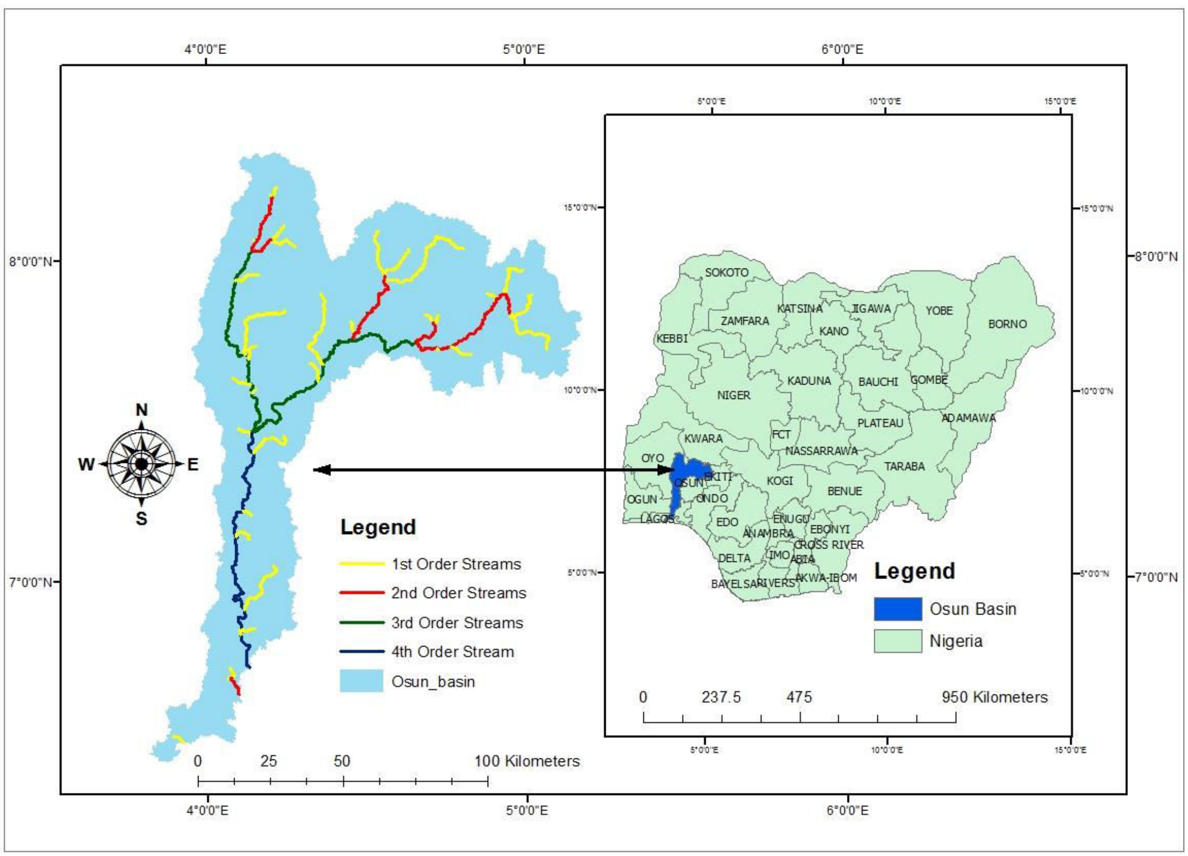

Figure 1. *Location and position of Osun Drainage Basin, Nigeria*

Soil and geology

1. Soil

The nature of soil characteristics and its antecedent moisture influence the amount of rainfall that infiltrate the ground to become groundwater, baseflow, as well as overland flow. Soil infiltration rate is a function of a constant and varying factors such as the soil texture and moisture content, respectively. The soil of the study area is examined based on the textural composition from 0-30cm depth, using the harmonized world soil database which was later confirmed during the fieldwork and ground truthing in some part of the basin. The soil is discussed in terms of the basic infiltration rate for various soil type as well as its influence on overland flow. The soil infiltration rate suggested by the Minnesota storm water manual (2014) are as follows: clay-1.524mm/hour, sandy clay loam- 5.08mm/hour, sandy loam- 20.32mm/hour and loamy sand- 20.32/mm. Table 2 shows the four (clay, sandy clay loam, sandy loam and loamy sand) basic soil of the study area based on their texture. It revealed that 50.89% of the basin is covered by sandy clay loam which have a basic infiltration rate of 5.08mm/hour, although, this rate is dependent on the antecedent soil moisture of the basin at any point in time. This is an indication that rainfall amount received in the study are will infiltrate at the rate of 5.08mm/hour in half of the basin that consist of sandy clay loam soil.

Table 2. Soil type and percentage area covered

SN	Soil Type	Area (Km^2)	% Coverage
1.	Clay	2813.09	28.34
2.	Sandy Clay Loam	5052.44	50.89
3.	Sandy Loam	1597.13	16.09
4.	Loamy Sand	366.28	3.69

Sandy loam and loamy sand both have a basic infiltration rate of 20.32mm/hour and they covered 19.78% of Osun drainage basin. Lastly, clay soil which covered 20.34% of the basin area has infiltration rate of 1.524mm/hour. The total area covered by sandy clay loam (50.89%) and clay soil (20.34%) in the basin is 79.23%. This suggested that about 80% of the basin soil have low infiltration and there may be high overland flow in the basin. However, the rate of infiltration and overland flow are also influenced by land use/cover practices, basin characteristics such as slope, form factor, elongation ratio among others, as well as rainfall characteristics such as intensity, amount and duration. All these factors are woven together to determine infiltration and overland infiltration rate, thus, a single factor such as soil type/texture is not enough to explain these processes. Whatever is the case, the surface and groundwater of the area will be affected by soil texture as it is one of those constant factors that determine the rate of infiltration and overland flow. Figure 2 shows the soil map of Osun drainage Basin.

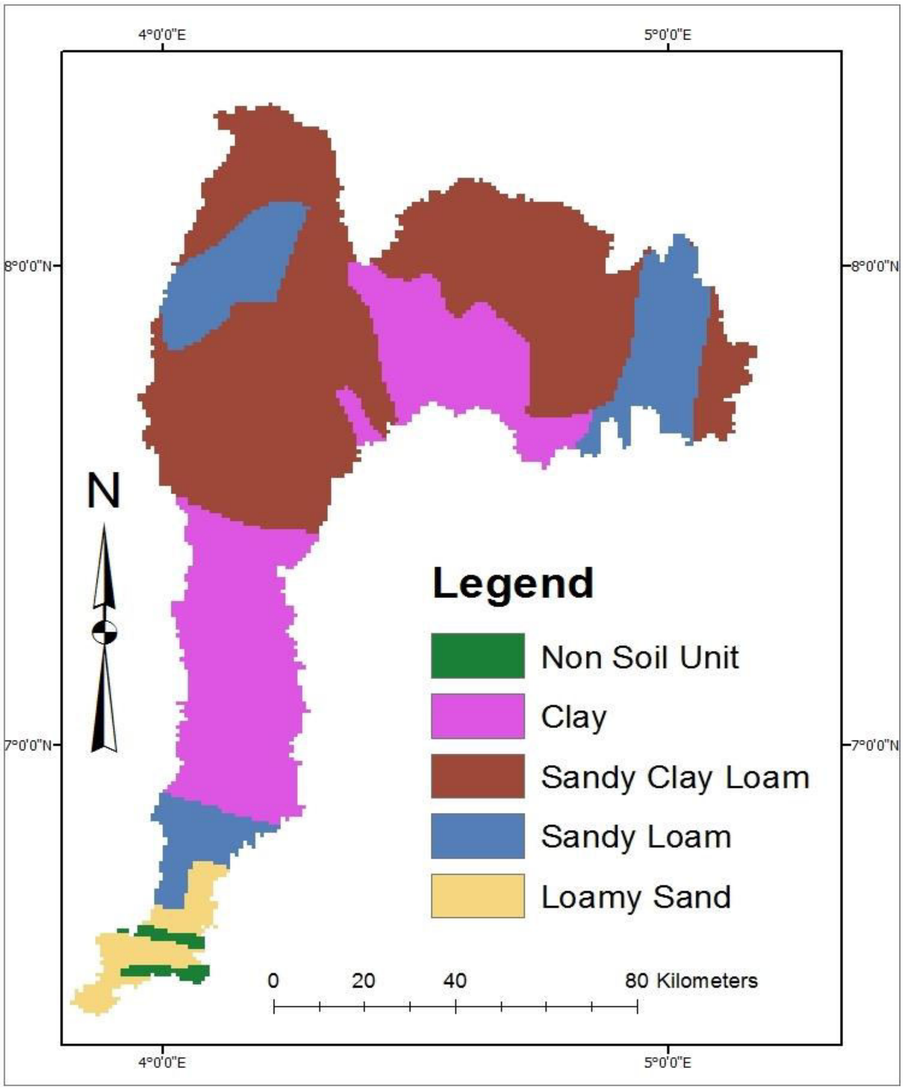

Figure 2. *Osun Drainage Basin Soil*

2. Geology

Oke et al. (2013) and Ifabiyi (2005) confirmed that the geology of the basin comprises of two types of rock which are Basement Complex rocks and Sedimentary basins. They qualitatively describe that the larger part of the basin is underlain by Basement Complex rocks and that Sedimentary basins are found in the southern part of the area. Thus, this study takes a step further to present the spatial distribution pattern and quantify the percentage land area covered by the two types of geology found in the basin. The study discovered that the total area of Osun drainage basin is 9926.22km ^{2} out of which the Basement Complex rocks underlain 9,258.5 km ^{2} , a total of 93.28% of the basin. This is in contrary to the total area (11,000 km ^{2}) of Osun drainage basin underlain by the Basement Complex rocks reported by Oyegoke et al (1983). This is expected because the method use in determining the area covered was not mentioned and it is believed to be done manually. The younger sedimentary basins found in the southern part of the basin only cover a total of 667.72 km ^{2} which is about 6.72% of the total basin area. See Table 3 and Figure 3 for the detailed description of the geology/rock type and distribution pattern in the study area.

© 2016, ISSN 2180-2491

Table 3. Geology/rock type and percentage area covered

SN	Geology	Rock Type	Area (Km^2)	% Coverage
1.	Basement Complex Rocks	Intracrustal (Granite, Gneisis, Migmatite etc.)	6,354.34	64.02
		Supracrustal (Volcanic & Sediments)	2,904.16	29.26
	Total		**9,258.5**	**93.28**
2.	Younger Sedimentary Basins	Neogene-Mesozole	328.66	3.31
		Quatenary	339.06	3.41
	Total		**667.72**	**6.72**

The geology of the basin and the percentage area covered was looked at in terms of its groundwater potential. Azeez (1972) who studied the groundwater exploration of the Basement Complex of the Western Nigeria where this basin is located posited that the presence of groundwater in any rock is a function of adequate porosity and adequate permeability of such rock type. He stressed further that the crystalline nature of the metamorphic and igneous rocks of the Basement Complex does not have adequate porosity and permeability on any regional scale in Nigeria. However, local factors such as weathering, the presence of faults, fractures, joints, shears which serves as transmission conduit within the aquifer provide the medium through which water can percolate and made available exploitable quantities of groundwater (Azeez, 1972; Gustafson and Krasny, 1994; Batchelor et al., 1996; Taylor and Howard, 2000). As revealed that 93.28% of the basin is underlain by Basement Complex which is a poor aquifer, shows that the groundwater potential of the basin might be low if not for the local factors described earlier.

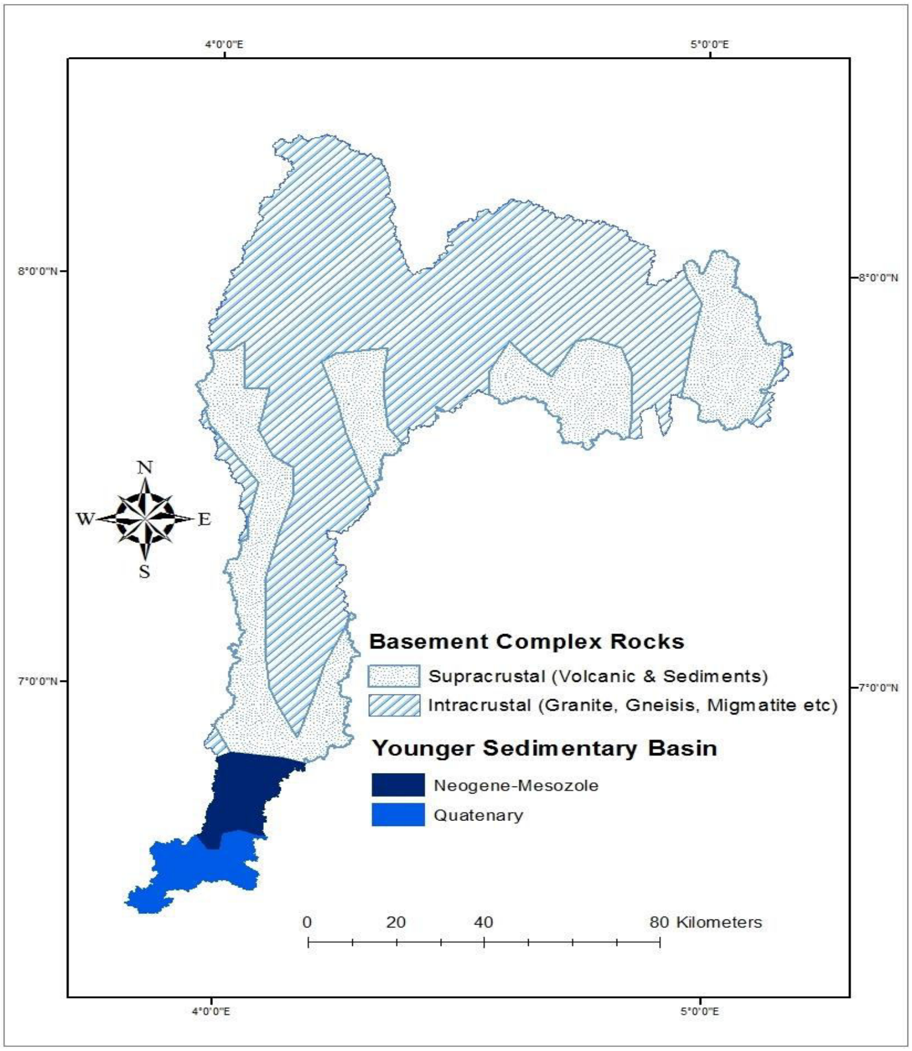

Figure 3. *Simplified Geological Map of Osun Dranage Basin, Nigeria*

The presence of fractured zone that serves as transmission conduit varied across space, depending on the nature of the faults and fractures, hence, groundwater yield can differ largely within the same rock unit and often within short distances (Gustafson and Krasny, 1994). This means that despite this area having low groundwater yield based on the geology, the yield can vary from one part of the basin to another depending on the nature, size of faults and fractures that influence aquifer transmissivity. However, groundwater in this part of the basin is shallow and requires little investment in its development, as revealed with numerous number of hand dug wells found in the basin. On the other hand, 6.72% of the basin is underlain by the younger sedimentary basin which is located at the southern part of the basin closer to the coast of Atlantic Ocean. The groundwater potential of this smaller part of the basin will be high but the quality may be compromised as a result of salt water intrution. This may incrase the cost of groundwater exploration and development in this part of the basin.

Areal features of Osun Drainage Basin

1. Basin Area (B_a), Perimeter (B_p) and Length (B_l)

Area, perimeter and length of a basin are the most significant parameters in quantitative morphology (Hajam et al., 2013) and of all the morphometric parameters controlling drainage runoff pattern (Ajibade et al., 2013). Basin perimeter is measured along the divides between basins and can be used as an indicator of basin size and shape (Schumm, 1956, Hajam et al., 2013). Basin area directly influences the size of the storm hydrograph, the magnitudes of peak and mean runoff. It is important to note that the maximum flood discharge per unit area is inversely related to size (Chorley et al., 1957, Hajam et al., 2013). Table 4 shows that the basin area, perimeter and length are 9,926.22km^2, 1,193.26km and 213km, respectively. The large basin area and length of Osun drainage basin revealed the reasons why there are no major flood occurrence experienced in the basin over the years. The area and length of a basin are directly related because the larger the basin, the longer the length. This factor affect the rate of discharge and chances of flood occurrence in the basin, as a result of higher concentration time (lag time) which will increase infiltration rate and water lost through evapotranspiration, hence, reduced runoff volume. This is in agreement with the works of Ifabiyi (2004) in the upper Kaduna catchment of Nigeria where drainage size is linked to the amount of runoff, and Ajibade et al. (2013), where the size of Ogbere and Ogunpa drainage basins in Ibadan, Nigeria were compared and the frequencies of flood occurrences linked to their sizes.

2. Form Factor (F_f)

Horton (1932) defined form factor as the ratio of the basin area to square of the basin length, which reflects the flow intensity of a basin for a defined area. The smaller the form factor, the more elongated the basin. It is important to note that the value of form factor should be less than 0.7854. Drainage basins with high form factor experience larger peak flows of shorter duration, while basins with low form factors experiences lower peak flow of longer duration (Singh et al., 2014). The form factor of 0.217 (Table 4) indicates that the shape of Osun basin is elongated and will have a lower peak flow with longer duration, hence, the flood flows of the basin will be easier to manage. This is also in agreement with the early study of Onosemuode et al. (2010) in Onitsha Northeast drainage basin, Nigeria.

3. Elongation Ratio (R_e)

Elongation ratio is a very important factor in the assessment of basin shape which gives an information on the hydrological character of a drainage basin (Onosemuode et al., 2010; Hajam et al., 2013). This is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin (Schumm, 1956). The values that ranges between 0 and 0.6 are associated with areas of low relief, while values between 0.6 and 1.0 are related to high relief and steep ground slope (Strahler, 1964). According to Singh et al., (2014), the values of elongation ratio can be categorized into three to describe the shape of a basin, which are: circular (>0.9), oval (0.8-0.9) and elongated (<0.7). The elongation value of Osun basin is 0.53 (Table 4) indicates that the basin has elongated shape with low relief. The elongated nature of the Osun drainage basin has implication on both hydrologic and geomorphic processes. Mustafa and Yusuf (1999) reported that the flow of water in elongated basins is distributed over a longer period than in circular ones. This will influence the rate of runoff, thereby reducing the chances of flash flood occurrences in the basin. Also, the lower peak with longer duration as a result of the elongation ratios will possibly increase infiltration rate, although, this is also dependent on other factors within the drainage basin.

4. Circulatory Ratio (R_c)

Circularity ratio is a quantitative measure for visualizing the shape of the basin, which is expressed as the ratio of basin area to the area of a circle having the same perimeter as the basin (Miller 1953; Strahler 1964). It is generally influenced by the length and frequency of streams, geological structures, land use/cover, climate, relief and slope of the basin. Miller (1953) described the circularity ratios of a basin to range from 0.4 to 0.5 which revealed a strongly elongated and highly permeable homogenous geologic materials. The value of circulatory ratio for Osun basin is 0.1 (Table 4), which does not fall within the range described by Miller (1953). This can be attributed to the geologic structure, land use/cover within the study area, though, the shape of the basin is elongated, the geologic materials have varying level of permeability because of the nature of the Basement Complex rocks found in the basin.

Table 4. Areal feature of Osun Drainage Basin

Basin Area (Km^2)	Basin Peri-meter (Km)	Basin Length (Km)	Form Factor	Elo-ngation Ratio (R_e)	Circu-latory Ratio (R_c)	Drainage Density (Km)	Drainage Texture (D_t)	Leminis-cate Ratio	Constant Channel Main-tenance	Stream Frequ-ency
9,926.22	1,193.26	213.80	0.217	0.53	0.1	0.082	0.04	1.151	12.195	0.004

5. Drainage Density (D_d)

The drainage density is an expression of the closeness or spacing of channels (Horton, 1932) and it is a factor determining the time travel of water within a basin (Schumm, 1956). The estimation of drainage density is a useful numerical measure of landscape dissection and runoff potential (Chorley, 1969). Drainage density is a consequence of interacting factors controlling surface runoff; and in itself influencing the output of water and sediment from the drainage basin (Ozdemir and Bird, 2009). The nature of drainage density of any particular basin varies with climate, vegetation, soil, rock properties, relief and landscape evolution processes operating within the basin (Kelson and Wells, 1989; Oguchi, 1997; Moglen et al., 1998; Hajam et al., 2013). Low drainage density generally result in the area of highly resistant surface material or permeable subsoil material under dense vegetation cover and low relief. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief (Onosemuode et al., 2010; Singh et al., 2014).

Drainage density value for Osun basin is 0.082 (Table 4) and the result shows that for every square kilometer of the basin, there is 0.082 kilometer of stream channel, suggesting that the area has highly resistant or permeable subsoil, dense vegetation cover and low relief. This can be seen in the drainage pattern of the basin with widely spaced streams. According to Onosemuode et al. (2010), lower value of drainage density tend to occur on granite gneisis and schist group of Basement rocks. The main rock type of the study area is the hard Basement Complex rocks which explains the low drainage density in the basin. The low drainage density of Osun basin will also yield high baseflow and resulted in low magnitude peak flood. However, the low drainage density resulting to low magnitude peak flood may be override by the effects of channel storage, as well as saturated overland flow which may lead to high magnitude peak flood.

6. Drainage Texture (D_t)

Low drainage density leads to coarse drainage texture (D_t) while high drainage density leads to fine drainage texture (Strahler, 1957). Drainage density has been classified into five texture; drainage density less than 2 indicates very coarse, between 2 and 4 as coarse, between 4 and 6 as moderate, between 6 and 8 as fine and greater than 8 as very fine drainage texture (Smith, 1950). Drainage texture is considered as one of the significant concept of geomorphology which shows the relative spacing of the drainage lines (Chorley et al., 1957). Soil type which influences the rate of surface runoff, usually affects the drainage texture of an area (Chopra et al., 2005). The soft or weak rocks unprotected by vegetation produce a fine texture, whereas massive and resistant rocks cause coarse texture (Rama, 2014) and this coarse texture is expected of Osun basin because about 93% of the basin is underlain by hard resistant Basement Complex rocks. The calculated drainage texture is 0.04 (Table 4), which indicates a very coarse drainage texture, with good permeability of sub-surface material and infiltration capacity, which may lower run off rate, and significantly recharge the ground water.

7. Leminiscate Ratio (L_r)

Lemniscate ratio is an expression of the slope of a basin (Chorely et al., 1957). Higher value of leminiscate ratio indicates high runoff and vice-versa. The calculated leminiscate ratio for the study area is 1.151 (Table 4) which indicate low runoff in the basin, all things been equal. Although, surface runoff is generally low on a gentle slope, the rate of surface runoff can be influenced by the characteristics of the falling rain and the prevailing environmental factors.

8. Constant Channel Maintenance (Cm)

Schumm (1956) used the inverse of drainage density or the constant channel maintenance as a property of landforms. Constant channel maintenance indicates the number of Sq.km of drainage basin required to sustain one linear km of channel. The constant channel maintenance indicates the relative size of landform units in a drainage basin and has a specific genetic connotation (Strahler, 1957). It not only depends on rock type permeability, climatic regime, vegetation, relief but also on the duration of erosion and climatic history. The constant is extremely low in areas of close dissection. Constant of channel maintenance for Osun basin is 12.195 (Table 4). This indicate that a minimum of 12.20km ^{2} is required for the development and maintenance of the stream channels in Osun basin, that is, 12.20km ^{2} of the basin area is required to maintain one linear unit of channel length.

9. Stream Frequency (F_s)

Horton (1945) introduced stream frequency or channel frequency as number of stream segments per unit area or the total number of stream segments of all orders per unit area. Stream frequency shows a positive association with drainage density suggesting an increase in stream population with increasing drainage density. Stream frequency mainly depends on the lithology of the basin and reflects the texture of the drainage network, infiltration capacity, vegetation cover, relief, nature and amount of rainfall and subsurface material permeability. (Parveen et al., 2012). Stream frequency reflects the degree of dissection of the terrain. The high stream frequency, indicate high degree of dissection and vice versa. The stream frequency for the whole Osun basin is 0.004 km/km ^{2} (Table 4) indicating low relief and permeable subsurface material and is less likely prone to flooding. A basin with lower drainage density and stream frequency will have slower flow, and therefore is less likely prone to flooding (Carlston, 1963).

Linear feature of Osun Drainage Basin

1. Stream Order (u) and Stream Number (N_u)

The Osun drainage has a dendritic drainage pattern which is an indication of homogeneous subsurface strata of the area. Stream ordering of a basin is the first step in drainage basin analysis, which is an

© 2016, ISSN 2180-2491

expression of the hierarchical relationship between stream segments, their connectivity and the discharge arising from the contributing sub-basins. The stream ordering has been ranked based on the method of hierarchical ordering proposed by Strahler (1964) from the Digital Elevation Model (DEM). In the study area the highest order obtained is 4th order and hence designated as 4th order drainage basin. The total number of stream in the basin is forty-four (44). Table 5 shows that maximum number of streams (34) was found in the first order and as the stream order increases, the stream number decreases. This can be attributed to flowing of streams from high altitude and lithological variations. The drainage map with stream order of the Osun basin is presented in Figure 4.

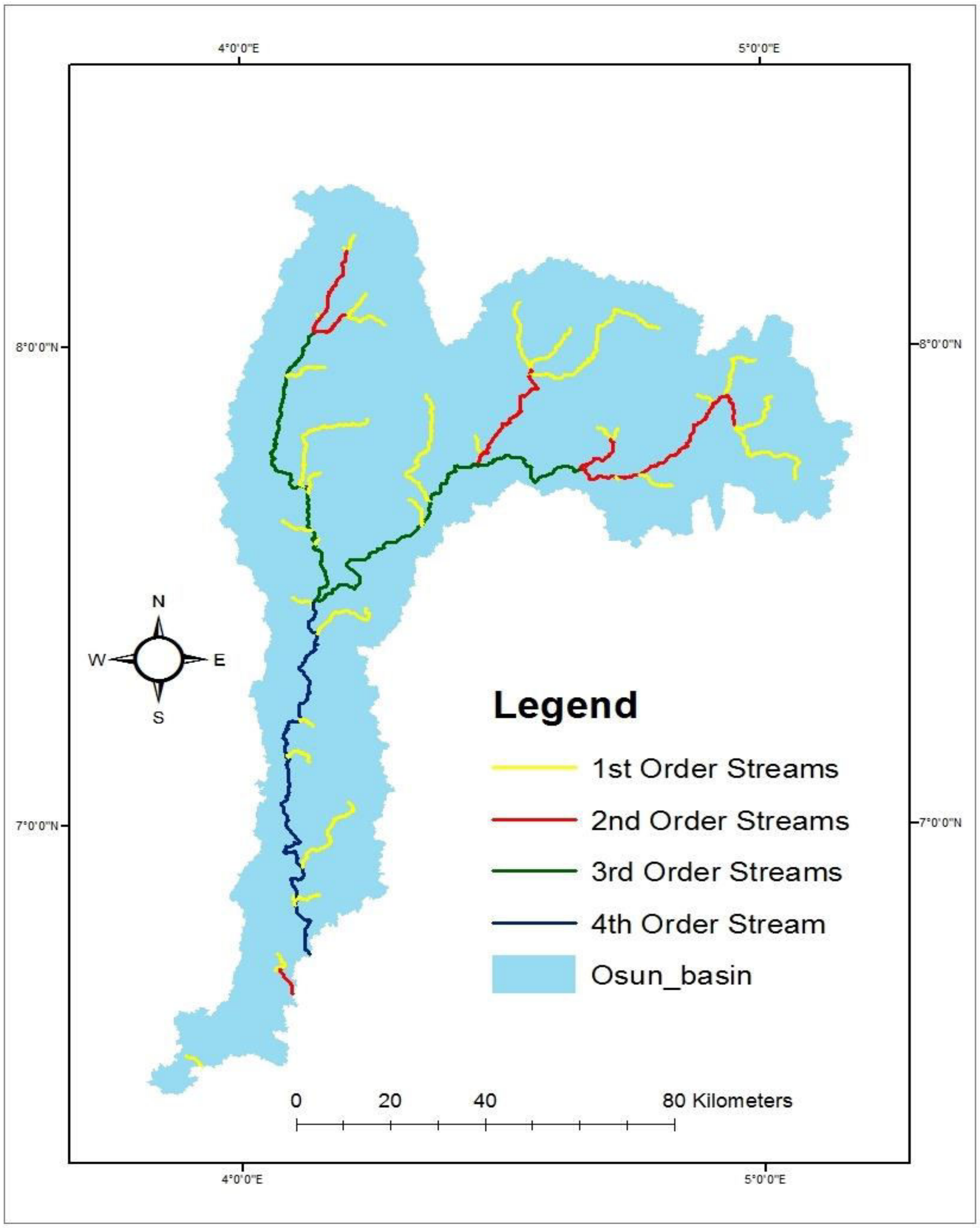

Figure 4. *Stream order of Osun Drainage Bain, Nigeria*

2. Total stream length, mean stream length and main stream length

The total stream length and main stream length were computed using ArcGIS on the basis of the study of Schumm (1963), while the mean stream length is computed on the basis of the works of Schumm (1963) and Strahler (1964). Length of the stream is an indicator of the area contribution to the basin, steepness of the drainage basin as well as the degree of drainage. Steep and well drained areas generally have numerous small tributaries; whereas, in plains, where soils are deep and permeable, only relatively long tributaries (generally perennial streams) will be in existence (Rama, 2014). Hence, this factor gives an idea of the efficiency of the drainage network. Generally the total length of the stream segments decrease with stream order. Deviation from its general behavior indicates that the terrain is characterized by high relief and moderately steep slopes, underlying by varying lithology and probable uplift across the basin (Singh and Singh, 1997; Rama, 2014). Table 5 shows that the total stream length in each order of the basin ranges from 111.91km in the fourth order to 373.87km in the first order. The mean stream length for the whole basin is 18.43km, while the main stream length (River Osun) is 291.43km.

Table 5. Liner feature of Osun Drainage Basin

Stream Order (W)	No. of Stream (N_u)	Total Stream Length (Km)	Mean stream Length (Km)	Main Stream Length (Km)	Bifurcation ratio (Rbf)	Mean Bifurcation Ration (Rbm)	Length of overland flow
I	34	373.87	18.43	291.43	-	3.45	6.17
II	7	143.58			4.86		
III	2	181.38			3.5		
Iv	1	111.91			2		
Total	44	810.749					

3. Bifurcation ratio and mean bifurcation ratio

Bifurcation ratio is the ratio of the number of stream segments of a given order to the number of segments of the next higher order (Schumm, 1956). Chorley (1969) had noted that the lower the bifurcation ratio, the higher the risk of flooding, particularly of parts and not the entire basin. Bifurcation ratios ranging from 3 to 5 indicate natural drainage system characteristics within a homogeneous rock (Kale and Gupta, 2001) which have experience minimum structural disturbances (Strahler, 1964). The bifurcation ratio of Osun drainage basin range from 2 to 4.86, with mean bifurcation ratio of 3.45 (Table 5). This revealed that the drainage pattern of the basin is still the natural drainage system characterized with a homogeneous rock that has not been affected by structural disturbances. The observed bifurcation ratio is not uniform across the four order of stream and this is an indication of the geological and lithological development of the basin.

4. Length of overland Flow (Lg)

It is the length of water over the ground before it gets concentrated into definite stream channels. This factor relates inversely to the average slope of the channel and is quite synonymous with the length of sheet flow to a large degree. It approximately equals to half of reciprocal of drainage density (Horton 1945). The length of overland flow measure the level of erodibility and is one of the independent variables influencing both the hydrologic and physiographic development of the drainage basin. Horton (1945) defined the length of overland flow as the length of flow path, projected to a horizontal plane of the rain flow from a point on the drainage divide to a point on the adjacent stream channel. Overland flow is significantly influenced by infiltration and percolation through the soil, both varying in time and space (Schmid, 1997). According to Kumar et al. (2011), the shorter the length of overland flow, the quicker the surface runoff from the streams and vice versa. The estimated length of overland flow value for the study area is 6.17, indicating the occurrence of long flow-paths, and thus, gentle ground slopes, which reflects areas of less surface run-offs and more infiltration. (Result to be related to geology & soil & the effect on recharge)

Relief feature of Osun Drainage Basin

1. Total basin relief and relief ratio

The elevation difference between the highest and lowest points on the valley floor of a basin is referred to as the total basin relief of the basin. The relief ratio is the ratio of maximum basin relief to the horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956). It is the expression of the overall steepness of a basin, which indicates the intensity of erosion processes operating on slopes of the basin. The results in Table 6 shows that the minimum basin relief is 50m found in areas around Epe and Ibeju Lekki at the mouth of the basin, while the maximum relief is 700m found in Efon Alaye in the Northeastern part of the basin where the Osun river originated. The total basin relief is 650m and the relief ratio is 3.04 which shows that the major portion of the basin is having gentle slope. This also confirmed that the runoff from the basin will be low as a result of gentle slope in major portion of the basin. The relief map of the basin is presented in Figure 5.

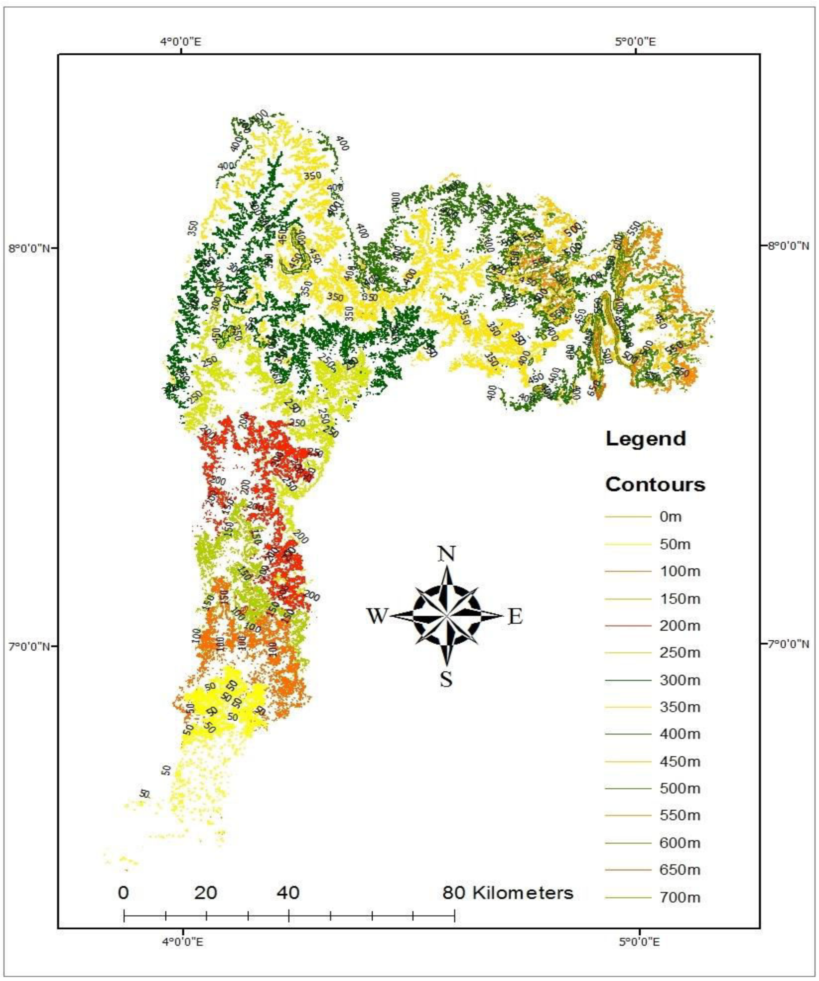

Figure 5. *Relief Map of Osun Drainage Basin, Nigeria*

2. Ruggedness number

Ruggedness number is the product of maximum basin relief and drainage density, where both parameters are in the same unit. An extreme high value of ruggedness number occurs when both variables are large and slope is not only steep but long as well (Strahler, 1956). The ruggedness number for the basin is 53.3 which shows that the study area is moderately rugged with moderate relief and low stream density.

Table 6. Relief feature of Osun Drainage Basin

Height of Basin Mouth (m)	Maximum Height of the Basin (m)	Total Basin Relief (m)	Relief Ratio	Ruggedness Number
50	700	650	3.04	53.3

Conclusions

This study has succeeded in shielding light on Osun drainage basin by updating the existing records on location, position, population, soil and geology. Previous qualitative description of the total and percentage area underlain by the basin geology, and covered by the soil types were successfully quantified and the basin population estimated. Twenty one (21) morphometric parameters of the basin were estimated and hydrological inferences were made. This study is a step in the right direction in correcting the trend in misinformation on drainage basin using GIS and remote sensing data. In conclusion, the findings of this study will serve as the scientific data base for further detailed hydrological investigation of Osun drainage basin for sustainable water resources development and management. Also, it will be of great benefit to Ogun-Osun River Basins Development Authority for sustainable drainage basin management and development programmes.

Acknowledgement

Special thanks to these organizations: United State Geological Survey (USGS), Nigeria Geological Survey Agency (NGSA), Food and Agricultural Organization (FAO) and National Population Commission (NPC) for the data used in this research work. I also appreciate the efforts of Mr Lateef Abolaji Shittu and Mr Ibrahim Azeez Kolawole during the period of field work and ground truthing.

References

Adeboye OB, Alatise OM (2008) Surface Water Potential of the River Osun at Apoje Sub-basin Nigeria. *Soil and Water Resources* **3** (2), 74-79.

Adediji A, Ajibade LT (2008) The Change Detection of Major Dams in Osun State, Nigeria using Remote Sensing (RS) and GIS Techniques. *Journal of Geography and Regional Planning* **1**(6), 110-115.

Ajibade LT, Ifabiyi IP, Iroye KA, Ogunteru S (2010) Morphometric Analysis of Ogunpa and Ogbere Drainage Basins, Ibadan, Nigeria. *Ethiopian Journal of Environmental Studies and Management* **3**(1), 13-19.

Awokola OS, Martins O (2001) Regional Flood Frequency Analysis for Osun Drainage Basin, South Western Nigeria. *Nigerian Journal of Science* **35**(1), 37-44.

Batchelor C, Lovell C, Chilton J, Mharapara I (1996) Development of Collector Well Gardens. 22nd WEDC Conference: Reaching the Unreached, Challenges for the 21st Century, New Delhi, India, Pp 172-174.

Boyce RB, Clark WAV (1964) The Concept of Shape in Geography, *Geographical Review* **54**, 561-72.
Carlston CW (1963) Drainage Density and Streamflow, U.S Geological Survey Professional Paper.
Chopra R, Dhiman R, Sharma PK (2005) Morphometric Analysis of Sub-watersheds in Gurdaspur District, Punjab using Remote Sensing and GIS Technique. *Journal of the Indian Society of Remote Sensing* **33**(4), 531-539.
Chorley RJ (1969) *Introduction to Physical Hydrology*. Methuen and Co. Ltd., Suffolk. 211.
Chorley RJ, Donald EG, Malm, Pogorzelski HA (1957) A New Standard for Estimating Drainage Basin Shape. *American Journal of Science* **255**, 138-141.
Dingman SL (1978) Drainage Density and Streamflow: A Closer Look. *Water Resources Research* **14**(6), 1183-1187.
Gregory KJ, Walling DE (1973) *Drainage Basin Form and Process: A Geomorphological Approach,* Edward Arnold, London, 456pp.
Gustafson G, Krasny J (1994) Crystalline Rock Aquifers: Their Occurrence, Use and Importance. *Applied Hydrogeology* **2**, 64-75.
Hajam RA, Hamid A, Ahmad DN, Bhat, SU (2013) Morphometric Analysis of Vishav Drainage Basin using Geo-Spatial Technology (GST). *International Research Journal of Geology and Mining* **3**(3), 136-146.
Hadley RF, Schumm SA (1961) Sediment Source and Drainage basin characteristics in Upper Cheyenne River Basin, *US Geological Survey Water-Supply Paper* **1531-B**, 198.
Horton RE (1932) Drainage Basins Characteristics, *Transactions of American Geophysics Union* **13**, 350-361.
Horton RE (1945) erosional Dvelopment of Streams and their Drainage Basins: Hydrophysical Approach to Quantitative Morphology. *Bulletin of Geological Society of America* **56**, 275-370.
Ifabiyi IP (2004) A Reduced Rank Model of Drainage Basin Response to Runoff in Upper Kaduna Catchment of Northern Nigeria. *Geostudies Forum* **2**(1), 109-117.
Ifabiyi IP (2005) Construction versus Yield of Deep Wells in the Regolith Aquifer of Osun River Basin, Nigeria, *Water Resources* **16**: 1-16.
Japan International Cooperation Agency (2014) The Project for Review and Update of Nigeria National Water Resources Master Plan. Volume 8, Draft Catchment Management Plan, Ogun-Oshun Basin in Ha-6: Western Littoral.
Javed A, Khanday MY, Ahmed R (2009) Prioritazation of Sunwatershed based on Morphometric and Land Use Analysis using Remote Sensing and GIS Techniques. *Journal of Indian Society of Remote Sensing* **37**, 261-274.
Kale VS, Gupta A, (2001) *Introduction to geomorphology*. New Delhi: Academic (India) Publishers.
Kelson KI, Wells SG, (1989) Geologic Influences on Fluvial Hydrology and Bed Load Transport in Small Mountainous Watersheds, Northern New Mexico, USA. *Earth Surface Processes Landforms* **14,** 671–690.
Krishnamurthy J, Srinivas G, Jayaraman V, Chandrasekhar MG, (1996) Influence of Rock Types and Structures in the Development of Drainage Networks in Typical Hard Rock Terrain. *ITC Journal* **3-4**, 252–259.
Kumar AB, Jayappab KS, Deepika B, (2011) Prioritization of Sub-basins Based on Geomorphology and Morphometric Analysis using Remote Sensing and Geographic Information System (GIS) Techniques. *Geocarto International* **26** (7), 569–592.
Maathuis BHP (2006) Digital Elevation Based Hydro-processing. *Geocarto International* **21**(1), 21-26.
Miller VC (1953) A Quantitative Geomorphic Study of Drainage Basin Characteristics on the Clinch Mountain Area, NR Technical Report 3: Virgina and Tennessee, Project, 389-402.
Moore ID, Grayson RB, Ladson AR (1991) Digital Terrain Modelling: a Review of Hydrological, Geomorphological and Biological Applications. *Hydrological Processes* **59**(1), 3-30.
Moglen GE, Eltahir EA, Bras RL, (1998) On the Sensitivity of Drainage Density to Climate Change. *Water Resources Research* **34**, 855–862.

Mustafa S, Yusuf MI, (1999) *A Textbook of Hydrology and Water Resources*. (1st ed.). Jenas Prints and Publishing Company, Abuja.

Nag SK, Chakraborty S, (2003) Influence of Rock Types and Structures in the Development of Drainage Network in Hard Rock. *Area. Journal of Indian Society of Remote Sensing* **31**(1), 25-35.

Oguchi T (1997) Drainage Density and Relative Relief in Humid Steep Mountains with Frequent Slope Failure. *Earth Surfaces Processes Landforms* **22**, 107–120.

Odusote AO (1989) Regional Flood-Frequency Analysis of Ogun-Oshun River Basins. *Unpublished MSc. Dissertation*, Ahmadu Bello University, Zaria, Nigeria. Pp 130.

Oke MO, Martins O, Idowu O, Aiyelokun O (2013) Comparative Analysis of Empirical Formulae Used in Groundwater Recharge in Ogun-Oshun River Basins. *Journal of Scientific Research & Reports* **2**(2), 692-710.

Oke MO, Martins O, Idowu OA, Aiyelokun O (2015) Comparative Analysis of Groundwater Recharge Estimation Value Obtained Using Empirical Methods in Ogun and Oshun River Basins, *Ife Journal of Science* **17**(1), 53-63.

Oyegoke ES, Ige ED, Oyebande L (1983) River Flow Forecasting through a regression Model: a Case Study of the Basement Complex of Western Nigeria, Proceedings of the Harmburg Symposium. IANS Publication No. 140.

Ozdemir H, Bird D (2009) Evaluation of Morphometric Parameters of Drainage Networks Derived from Topographic Maps and DEM in Point of Floods. *Environmental Geology* **56**, 1405–1415.

Onosemuode C, Adetimirin OI, Aboderin SO (2010) Hydrological Analysis of Onitsha North East Drainage Basin Using Geoinformatics Techniques. *World Applied Sciences Journal* **11**(10), 1297-1302.

Pankaj A, Kumar P, (2009) GIS Based Morphometric Analysis of Five Sub-watershed of Song River, Dehradun District, Uttarak –hand with Special Reference to Landslide Incidences. *Journal of Indian Society of Remote Sensing* **37**, 157-166.

Parveen R, Kumar U, Singh VK (2012) Geomorphometric Characterization of Upper South Koel Basin, Jharkhand: A Remote Sensing & GIS Approach. *Journal of Water Resource and Protection* **4**, 1042-1050.

Rama VA (2014) Drainage basin analysis for characterization of 3rd order watersheds using Geographic Information System (GIS) and ASTER Data. *Journal of Geomatics* **8**(2), 200-210.

Schmid BH, (1997) Critical Rainfall Duration for Overland Flow on Infiltrating Plane Surface. *Journal of Hydrology* **193**, 45-60.

Schumm SA (1963) A Tentative Classification of River Channels. *U.S. Geological Survey Circular* **477** (10pp).

Schumm SA (1956) The Evolution of Drainage Systems and Slopes in Badlands at Perth Amboy,New Jersey. *Bulletin of Geological Society of American* **67**, 597-646.

Singh S, Singh MC (1997) Morphometric Analysis of Kanhar River Basin. *National Geographical Journal of lndia* **43**(1), 31-43.

Singh P, Gupta A, Singh M, (2014) Hydrological Inferences from Watershed Analysis for Water Resource Management Using Remote Sensing and GIS Techniques, *Egyptian Journal of Remote Sensing and Space Sciences* **17**(2),111-121.

Smith KG (1950) Standards for Grading Texture of Erosional Topography. *American Journal of Science* **248**, 655-668.

Strahler AN (1957) Quantitative analysis of watershed geomorphology, *Transactions of American Geophysics Union* **38**, 913-920.

Strahler AN (1964) Quantitative Geomorphology of Drainage Basins and Channel Networks, In: VT Chow (ed) *Handbook of Applied Hydrology*, section 4-11. McGraw Hill Book Company, New York.

Taylor R, Howard K (2000) A Tectono-geomorphic Model of the Hydrogeology of Deeply Weathered Crystalline Rock: Evidence from Uganda. *Hydrogeology Journal* **8**(3), 279-294.