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Hydrological Analysis of Onitsha North East Drainage Basin Using Geoinformatic Techniques

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Abstract: The hydrological analysis of Onitsha North East drainage basin geared at validating the hortinian postulation is reported. The study focused mainly on the geometry, more emphasis being placed on the relationship between morphometric characteristics such as stream order (N_u), stream length (L_u), bifurcation ratio forming the linear properties and drainage density (D), stream frequency (F_s), texture ratio (T), elongation ratio (R_e), circularity ratio (R_c) form factor ratio (R_f) comprising the area properties of the drainage basin were computed, forming the basis of analysis of the drainage basin. A total number of 396 streams were identified of which 289 are 1st order streams, 82 are 2nd order, 19 are 3rd order, 5 in 4th order and one is indicating 5th order streams. Drainage patterns of stream network from the basin have been observed as mainly dendritic type which indicates the homogeneity in texture and lack of structural control. The mean bifurcation ratio value is 4.16 for the study area falls within the standard range and shows that the basin conforms to the characteristics of a natural stream which indicates that the geological structures are less disturbing to the drainage pattern. The drainage density (D) of the study area is 1.0 km/sq. km. This value indicates that for every square kilometer of the basin, there is 1.0 kilometer of stream channel. This makes the study area fall into the group of low density basins which suggest that the low drainage density indicates that the basin is highly permeable subsoil and thick vegetative cover. The elongation ratio (Re) value of the study area is 0.78, the basin in the study area assumes a pear shaped characteristics indicating high degree of integration. The circularity ratio of the study area is 0.01 which indicates that the basin is oval tending towards elongation in shape with high level of integration.

Key words: Morphometric · GIS · Basin · Ordering · Lithology

INTRODUCTION

A drainage basin is the part of the earth's surface that is drained by main stream and its tributaries. The drainage basin is fundamental geomorphic unit of land and all flow of surface is governed by its properties. It is an open system into which and from which energy flows.

Drainage basin is a fundamental, precise and usually ambiguous unit that is recognized as a reliable and useful planning unit. It has now formed a framework for human activities like agriculture and has guided river navigation towards sustainable agriculture [1].

The scientific approach to the hierarchical classification of streams and basin area was initiated by [2] who defined several drainage basin characteristics that were measurable on topographic maps. Today, these characteristics can be measured not only on topographic maps but also on satellite imageries. These characteristics include stream order, stream length, bifurcation ratio, basin area and length, perimeter, drainage density, stream frequency, elongation ratio, circularity ratio, texture ratio and form factor ratio [3].

One of the early accomplishments of fluvial morphometry was the analysis of branching drainage network an ingenious numbering system derived by [2] and modified by[4] whereby fingertip tributaries of streams originate from overland or ground water flow and they are designated as first order stream. A second order stream begins at the junction where two first order streams meet, it may receive additional first order tributaries but there is no increase in the second order stream. Where two order streams meet a third order stream is formed. It continues like that till the last order is reached.

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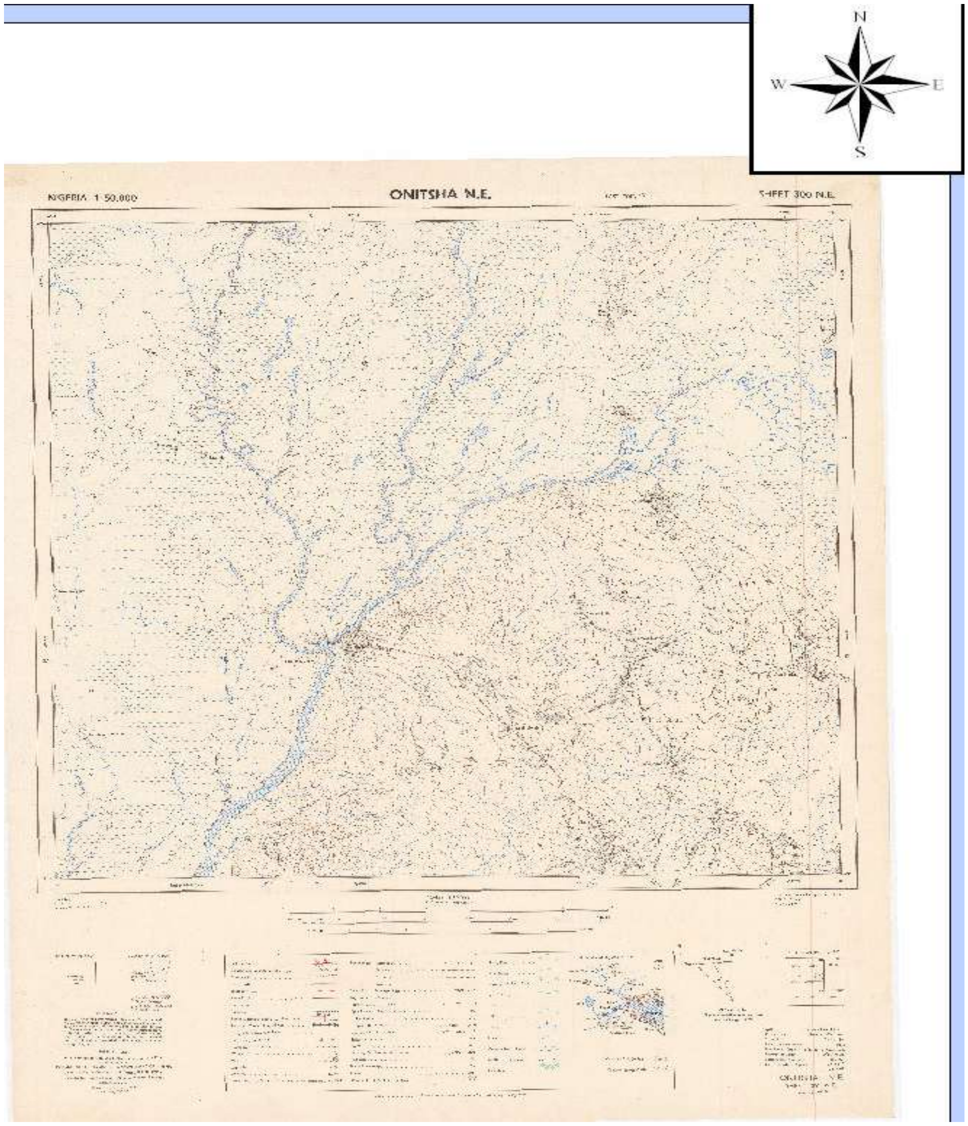

Fig. 1: Locational Map of the Study Area

Today, more efficient technique of Geographical Information System has been put in place to boost the work of [2] in measuring drainage basin characteristics. It is a technique used for spatial analysis of spatially referenced data. Prior to this era, the application of GIS in drainage basin analysis has not been widely used. Thus, this technique would be used to measure the morphometric characteristic of Onitsha North East drainage basin. Onitsha North East is located within latitude 6°15' to 6° 30' N and longitude 6°45' to 7°00' E. Its elevation ranges from 50m to 450m with an average elevation of about 250 m. The Onitsha North East water shed is situated on a rugged terrain of lowland. It is also bounded by steep fall to the surrounding plain; however the fall is less marked especially in the area drained by tributaries of Niger River (Fig 1). The relief of the watershed is developed on 'the older granites of the Precambrian Basement Complex. This Geologic formation comprises of both Igneous and Metamorphic rocks, Biotitic, Gneiss and Meta-sediments. The topography forms part of the vast undulating Plains of the Niger Delta. The watershed is highly noted for its drainage network made up of streams which form the tributaries of the River Nigeria. The natural vegetation of the study area is perhaps closest to the Mangrove swamp forest which is characterized by dense canopy trees, shrubs and few under growth. However, the watershed is distinct from its surrounding vegetation especially in terms of woodland and peculiarity of floristic composition. Socio-economic environment is a composite of numerous interrelated and

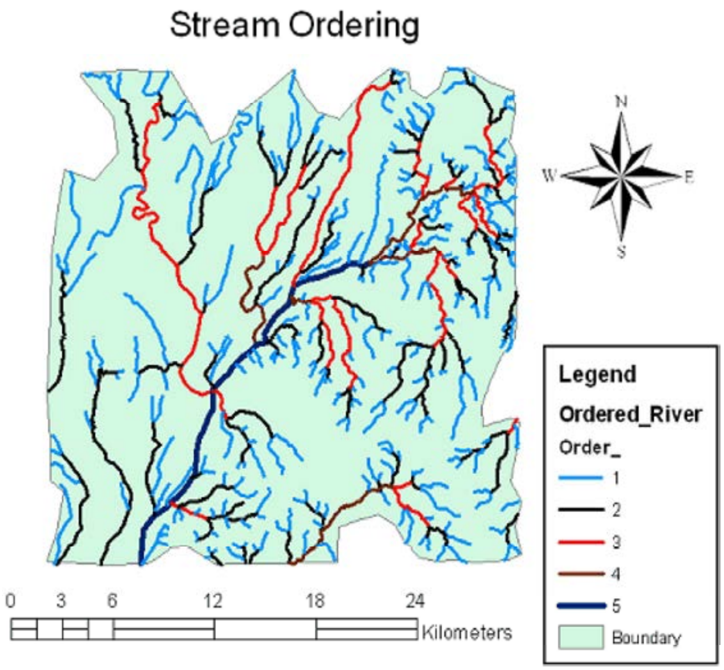

Fig. 2: Ordered Stream Using Factorization Process in ArcGIS 9.3 after Strahler (1964)

non related items, descriptive of human relationships and interactions. Most economic activities of the people living in and around the watershed are: lumbering, farming, sharp sanding extraction from the river bed,, block industries, commercial activities etc. Around the watershed and along the floodplain are subsistent farming activities.

MATERIALS AND METHODS

The base map for the study is a hard copy topographic map on 1: 50000 scale. The hard copy topographic map was scanned and exported in ArcGis 9.3 environment where it was georeferenced. After georeferencing, onscreen digitization process was carried out to extract the stream network according to their order following [5] stream ordering technique. The attributes were assigned to create the digital data base for the drainage layer of the river basin. The map showing drainage pattern in the study area (Figure 2) was prepared after detailed ground checks with GPS survey on channel network. Various morphometric parameters such as stream order (N_u), stream length (L_u), bifurcation ratio forming the linear properties and drainage density (D), stream frequency (F_s), texture ratio (T), elongation ratio (R_e), circularity ratio (R_c) form factor ratio (R_f) comprising the area properties of the drainage basin were computed, forming the basis of analysis of the drainage basin.

DISCUSSION OF RESULTS

The various morphometric parameters of the Onitsha north east drainage basin using ArcGis 9.3 and are summarized in Tables 1 and 2

Linear Aspect of the Drainage Network: The linear aspects of drainage network such as stream order (N_u), bifurcation ratio (R_b), stream length (L_u) results have been presented in Table 1.

Stream Order (Nu): In the drainage basin analysis the first step is to determine the stream orders. The channel segment of the drainage basin has been ranked according to [5] stream ordering system using ArcGIS 9.3. The study area is 5th order drainage basin (Figures 1). The total number of 396 streams were identified of which 289 are 1st order streams, 82 are 2nd order, 19 are 3rd order, 5 in 4th order and one is indicating 5th order streams. Figures 3a to 3e show the results of the queries that retrieved the total number of streams for each of the order as shown in Table 1. Drainage patterns of stream network from the basin have been observed as mainly dendritic type which indicates the homogeneity in texture and lack of structural control. This pattern is characterized by a tree like or fernlike pattern with branches that intersect primarily at acute angles. The properties of the stream networks are very important to study the landform making process [6].

Table 1: Linear Aspect of the Drainage Network of the Study Area

River Basin	Stream Order (U)	Stream Number (Nu)	Stream Length in Km (Lu)	Stream mean length in Km (Lu)	Cumulative Stream Length in Km (Lu)	Log Nu	Log Lu
Onitsha Drainage Basin	1	289	356.78	1.24	1.24	2.461	2.552
	2	82	178.53	2.18	3.42	1.914	2.252
	3	19	97.45	5.13	8.55	1.279	1.989
	4	5	33.23	6.65	15.2	0.699	1.522
	5	1	24.03	24.03	39.23	3.111	1.381
Total	-	396	690.02			-	-

Bifurcation Ratio

1st order/ 2nd order	2nd order/ 3rd order	3rd order/ 4th order	4th order/ 5th order	Mean Bifurcation Ratio
3.52	4.32	3.80	5.00	4.16

Table 2: Aerial Aspects of the Study Area

Morphometric Parameters	Symbol/Formula	Result
Area (sq. km)	A	691.35
Perimeter (km)	P	126.30
Drainage density (km/sq. km)	$D=\sum Lu/A$	1.0
Stream frequency	$F_s = \sum Nu/A$	0.57
Texture ratio	$T = \sum N_1/P$	2.29
Basin Length (km)	L_b	36.95
Elongation ratio	$Re = \underline{2\sqrt{A/\Pi}}$	
	L_b	0.78
Circularity ratio	$Rc = \underline{4\Pi A}$	
	P^2	0.01
Form Factor ratio	$R_f = A/L_b^2$	0.51

Where

ΣLu = Total stream length of all orders

ΣNu = Total number of all orders

ΣN_1 = Total number of 1st order streams

Σ = 3.14

The order wise total number of stream segment is known as the stream number. [2] laws of stream numbers states that the number of stream segments of each order form an inverse geometric sequence with plotted against order, most drainage networks show a linear relationship, with small deviation from a straight line. This means that the number of streams usually decreases in geometric progression as the stream order increases.

Bifurcation Ratio (R_b): The term bifurcation ratio (Rb) is used to express the ratio of the number of streams of any given order to the number of streams in next higher order [7]. Bifurcation ratios characteristically range between 3.0 and 5.0 for basins in which the geologic structures do not distort the drainage pattern [5]. [8] demonstrated that bifurcation ratio shows a small range of variation for different regions or for different environment dominates. The mean bifurcation ratio value is 4.16 for the study area (Table 1) falls within the standard range and shows that the basin conforms to the characteristics of a natural stream which indicates that the geological structures are less disturbing to the drainage pattern.

Stream Length (L_u): Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics streams of relatively smaller lengths are characteristics of areas with larger slopes and finer textures. Longer lengths of streams are generally indicative of flatter gradients. Generally, the total length of stream segments is maximum in first order streams and decreases as the stream order increases. The number of streams of various orders in the basin were queried and their lengths also determined and summed in ArcGis 9.3 environment. The relationship between stream order and cumulative stream length was examined (Table 1), it seems to be in geometric progression and agrees with Horton's law of stream length, which states that the "The Cumulative Length of stream segment of successive orders tend to form a geometric series beginning with the mean length of the first order segment and increasing according to a constant length ratio". Slight deviation from its general behavior between the third and forth orders and between the forth and fifth orders indicate that the terrain is characterized by variation in lithology and topography.

Areal Aspects of the Drainage Basin: Area of a basin (A) and perimeter (P) are the important parameters in quantitative morphology. The area of the basin is defined as the total area projected upon a horizontal plane contributing to cumulate of all order of basins. Perimeter is the length of the boundary of the basin which can be drawn from topographical maps. Basin area is hydrologically important because it directly affects the size of the storm hydrograph and the magnitudes of peak and mean runoff. It is interesting that the maximum flood discharge per unit area is inversely related to size [9]. The aerial aspects of the drainage basin such as drainage density (D), stream frequency (Fs), texture ratio (T), elongation ratio (Re), circularity ratio (Rc) and form factor ratio (Rf) were calculated and results have been given in Table 2.

Drainage Density (D): [10, introduced the drainage density (D) is an important indicator of the linear scale of landform elements in stream eroded topography. It is the ratio of total channel segment lengths cumulated for all orders within a basin to the basin area, which is expressed in terms of mi/sq. mi or km/sq. km. The drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. It has been observed from drainage density measurements made over a wide range of geologic and climatic types that a low drainage density is more likely to occur in regions of highly resistant of highly permeable subsoil material under dense vegetative cover and where relief is low. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture [5].

The drainage density (D) of the study area is 1.0 km/sq. km. This value indicates that for every square kilometer of the basin, there is 1.0 kilometer of stream channel. In order words, 1.0 is the mean length of stream channel for each unit area. According to [5] values of Drainage density under 12 are low density, those with values of between 12 and 16 are medium density basins while basins with values above 16 are high density basins. From this classification, Onitsha east drainage basin falls into the group of low density basins. It is suggested that the low drainage density indicates the basin is highly permeable subsoil and thick vegetative cover[11]. The type of rock also affects the drainage density.

Generally, lower values of D tend to occur on granite, gneiss and schist regions. The chief rock of type in the study area is Khondalite, which falls under the gneissic group of rocks. This corroborates the low drainage density observed in the drainage basin.

Stream Frequency (Fs): Stream frequency or channel frequency (Fs) is the total number of stream segments of all orders per unit area [10]. The stream frequency value of the basin is 0.57. The value of stream frequency (Fs) for the basin exhibit positive correlation with the drainage density value of the area indicating the increase in stream population with respect to increase in drainage density.

Texture Ratio (T): Texture ratio (T) is an important factor in the drainage morphometric analysis which is depending on the underlying lithology, infiltration capacity and relief aspect of the terrain. In the present study the texture ratio of the basin is 2.29 and categorized as moderate in nature.

Elongation Ratio (Re): [7] defined elongation ratio (Re) as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. It is a very significant index in the analysis of basin shape which helps to give an idea about the hydrological character of a drainage basin. Values of elongation ratio ranging between 0 and 0.6 indicate rotundity and low degree of integration within a basin and values between 0.6 and 1.0 assumes pear shaped characteristics of a well integrated drainage basin [5]. The Re value of the study area is 0.78, the basin in the study area assumes a pear shaped characteristics indicating high degree of integration.

Circularity Ratio (Rc): [12] defined a dimensionless circularity ratio (Rc) as the ratio of basin area to the area of circle having the same perimeter as the basin. He described the basin of the circularity ratios range 0.4 to 0.5 which indicates strongly elongated and highly permeable homogenous geologic materials. The circularity ratio value (0.01) of the basin does not corroborates the Miller's range which indicated that the basin is elongated in shape, low discharge of runoff and highly permeability of the subsoil condition but rather the basin of the study area is pear in shape with high level of integration.

Form Factor Ratio (Rf): Quantitative expression of drainage basin outline form was made by [10] through a form factor ratio (Rf), which is the dimensionless ratio of basin area to the square of basin length. Basin shape may be indexed by simple dimensionless ratios of the basic measurements of area, perimeter and length [13]. The form factor value of the basin is 0.51 which indicate lower value of form factor and thus represents oval shape tending towards elongation. The oval basin tending towards elongation with low form factor indicates that the basin will have a flatter peak of flow for longer duration. Flood flows of such elongated basins are easier to manage than of the circular basin.

CONCLUSIONS

The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation and natural resources management at micro level. The morphometric analysis carried out in the Onitsha North East drainage basin shows that the basin is having low relief of the terrain and is oval tending towards elongated shape.

Drainage network of the basin exhibits dendritic type which indicates the homogeneity in texture and lack of structural control. The morphometric parameters evaluated using GIS helped us to understand various terrain parameters such as nature of the bedrock, infiltration capacity, runoff, etc. Similar studies in conjunction with high resolution satellite data will help in better understanding the landforms and their processes and drainage pattern demarcations for basin area planning and management.

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