

MORPHOMETRY ASSESSMENT OBA RIVER BASIN AND ITS IMPLICATIONS FOR FLOOD

Abstract

The morphometric analysis of the drainage basin and channel network plays a vital role for understanding the geo-hydrological behavior of drainage basin and its implication on flood. Besides the primary aim of studying drainage basin as a geographical unit in order to understand its hydrological nature, this study examined the morphometric characteristics of Oba river drainage basin in the South-west of Nigeria with the use of GIS in order to evaluate the implication of the morphometric characteristics on flood potential in the study area. The basin was found to be of 6th order where the total length of streams was 2754.48Km, total number of streams was 2979, basin area and perimeter were 2494.45Km² and 291Km respectively while the basin length was 96.1Km. The detailed morphometry results obtained in the study, to a significant extent, was found to be helpful for determining the tendency for flood events in the watershed.

Key words: Morphometry, watershed, Oba River basin, remote sensing, Geographic Information System (GIS) and flood.

1. INTRODUCTION

Drainage Basin is an area of land which is drained by a river and its tributaries. Drainage basin is also known as the *catchment area* of a river. Morphometry is the quantitative evaluation - measurement and mathematical analysis - of the configuration of the earth's surface, shape and dimension of its landforms [1, 2]. The morphometric analysis of the drainage basin and channel network play a vital role for understanding the geo-hydrological behavior of drainage basin and **expresses the prevailing climate**, geology, geomorphology, structural control, etc. Besides, the primary aim of studying drainage basin is to understand the hydrologic nature and morphometric expression of the basin area. According to [3], the need for a comprehensive study of drainage basin characteristics is necessitated by the spatio-temporal variation exhibited by the geometric attributes of the basin. Studies involving the

quantitative analysis of drainage basin characteristics show that the morphometric analysis has found utility in the realm of flood peak prediction, estimation of erosion rates, sediment yield assessment, river catchment evaluation and development studies, landslide susceptibility assessment, and watershed prioritization for soil and water conservation, amongst others.

The morphometric characteristics influence the hydrologic regimes of rivers and the overall efficiency of the landscape in transforming precipitation and groundwater into stream. Analysis of morphometric characteristics of a drainage basin is important for the fact that detailed knowledge of basin geometry not only facilitates a better understanding of the hydrologic system, but also allows for better analysis of hydrologic events within the basin. Furthermore, quantification of the morphometric parameters of a drainage basin has proved to be of immense benefit in river basin evaluation, watershed prioritization for soil and water conservation, flood peak prediction, sediment yield assessment, river catchment evaluation and development studies, landslide susceptibility assessment and in the management of natural resources at the watershed level [4, 5].

Recently, many researchers have used remote sensing data and analyzed geomorphology parameters on Geographical Information System (GIS) platform to understand the inherent morphometric ingredients of various catchments [6]. The recent rapid development of geospatial technology has made it become an effective tool to overcome many problems associated with identification and interpretation of basin morphometric parameters and to design an effective land [7] and water resource plan for a basin area [8].

According to [9] the description and analysis of drainage basin geometry are mainly of three categories viz: linear, areal and relief measurements. Linear aspect involves measurement of parameters such as stream number in each order, total stream numbers in a basin, average stream length, total stream length, bifurcation ratio, length ratio, and length of overland flow. Areal aspect comprises the measurement of parameters such as stream areas in each order, length-area, basin shape, drainage density, stream frequency, and constant of channel maintenance, while relief aspect involves measurements of parameters such as relief ratio, relative relief, relative basin height, relative basin area, and ruggedness number.

A substantial amount of studies had attempted identifying the relationship between basin morphometry parameters and stream/river basin. The interdependence of hydrology and morphometry has been found statistically real; a major reason put forth is because both vary

uniformly with same set of underlying climatic and geologic conditions [10]. Usually areal and relief parameters are associated with flow magnitude while length parameters are related to the timing of hydrologic events. However all the morphometric categories are complexly and practically interdependent [11]. By means of experimental studies, Basin area, Drainage density and Ruggedness number have been found to be highly correlative with flood occurrence [11]. It was submitted by [12] that the capacity of a terrain to infiltrate precipitated water and transport it through underground is the main determinant of the Drainage density and flood relationship. Consequently, high underground transmissibility (due to infiltration capacity) brings about to low-magnitude flood. In contrast, an impermeable surface produces high Drainage density and high-magnitude flood.

The specific objectives of the study are to examine the morphometric characteristics of Oba river drainage basin in South-West Nigeria and evaluate the implication of the morphometric characteristics on flood potential in the study area.

2. MATERIALS AND METHOD

2.1 The study Area

Oba river basin cuts across Osun and Oyo States in the South-western Nigeria. The basin lies between Longitudes 4.145651° E and 4.220588° E; Latitudes 7.473872° N and 8.314248° N; It is located in a warm tropic region of the rain forest of the South Western Nigeria (Figure 1). The climate in the Northern part of Oba river basin (around Ogbomoso) is steadily of high temperature. The rainfall is moderate to heavy rainfall in March to July; the average annual rainfall in the basin is 1,247mm. The vegetation of the basin is derived savanna; it varies from wooded savanna in the north to rain forest in the south [13]. Settlements along Oba River course from North to South are Apo, Iluju, Obada, Mosunmade, Otuokun, Bale, Odo-Oba, Olori and Olumoye, to mention a few. The residents along the whole length of Oba River are mostly into farming and fishing. The main crop being cultivated are maize, okro, vegetable, water melon and garden egg [14].

88

95 Table 1: Data sourcing

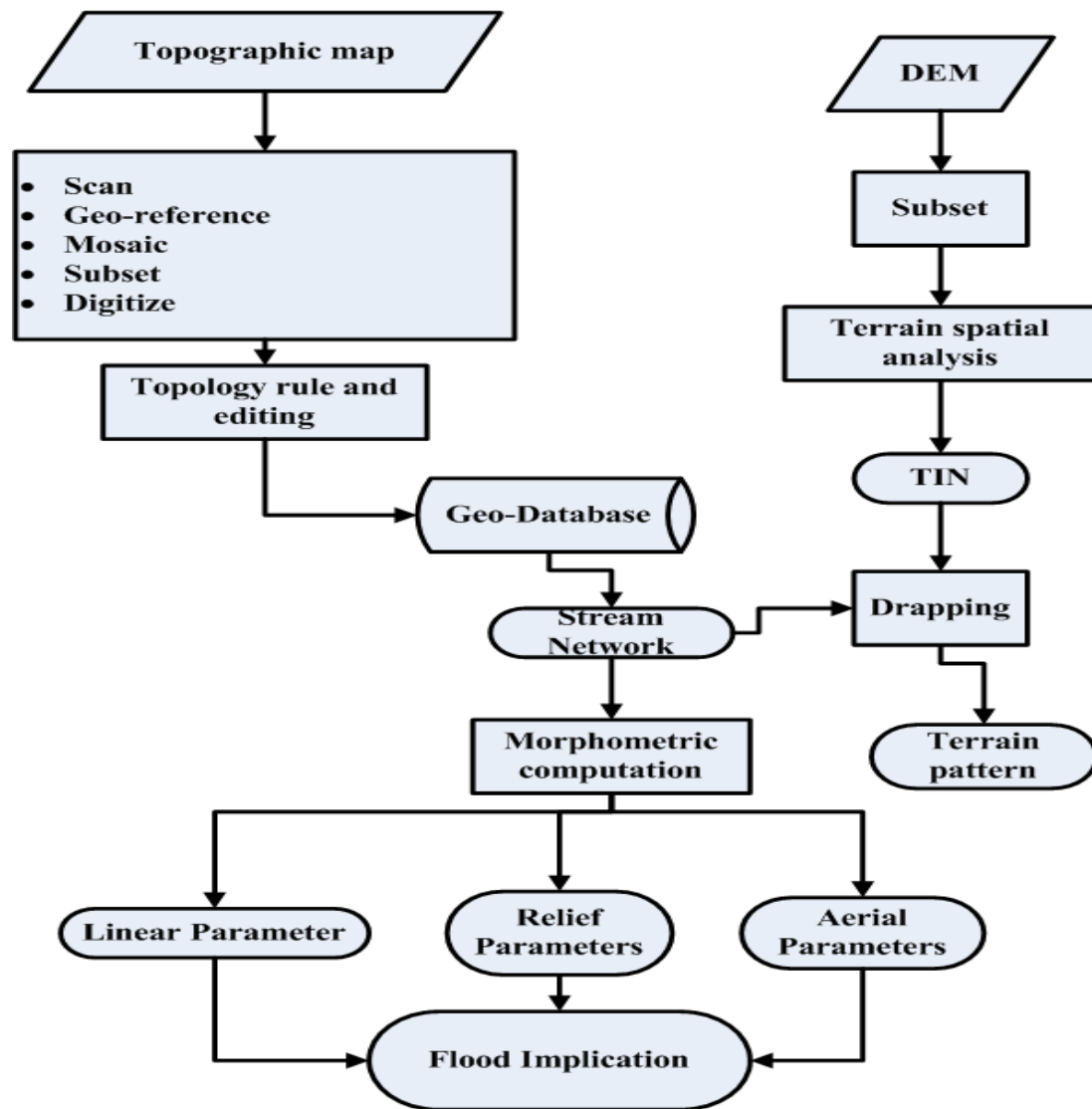
S/no	Data name	Acquisition date	Format	Scale	Source
1	Topographic map (Apomu NW, Iwo SW, SE, NW, NE, Oyo NE, NW, Ogbomoso SW, SE)	1960	Analogue	1:50,000	OSGOF
2	Administrative boundary map of Nigeria		Digital		OSGOF

96

97 2.3 Methodology

98 About ten topographic maps covering the basin under study were georeferenced and merged,
 99 after which the drainage network and basin boundary were extracted from the merged piece
 100 using Arcmap, GIS software. The drainage segments were ordered according to Shreve and
 101 Strahler principles [9, 15] however, the [9] ordering formed the basis for the morphometris
 102 analysis in the study. The workflow of study is given in Figure 2.

103 Using GIS, drainage segments were ordered numerically as order 1 starting from the basin's
 104 head waters. Two order 1 stream segments join to form an order 2 stream, two order 2
 105 streams join to form an order 3 stream segment and so on. When two streams segments of
 106 different orders meet, the resulting segment will assume the higher value of the two streams
 107 (Figure 3). Basin area, perimeter, length and length of streams were calculated with GIS. The
 108 morphometric parameters considered in this study include those of linear, areal and relief
 109 categories, The formulae adopted for the parameters are given in Table 2.



110

111 Figure 2: Workflow of the study

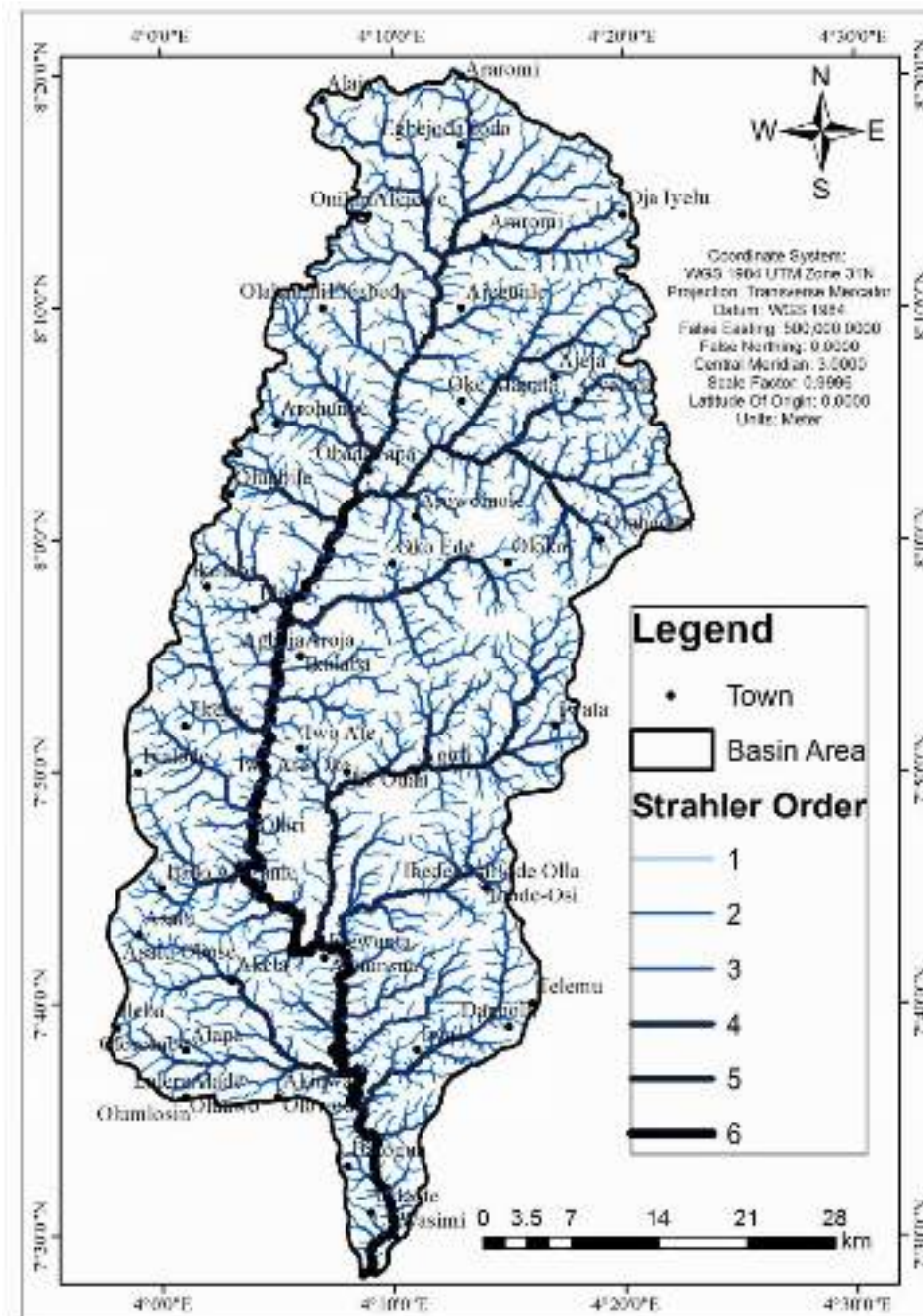


Figure 3: Map of the ordered streams of Oba river basin

115 Table 2: Description of Morphometric Parameters used in this study

	Morphometric Parameters [Symbol]	Formula/Description	Reference
LINEAR	Total Length of streams [L]	Overall Length of the stream segments	GIS
	Total Number of streams [N]	Overall Number of the stream segments	GIS
	Mean stream length [Lsm]	Lsm = L/N	[16]
	Stream Length ratio [Rl]	Rl = Lu/Lu-1 ; where Lu =Total stream length of order 'u', Lu-1 = Total stream length of its next lower order	[16]
	Bifurcation ratio [Rb]	Rb = Nu/Nu+1 ; where Nu = Total number of stream segments of order 'u', Nu+1 = Total number of stream segment of its next higher order	
AERIAL	Basin Area [A]	Area of the basin polygon	GIS
	Basin Perimeter [P]	Length of the basin polygon(or boundary)	GIS
	Basin length [Lb]	The longest dimension of the basin parallel to the main drainage line in the basin.	[17]
	Drainage Density [Dd]	Dd = L/A	[16]
	Stream Frequency [Fs]	Fs = N/A	[16]
	Texture ratio [Rt]	T = N₁/P ; where N ₁ = number of first order streams, P = Basin Perimeter	[16]
	Form Factor [Ff]	Ff = A/(Lb)² ; where A = Basin Area, Lb = Basin Length	[16]

	Circulatory Ratio [Rc]	$Rc = (4\pi A)/P^2$; where A = Basin Area, $\pi = 3.14$, P = Basin Perimeter	[18]
	Elongation Ratio [Re]	$Re = 2/Lb*\sqrt{(A/\pi)}$; where $\pi = 3.14$	[17]
	Length of overland flow [Lf]	$Lf = 1/2Dd$; where Dd = Drainage density	[16]
	Maintenance Coefficient [Mc]	$Mc = 1/Dd$	[16]
RELIEF	Basin Relief [R]	Difference between the highest relief (contour) and lowest relief in the basin.	[17]
	Relief Ratio [Rr]	$Rr = R/Lb$; where R = Basin Relief, Lb= Basin Length	[17]
	Ruggedness number [Rn]	$Rn = R/Dd$; where Dd = Drainage density	[17]

116

117 3. RESULT AND DISCUSSION

118 3.1 Linear parameters and the implications

119 The stream segment and intersections characterize the ‘linear aspect’ of the basin. Stream
 120 length reveals surface runoff peculiarities of a basin. Oba river basin spreads over an area of
 121 2,494.45Km², a total number of 2927 streams that are linked up to 6th order. Total lengths of
 122 streams and total no of streams in each order are decreasing with increasing order in the
 123 basin, this corroborates [19]. Streams of relatively longer length indicate flatter surface and
 124 low gradients. While those of shorter lengths are indicative of high slope and finer texture
 125 [20]. The drainage pattern of the stream network in the basin has been found to be mainly
 126 dendritic type (Figure 3); Table 3 presents the summary of the areal parameters considered in
 127 this study.

128 **Mean stream length (Lsm):** [9]expressed that the mean stream length is a typical property of
 129 the drainage network components, and the associated basin surfaces. It is calculated by
 130 dividing the total stream length by the number of stream segments. (Table 2). **dendritic**
 131 drainage pattern is characterized by the irregular braiding of stream segments in various

directional angles that are less than 90^0 . The pattern is typically found in the areas of sedimentary rocks or of massive igneous rocks [21].

Bifurcation ratio (Rb): The bifurcation ratio is a dimensionless linear parameter that gives index of reliefs and structural disturbances about the basin [16]. It is defined as the ratio between the total number of stream segments in one order to the number of segments in the next high order in a given drainage [17]. [9, 22] established that the values are generally between 3 and 5. According to [9, 6], the lower values of Rb are less than 3; this is typical of the basins which have record of less structural disturbances and vice versa.

The Rb of Oba river basin ranges between 0.86 and 2.23 (by stream order) with the mean value of 1.72 (Table 3). The lowest Rb value in the table is the one of the highest order of stream in the study area. [23] noted that Rb is inversely proportional to flood potential in a basin. In order words low value of Rb will suggest high risk of flooding in some parts of the basin. [13] worked on Odo-Oba settlement, which is part of Oba river watershed, as a floodplain. The lowest Rb value at the tail end of the basin together with the elongated shape of the basin suggest high risk of flooding at the exit of the basin and some distance beyond due to high water accumulation around the place. This might have suggested the construction of the Asejire dam just beyond the exit of the basin.

Table 3: Summary of the linear parameters' result

Stream order (u)	Number of stream by order (Nu)	Bifurcation ratio (Rb)	Mean of Rb	Length of stream by order (Lu)	Stream length ratio	Mean Stream length	Log Nu	Log Lu
1	1470	2.23	1.72	1492.1	-	1.02	3.17	3.17
2	659	1.79		594.14	0.4	0.9	2.82	2.77
3	369	1.86		296.57	0.5	0.8	2.57	2.47
4	198	1.85		165.72	0.56	0.84	2.30	2.22
5	107	0.86		96.11	0.58	0.9	2.03	1.98
6	124	-		109.9	1.14		2.09	2.04

3.2 Areal parameters and the implications

The areal parameters considered in this study are drainage density, stream frequency, texture ratio, form factor, circulatory ratio, elongation ratio, length of overland flow and Maintenance coefficient; Table 4 includes the summary of the areal parameters considered in this study.

The perimeter of a basin (P) and area (A) are of great significance and fundamental in generating other areal morphometry parameters of a basin. Perimeter of a basin is the boundary length of the basin; while the area of the basin is the total area projected over a horizontal plane. GIS environment helps a great deal in generating the basin perimeter and area values with high accuracy. The perimeter and area value of Oba river basin are 291 Km and 2494.45 km² respectively.

The basin length (Lb) could be expressed as the longest dimension of the basin parallel to the trunk (principal) drainage segment [17]. In this study the length of the basin is 96.1 km.

Drainage density (Dd): Drainage density has been identified as a vital parameter to indicate the linear scale of landform elements in stream eroded terrain [19]. Technically Dd of a basin is the total length of all stream segment divided by the basin area and it is measured in Km/Km². Dd gives an idea about the spacing- closeness - of the streams, thereby providing a quantitative measure of the average length of drainage channel per Km² unit area in the basin under study [19]. Low Dd values (usually less than 5Km/Km²) often associate with largely spaced streams as a result of the presence of less resistant materials (i.e. permeable rocks), gentle slope and low rainfall; while high Dd values (5km/km² and above) characterize environments with high rainfall, steep slope and poor infiltration or impermeable rocks [24]. In this study, drainage density value is found to be 1.1.Km/Km². This low Dd value would be as a result of the well drained nature of the soil types prevalent in the area and low to moderate relief nature therein. Low value of Dd in the study area also suggest the general low magnitude of flood *within* the basin despite the largeness of the area and length [11].

Stream frequency (Fs): This is also known as *drainage frequency*. It could be expressed as the total number of streams in a basin per unit area [16]. Fs indicates the drainage network distribution in a basin. Generally the value of the perimeter has been found to range from less than 1 to 6 or more based on the basin rock type [22]. Oba river basin has its Fs to be 1.17; a low value which is peculiar to terrain of low relief and high infiltration capacity [25]. The presence of large number of streams in a basin indicates that the basin is still undergoing erosion, while less number of streams in a basin shows matured topography.

183 **Texture ratio (T):** Texture ratio is defined as ratio of the total number of stream segments in
 184 the first order of the basin to the basin parameter [16]. T is a dependent of the underlying
 185 lithology (rock type) terrain relief, soil type, infiltration capacity, vegetation and rainfall in
 186 the concerned basin. He also submitted that T could be grouped into 5 classes as: very coarse
 187 (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8), and very fine (>8). [26] further
 188 established that hard (or preamable) rocks with little or no vegetation produces fine drainage
 189 texture. The drainage texture of Oba river watershed is found to be moderate with a value of
 190 5.05.

191 **Form factor (Ff):** Form factor is a numerical expression used to represent basin shapes. It is
 192 defined as the ratio of the basin area to the square of basin length [19]. A value of 0.7584 was
 193 given by Hortan as the apex Ff value, which represents the value of a perfectly circular basin
 194 thus Ff value would always be less than 0.7584. the less the value the more elongated is the
 195 watershed in question. Oba River Basin Ff is 0.27 which indicates that the basin tends to an
 196 elongated shape.

197 **Elongation ratio (Re):** elongation ratio expresses the ratio between the diameter of the circle
 198 of the same area as the drainage basin in question and the basin length [17]. The significance
 199 of Re is in the analysis of basin shape and it provides idea about the hydrological character of
 200 the watershed. The values of Re typically range from 0.6 to 1.0, according to [9], Re has been
 201 classified as: circular (0.9 - 1.0), oval (0.8 - 0.9), less elongated (0.7 - 0.8), elongated (0.5 -
 202 0.7) and more elongated (less than 0.5). The value of Re for this study is 0.59; a low value
 203 indicating that the basin is of elongated shape. Values of 0.6 to 0.8 (low values) usually
 204 associate with high relief and steep slope whereas high values of greater than 0.8 associate
 205 with low relief.

206 **Circulatory ratio (Rc):** Circulatory ratio as defined by [18] is the ratio of basin area to the
 207 area of a circle which has same perimeter as the basin perimeter. It was established that the
 208 higher the value of Rc, the more circular shape of the watershed and a lower value indicate an
 209 elongated basin with permeable lithology [17, 9]. Rc values usually range from 0 (elongated
 210 shape) to 1 (circular shape). In this study Rc is 0.37. This low value of Rc agrees with the Re
 211 and Ff value in the study that the basin is elongated (Table 4). This could be observed from
 212 the funnel shape of Oba river basin (Fig 3). Low Rc also implies that the watershed has low
 213 discharge of runoff.

Length of overland flow (L_f): Length of overland flow is technically given by [16] as half of reciprocal of the drainage density. Physically L_f could be described as the length of the runoff of the rainfall on the basin surface before it assumes definite drainage channels. A high L_f (> 0.5) would suggest high surface runoff in a basin and consequently make the basin vulnerable to flooding and vice versa. The L_f of the Oba river basin is found to be 0.45, a low value. This implies that there is low surface runoff within the basin and thus making the basin to be less prone to high magnitude flooding and soil erosion within it.

Maintenance coefficient (C): This is also known as Constant of channel maintenance of a basin. [17] gave the explanation of the parameter as the extent of the drainage area that is needed to sustain or maintain one kilometer of drainage length in the concerned watershed. It is mathematically defined as the reciprocal of the drainage density. The maintenance coefficient of Oba river watershed is 0.91Km^2 . This could be interpreted as in the study area, about 1Km^2 area of the basin is needed to maintain 1Km of drainage channel. This is an indication of high infiltration or high base flow in the basin.

3.3 Relief Parameters values and the implications

The relief parameters considered in this study include basin relief, relief ratio and ruggedness number; Table 4 includes the summary of the relief parameters considered in this study.

Basin relief (R): Basin relief is given as the difference between the highest elevation (H) of a basin and the lowest point (h) therein [9]. Concerning Oba river basin, H is 396.24m and h is 167.64m. R is therefore 228.6m (2.3Km).

Relief ratio (R_r): It is given by dividing R by the basin length. [17] expressed that R_r is a numerical representation of the overall steepness within a river basin and thus it indicate the intensity of erosion within a basin. R_r of the basin under study is 0.02, a low value. This could be interpreted that Oba river basin is less prone to large scale erosion.

Ruggedness number (R_n): This is the product of the basin relief and drainage density. Obviously, high values of the two parameters will bring about very large R_n and vice versa. R_n is an indication of structural complexity of a terrain [27]. Oba river basin has an R_n of 1.25; this shows that the basin is not so rugged. It is also a pointer to low relief and low drainage density within the basin.

244 Table 4: Summary of the areal and relief parameters' results

	Morphometric Parameters [Symbol]	Result
AERIAL	Basin Area [A]	2494.45km ²
	Basin Perimeter [P]	291km
	Basin length [Lb]	96.1km
	Drainage Density [Dd]	1.1Km/Km ²
	Stream Frequency [Fs]	1.17
	Texture ratio [Rt]	5.05
	Form Factor [Ff]	0.27
	Circulatory Ratio [Rc]	0.37
	Elongation Ratio [Re]	0.59
	Length of overland flow [Lf]	0.45Km
	Maintenance Coefficient [Mc]	0.91Km ²
RELIEF		
	Basin Relief [R]	0.23km (750Ft)
	Relief Ratio [Rr]	0.002
	Ruggedness number [Rn]	0.25

245

246 4. CONCLUSION

247 It could be deduced from the study that Oba river basin is susceptible to flooding, though of
 248 low magnitude, within it. This is due to the generally low values of the bifurcation ratio (Rb)
 249 in all of the stream orders. The low drainage density, stream frequency reinforced by the
 250 elongated shape of the basin also contributes significantly to the flood tendency. Moreover
 251 the lowest Rb being found at the trunk drainage give a geomorphological proof of the
 252 likelihood of high magnitude flood at the mouth of the basin extended to a significant
 253 distance beyond it. This could have contributed to the rationale behind the construction of the
 254 Asejire dam/reservoir just some kilometers beyond the basin outlet, which was completed
 255 and has been in use as far back as 1972.

256

5. RECOMMENDATION

It is recommended that the constructed water reservoir be adequately managed and be given proper maintenance as at when due so as to forestall disastrous flooding events. Furthermore human activities that could negatively impact the drainage network should be dissuaded.

There is also the need to investigate some other factors like climate, land use-land cover, geology etc that do affect the hydrological processes in a basin in order to establish more facts so as to optimize the strategic use of the basin for sustainable development and to enhance the quality of lives of the people. **REFERENCES**

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