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Groundwater Resources Prospecting Using Morphometric Techniques: A Case Study of Oji Watershed, Southeastern Nigeria

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ABSTRACT
Watershed morphometric techniques have been effectively employed in the ground water studies in different climatic zones of the world. In this study, morphometric analysis was carried out using geospatial technologies (Geographical Information Systems and Remote Sensing) to assess the geo-hydrological properties of the Oji watershed and to determine if the area has good or poor prospects for ground water resource development through geo-morphometric specs. The linear parameters (Rb=3.65, and Lg=1.02) indicate lowland areas, gentler slopes in the valleys, low surface runoff and more infiltration of discharged water into the subsurface formation and the recharging groundwater aquifers. The shape parameters (Re=0.15, Rf=0.22 and Rc=0.63) indicate the elongated shape of the basin. The areal parameters (Dd=0.49, Df=0.27, Dt=0.97, If=0.13) and Relief parameters (H=900m, Rr=0.014, and Sb=1.4%) show that it has low discharge of runoff, permeable subsurface, moderate to high infiltration capacity and good groundwater resource. This research work has provided valuable information on the ground water status in the Oji watershed which can be of immense use to the policy makers with respect to ground water resource utilization and watershed management.
Keywords: Morphometric Techniques, Ground water resource prospecting, Oji Watershed.

INTRODUCTION
A watershed is a geomorphic or hydrologic unit bounded by ridges of high land areas and it controls the movement and occurrence of surface and the subsurface water.
Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998; Obi Reddy, Maji, & Gajbhiye, 2002). The morphometric analysis of the watershed and channel network plays a critical role in comprehending the hydro-geological behavior of watershed and expresses the prevailing climate, geology, geomorphology, and structural antecedents of the catchment (Hajam, Hamid, & Bhat, 2013).
Water wise, the world is divided into three parts: sufficient, insufficient and polluted. In 1981, the World Health Organization estimated that more than three billion people do not have enough clean water to meet their daily needs. Even more disturbing, 80 percent of all diseases and sicknesses are related to water or inadequate sanitation. And, in most vulnerable population group, children under five, there are 25 million deaths each year from water – related diseases. About 71% of the Earth’s surface is covered by water, 97% of this is salty water, 2% of the water is the form of glaciers in the polar regions and only 1% of this is in the stream channels and groundwater reservoirs (WWAP, 2009). The surface water is vulnerable to pollutants and contaminants and therefore not potable for direct human consumption. Emphasis is shifted to ground water resources development as an alternative because of its quality.

Morphometric analysis coupled with Geographic information systems and Remote sensing has advantages over the traditional methods of groundwater prospecting or exploration. This technique can substitute the surface and subsurface geological methods of ground water exploration and can precede the surface geophysical methods of seismic refraction and electrical resistivity methods. The technique has the capability of giving accurate information on the groundwater conditions of any part of the globe without being to the place or studying the geologic maps of the area. In this present study, the objective is to apply the morphometric technique in conjunction with geospatial technology in the groundwater resource prospecting/evaluation in the Oji watershed in Southeastern Nigeria.

STUDY AREA

The Oji watershed lies within latitudes 6^0 31′ 30″N and longitudes 7^0 44′ 0″ E. The Oji River is about 67.72km in length with a drainage basin area of about 927km^2 (Fig. 1.).

This area has relatively warm temperature days of 27^0C to 32^0C and moderately cool nights temperature of 17^0C to 28^0C. The area has two main seasons which are the dry season and rainy season. Dry season prevails from early November to March. The rainy season commences from April to October with an August break. The rains occur as violent downpours accompanied by thunderstorms. The area experiences high relative humidity of about 65% to 80% with the highest during the rainy season when there is medium to low sunshine hours and low evaporation. The landforms of the study area are categorized into cuesta, plains and lowland landscapes. The geology can be broadly classified into shales, false-bedded sandstones and coal measures (Akamigbo, 1987). The area is underlain by the Imo Shale, Nsukka Formation, Ajalli Sandstone, Lower Coal Measure (Mamu Formation), The Ajalli and Nsukka Formations are highly aquiferous. The region has numerous artesian boreholes. The underlying soils are of sedimentary origin and sandstones and shales are the dominant parent materials.

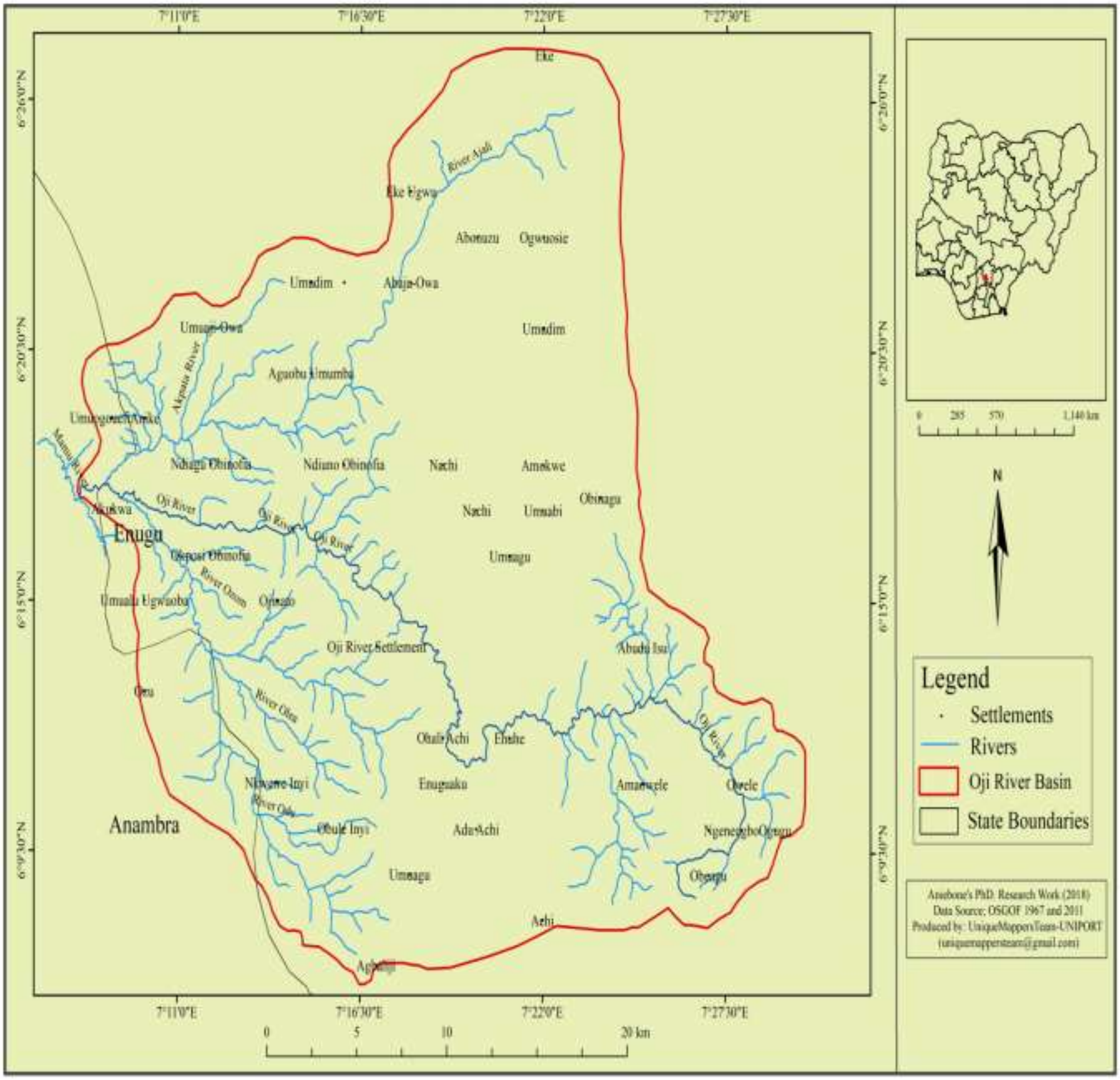

Fig. 1 The study area showing the Oji watershed and its dendritic pattern

MATERIALS AND METHODS

This present study is based on the survey of UDI-301 topographical map on a 1:100,000 scale. The map was used for the data extraction of this work. The Topo-sheet was scanned, rectified/georeferenced and mosaiced in ArcGIS platform. The satellite imageries of the watershed were downloaded from the United States Geological Survey Agency (USGS) Website as a secondary source and is employed to delineate the Stream ordering, Digital Elevation Model (DEM) and the watershed. The DEM image shows the distribution and spatial difference of elevation values at every geographic point/location in the area. It helps in the processing and delineating of the watershed parameters which are obtained from the elevation values. Employing the Strahler's technique of stream ordering, the basin morphometric parameters and stream order characteristics of the study area were extracted from the digitized data. Employing suitable tools in ArcToolbox, drainage network maps are digitized from the Topo-sheet and are projected onto proper coordinate system, that is World Geodetic System 1984, Universal Transverse Mercator Zone 32N. So far the morphometric analysis of a watershed requires the delineation of all the existing streams. The digitization of the watershed was carried out for morphometric analysis in GIS environment using Arc GIS 9.0 software. The technique used in deriving the variables is equally shown in Table 1.

RESULTS AND DISCUSSIONS

The morphometric analysis of a watershed provides quantitative description of the watershed geometry to comprehend the initial slope of inequalities in the rock hardness, structural controls, recent diastrophism, geological and geomorphologic history of the watershed (Strahler, 1964). The watershed morphometric study relates watershed and stream network geometries to the transmission of water and sediment through the watershed.

In this present study, the morphometric analysis has been carried out on parameters such as stream order, stream length, basin length, basin perimeter, bifurcation ratio, length of overland flow, drainage area, drainage density, drainage frequency, drainage texture, infiltration number, elongation ratio, circularity ratio, form factor, basin relief, relief ratio, and basin shape using mathematical formulae as given in Table 1 and the results are summarized in Tables 2-4. The parameters are used in relation to groundwater resources studies in the area of study. This present research adopted Horton's quantitative technique of drainage basin assessment. The Oji watershed exhibits dendritic type of drainage network as shown in figure 2 and this indicates the homogeneity in texture and lack of structural control in the study area. The results of the present morphometric analysis of this research as presented in (Table-2) are discussed.

Table 1. Drainage Basin Characteristics (Morphometric Parameters with formulae)

S/No.	Parameters	Symbol	Formula	Ref
			Linear Aspect	
1	Stream Order	Sμ	Hierarchical rank	Strahler & Chow (1964)
2	Bifurcation Ratio	R_b	Rb = Nμ / Nμ +1, Where, Rb = Bifurcation ratio, Nμ = No. of stream segments of a given order and Nμ +1= No. of stream segments of next higher order.	Schumn (1956)
3	Stream Length	Lμ	Length of the stream (kilometers)	Horton (1945)
4	Basin Length	L	$L = 1.312 \times A^{0.568}$	Schumn (1956)
5	Length of Overland Flow	Lg	Lg=1/2D Km Where, D=Drainage density (Km/Km2)	Horton (1945) Schumn (1956)
6	Basin Perimeter		P = Outer boundary of drainage basin measured in kilometers.	
			Areal Aspect	
7	Basin Area	A	Area from which water drains to a common stream and boundary determined by opposite ridges.	Strahler & Chow (1964)
8	Drainage Density	D_d	D_d = Lμ/A, Where, D_d = Drainage Density (Km/Km^2), Lμ = Total Stream Length Of All Orders and A = Area of the basin (Km^2)	Singh & Singh (1997)
9	Drainage Frequency	Df	Df = Nμ/A, Where, Df = Drainage frequency, Nμ = Total no. of streams of all orders and A = Area of the basin (Km^2)	Singh & Singh (1997)
10	Infiltration Number	If	If =Dd × Df Where Dd=Drainage density, Df =Drainage frequency(Km/Km^2) Df = Drainage frequency	Zavoiance I (1985)
11	Drainage Texture	Dt	Dt = Nμ /P Where, Nμ = No. of streams in a given order and P = Perimeter (Kms)	Horton (1945), Pareta K, Pareta U (2011)
12	Basin Relief	H	H = Z – z, Where, Z = Maximum elevation of the basin (m) and z = Minimum elevation of the basin (m)	Rudraiah , Govindaiah & Vittala (2008)
13	Relief Ratio	Rr	$R_r = H / L_b$, Where, H = basin relief (m) and L_b = Basin length (m)	Schumn (1956)
14	Basin Slope	S_b	Sw = H / L_b, Where H and L_b= given above	Miller (1953)

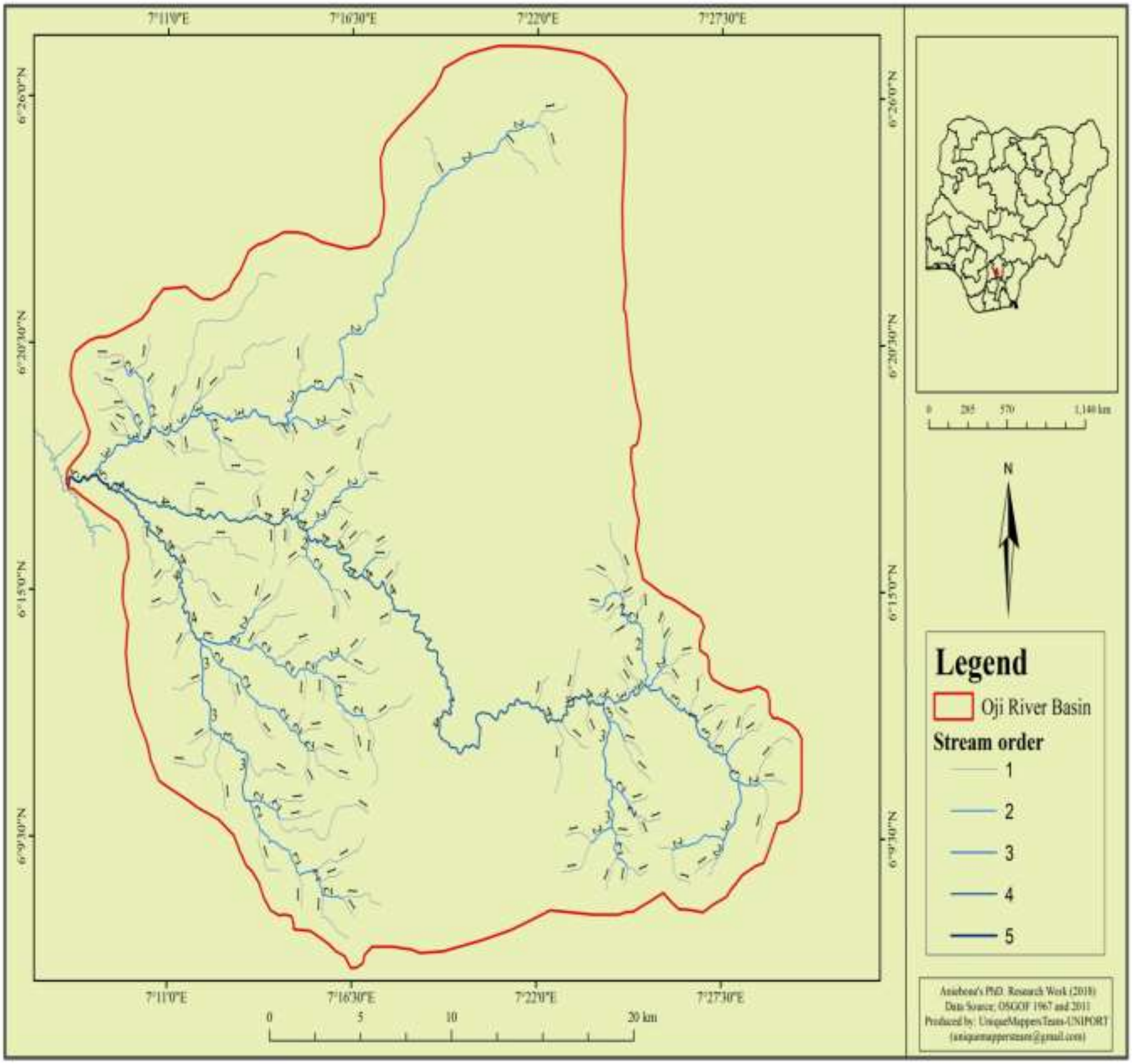

Figure 2. Drainage Network of Oji Watershed Showing the Pattern/Ordering

Table 2. Results of Linear Morphometric Parameters of the Oji Drainage Basin Network

WSD Name	No. of Stream of Different Orders					ΣLu (km)	Bifurcation Ratio(Rb)	Basin Length(Lb) (km)	Basin Perimeter(Pb)	Length of Overland Flow(Lg)
	I	II	III	IV	V					
OJI Watershed	131	63	33	26	1	454.19	3.65	63.59	135.70	1.02

Where ΣLu = the total stream length of order

Table 3. Results of Areal Morphometric Parameters of the Oji Drainage Basin Network

WSD Name	Area (A)	Drainage Density(Dd)	Drainage Frequency(Df)	Drainage Texture(Dt)	Infiltration Number(If)	Form Factor Ratio(Rf)	Elongation Ratio(Re)	Circularity Ratio(Rc)
OJI Watershed	928	0.49	0.27	0.97	0.13	0.22	0.15	0.63

Table 4. Results of Relief Morphomtric Parameters of Oji Drainage Basin Network

WSD Name	Basin Relief (H) in Meters	Relief Ratio(Rr)	Basin Slope(Sb)
OJI Watershed	900	0.014	0.014(1.4%)

Length of overland flow (Lg)

This is the length of flow of water over the ground before becoming concentrated in definite stream channels (Horton, 1945). This is significantly affected by infiltration/percolation through the soil that varies in time and space (Schmid, 1997). Oyatayo et al, (2017), are of the opinion that higher Lg value will provide longer concentration time and favourable condition for infiltration within the basin whereas a smaller length of overland flow indicates that the basin may have a higher flood hazard potential. The length of overland flow of the Oji watershed is 1.02 kilometers as shown in Table 2. This shows gentler slopes in the valleys and hence low surface runoff and longer flow paths. The implication of this is more infiltration of discharged water into the subsurface formation and the recharging groundwater aquifers. This means that the region has a good groundwater potential. Hence suitable for groundwater resource development.

Bifurcation Ratio (Rb)

Bifurcation ratio is about the branching pattern of a drainage network (Schumm, 1956). It expresses the ratio between the total numbers of stream segments of one order to that of the next higher order in a drainage basin. A low bifurcation ratio shows that there will be high possibilities of flooding as water will tend to accumulate rather than spreading out (Chorley, 1969; Kelson, and Wells, 2011). The study area has a mean bifurcation ratio of 3.65 as shown in Table 2 indicating that the area is a lowland area. This low value indicates less structural disturbance in the Oji watershed. It suggests that the study area has low potentials for discharge or runoff compare to those of highland areas with bifurcation ratio of 5.0 (Strahler, 1952). This implies more infiltration into the permeable subsurface formation. The relatively lower value of mean bifurcation ratio also suggests the geological heterogeneity, higher permeability and lesser structural control in the area. This shows that the area is suitable for groundwater development.

Drainage density (Dd)

The drainage density determines the time travel by water (Schumn, 1956). It is a numerical measure of landscape dissection and runoff potential. Drainage density is the outcome of interacting factors controlling the runoff and in turn influences the output of water and sediment from the drainage basin (Chorley, 1969). Drainage density depends on factors like soil permeability, lithological porosity etc. The hydrology of basin changes significantly in response to the changes in the drainage density. A high drainage density reflects a highly dissected drainage basin with a relatively rapid hydrological response (runoff) to rainfall events, while a low drainage density means a poorly drained basin with a slow hydrologic response (Melton, 1957). A high Dd is an indication of a weak basin, low ground water potentiality, an impermeable subsurface material with sparse vegetation and high relief, implying that a large proportion of the precipitation runs off. Also a low Dd reflects a weak coarse drainage texture, high porosity, permeable subsurface materials with dense vegetation and indicates that most rainfall infiltrates the ground and few channels are required to carry the surface runoff. (Roger, 1971). The Dd of the Oji watershed is very low (0.49km/km^2) as shown in Table 3 and this indicates clearly that the watershed has permeable subsurface material, good vegetation and low relief leading to greater infiltration of water with less overland flow and recharging of groundwater aquifers. This makes the region very suitable for groundwater development.

Drainage Frequency

Drainage frequency is the number of stream segments per unit area of the watershed (Horton, 1945). The Stream frequency is dependent on the rock structure, infiltration capacity, vegetative cover, relief, nature and amount of rainfall and subsurface material permeability. High drainage frequency value indicates greater surface runoff, steep slope, impermeable subsurface material, poor porosity and sparse vegetation whereas a low drainage frequency value exhibits presence of a permeable subsurface material with enhanced porosity. The drainage frequency of the Oji watershed is 0.27km^2 as shown in Table 3. By implication the region has a good potentiality for groundwater development.

Drainage Texture (Dt)

Drainage texture (Dt) plays a crucial part in hydrologic behavior which depends on the lithological porosity, infiltration and topographic properties of the watershed (Schumm, 1965). It gives information on the grainsize composition of the regolith. According to Smith (1950), the Dt is classified as coarse (<4 per km), intermediate (4–10 per km), fine (10–15 per km) and ultra-fine (>15 per km). Watersheds having low Dt values have a good potentiality for groundwater recharge than the others of high Dt values (Pareta and Pareta, 2011a). The Drainage texture value of the Oji watershed is 0.97 as depicted in Table 3. The Oji watershed falls into very coarse to coarse texture category and indicates good porosity and permeability of sub-surface material, high infiltration capacity, lower surface run off rate, and significant recharge of the ground water. The implication of these is good groundwater potential.

Infiltration Number (If*)*

The infiltration number of a watershed is defined as the product of drainage density and drainage frequency and gives information on the infiltration properties of the watershed. It is inversely proportional to the infiltration capacity of the basin. The infiltration number of the Oji watershed is 0.13 as shown in Table 3. This indicates that runoff will be very low and the infiltration capacity very high causing more infiltration of water and recharging of the groundwater aquifers.

Elongation ratio (Re)

According to Pareta and Pareta (2011), elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. It is very important index in the analysis of shape which helps to infer about the hydrological character of a watershed. Its value varies from 0 in highly elongated shape to unity i.e. 1.0 in the circular shape. The shape of the basin is determined by the Elongation ratio and can be classified based on these values as circular (0.9 - 1), oval (0.8 – 0.9), less elongated (0.7 – 0.8), elongated (0.5 – 0.7), more elongated (< 0.5). The elongation ratio of the Oji watershed is 0.15 as shown in Table 3, indicating relatively moderate relief of the terrain and elongated shape of the watershed. .By implication the watershed is less liable to flood hazard and has good potential for groundwater resource development.

Circularity ratio (Rc)

The circularity ratio (Rc) is used as a quantitative measure for visualizing the shape of the watershed and is expressed as the ratio of watershed area (A) to the area of a circle (Ac) having the same perimeter as the watershed (Meher-Homji, 1971; Strahler, 1964). It is affected by the lithological properties of the watershed. Higher values indicate that the watersheds shapes are circular whereas Lower Rc value indicates elongated shape of the watersheds. Watersheds having higher circularity ratios are more exposed to flooding because they will always experience shorter time lag, shorter time of rise and higher hydrographic peak (Ajibade, Ifabiyi, Iroye & Oguntero, 2010). The circularity ratio of the Oji watershed is 0.63 as presented in Table 3. By implication the Oji watershed will be less liable to flooding due to higher infiltration capacity and this makes the area good for groundwater development.

Form Factor (Rf)

Form factor is defined as the ratio of basin area to the square of the watershed length. It provides a measure of relationship between catchment area and catchment length and their effects on hydrology (Fryirs & Brierley, 2013). The values of form factor range between 0.1 to 0.8. The form factor value of Oji watershed is low, 0.22 as shown in Table 3, which represents elongated shape. Watershed morphology has profound impact on the watershed hydrology. The watersheds with high form factor (0.8), have high peak flows of shorter duration, whereas, elongated watershed with low form factors have lower peak flow of longer duration. So, the Oji watershed has (lower) flatter peaks of flow for longer duration that is easier to manage than of the circular watersheds. Hence low flooding incidence and greater infiltration capacity thereby has good groundwater potential.

Basin Relief (H)

Basin relief is the difference in elevation between the highest and lowest points within a particular watershed. It controls the stream gradient and therefore influences flood patterns and the amount of sediment that can be transported. Basin relief is an important factor in understanding the denudational characteristics of the basin (Oruonye, et al, 2016). Basins with higher relief will be more erosive and liable to flooding. The total basin relief of the Oji watershed is 900 ms as shown in Table 4. The Oji watershed has a low to moderate relief. By implication the basin will be less liable to flooding hazard and will have a good groundwater potential, hence the region is suitable for groundwater resource development.

Relief Ratio (Rr)

The relief ratio is a dimensionless number which provides a measure of the average drop in elevation per unit length of river (Fryirs and Brierley 2013). Relief ratio is an indicator of the intensity of erosional process operating on the slope of the basin (Schumm, 1956). Runoff travels faster in steeper basins, and vice versa; hence basins with higher relief ratio are more susceptible to floods and erosion. The relief ratio of the Oji river watershed is 0.014 as shown in Table 4. By implication the basin has a low flood potentiality and a good groundwater potential.

Basin slope (Sb).

Basin Slope is very crucial in the assessment of runoff generation, direction and volume (Zavoiance, 1985). Watersheds (basins) of low slope have small potentiality of surface runoff and the generating hydrograph is characterized by low peak of discharge and longer time of concentration. Basins of high (steep) slope yield hydrographs characterized by high peak discharge, high volume of surface runoff with short time of concentration (El Osta, et al, 2016). The Oji river basin has a basin slope of 0.014 as shown in Table 4. By implication the basin is less liable to flooding and posses good groundwater potential.

CONCLUSION

The Oji watershed's ground water potential was assessed using spatial technology based morphometry technique. The drainage parameters aided in understanding numerous basin characteristics, and are employed in the determination of ground water potential of the study area. The findings indicate that the area has low incidence of flooding, high infiltration capacity and a good ground water potential. The findings are said to be true bearing in mind the existence of numerous water boreholes in the area. All the communities depicted in figure 1 have one or more functional water borehole projects. The area has two aquiferous formations; the Ajalli Sandstone and Nsukka Formation among others as the underlying lithologic formations.

This research work has provided valuable information on the ground water status in the Oji watershed which can be of immense use to the policy makers with respect to ground water resource utilization and watershed management. It will also provide background information to the hydrogeologists, hydrologists, water resources engineers and others in ground water exploration/exploitation and drilling business in the area.

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