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Morphometric Analysis of Orammiriukwa River Catchment in Imo State, Nigeria

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ABSTRACT

To ascertain the geomorphological characteristics of watersheds in developing countries is difficult due to lack of equipment. The method of morphometric analysis in which computations involving the dimensions of catchment landforms reveal the geology, hydrology and geomorphology of the watershed is proposed in this study. This approach was applied to Orammiriukwa river system in Imo State, Nigeria. Dimensions of catchment landforms were measured from atlas map of the river using planimeter. Linear and areal aspects of morphometric paramters were computed. The results of the study indicate that there is no strong geological control in the development of the drainage area. The form factor of 0.754 showed that the river system is highly elongated and flood is difficult to manage. With the length of overland flow of 4.558km, low drainage intensity of 0.34, low infiltration number of 0.000352, the basin indicates very less permeable sub-soil, high susceptibility to flooding and gully erosion due to high runoff in the watershed. The results are consistent with the observed hydrological activities in the area as revealed by previous studies. The findings of this study have strengthened the understanding of the hydrologeological and geomorphological characteristics of the Orammiriukwa river system through simple geometric computations. This approach can be extended to other watersheds where assess to equipment is difficult.

1. INTRODUCTION

Morphometry is defined as the measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimension of its landforms (Pisal et al., 2012). Such analysis reveals the hydrological, geological and topographical characteristics of the basin. Basin morphometry is useful in understanding the existing geomorphic processes operating within the frame work of a drainage basin. The morphometric characteristics at the watershed scale may contain important information regarding its formation and development. Morphometric analysis of a watershed therefore provides a quantitative description of the drainage system (Vikrant et al., 2012).

Linear and areal aspects of morphometry include: stream order, stream length, mean strength length, stream-length ratio, bifurcation ratio, drainage density, stream frequency, form factor, elongation ratio, sinuosity index, channel index, length of main channel, length of overland flow, lemniscates, texture, fitness ratio, watershed eccentricity, center of gravity, infiltration number and area ratio. Stream length is one of the significant features of a basin as it reveals surface runoff characteristics (Vikrant et al., 2012). Stream of relatively smaller lengths indicates that the area has high slopes. Longer lengths are indicative of flatter gradient (Pawar and Raskar, 2011). A higher value of bifurcation ratio indicates a strong structural control in the drainage development where as the lower values indicates that some of the area in the basin is less affected by structural disturbances (Vittala, 2004; Chopra, 2005). Drainage density indicates the closeness in spacing of channels (Yadav and Sawant, 2014). Form factor is the quantitative expression of drainage basin outline form. The smaller the value of form factor, the more elongated will the basin be. Pareta and Pareta (2012) reported that the circulatory ratio ranges from 0.4 to 0.5 which indicates strongly elongated and permeable homogenous geological structures, land use, climate, relief and slope of the basin.

The morphometric analysis of different basins has been done using remote sensing and Arch GIS (Vikrant et al., 2012; Yadav and Sawant, 2014); earth observation data and GIS method (Rao, 2002). In a developing country like Nigeria, access to facilities like remote sensing and Arch GIS maybe difficult. There is need to use simple techniques involving atlas maps and planimeters in order to conduct morphometric study. This work was therefore aimed at using atlas maps and planimeter to compute the morphometric characteristics of Orammiriukwa river system, located in south-eastern Nigeria.

2. METHODOLOGY

2.1. Study Area

As shown in Figure 1, Amangabara et al. (2015) reported that Orammiriukwa river system had three major tributaries namely: Orammiriukwa river ($05^0\ 30^1$ to $05^0\ 11^1$N latitudes and 06^054^1 to 06^043^1E longitudes), Mba river (04^085^1 to 06^036^1N latitudes and 06^040^1 to 06^030^1E longitudes) and Okitankwu river (05^015^1 to 05^033^1N latitudes and 06^037^1 to 06^025^1E longitudes). The approximate area of the Orammiriukwa river system is 919.979km^2. It is 75.25km long with Mba river 18.20km long to its west. The Okitankwu River, which has a length of 47.25km, is located further west from Orammiriukwa river as its longest tributary. The elevation of the area ranges between 200m to 400m above sea level. Topographical map of the river system, at a scale 1:3500000, provided the base material for the study. Ranking of streams (U) was carried out based on the method proposed by (Vikrant et al., 2012). The smallest fingertip tributaries were designated as order 1. Where the two first-order channels join, a channel segment of 2nd order was formed and so forth. The trunk stream through which all discharge passed through was considered the stream segment of the highest order. Stream length $(\acute{L}_u)$ was measured from the farthest drainage divide to the mouth of a river according to method suggested by Pawar and Raskar (2011). Formulae adopted for computation of linear aspects include:

Bifurcation ratio (Mallo (2001): $R_b^{(k-u)}=N_U$ (1)

Stream length ratio (Pareta and Pareta 2012): $L_U=L_1R_L^{(U-1)}$ (2)

Length of overland flow (Yadav and Sawant 2014) $Lg = \dfrac{1}{2D_d}$ (3)

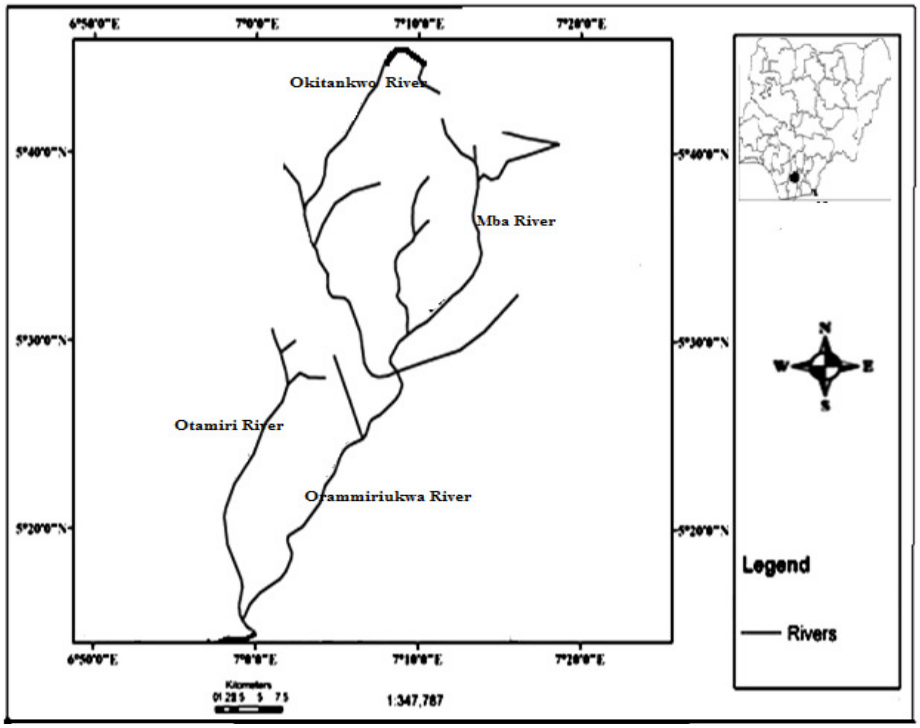

Figure 1: Orammiriukwa river system showing its major tributaries

Stream frequency (F_s) was obtained as the total number of stream segments of all orders per unit area (Yadav and Sawant (2014). Form factor (F_f) was calculated as the ratio of the area of the basin to the square of the basin length (Mallo, 2001). Elongation ratio (R_L) was computed as the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the drainage basin**.** The basin length (L_b)was calculated as the length of the line from a basin mouth to a point on the perimeter equidistant from the basin mouth in either direction around the perimeter (Geena and Ballukraya, 2011). According to Nageswara et al. (2010), texture ratio (R_t) was obtained as the ratio between the first-order streams and perimeter of the basin. Drainage texture (D_t) was obtained as the total number of stream segments of all orders per perimeter of that area (Pisal et al., 2012). Nageswara et al. (2010) suggested that the drainage intensity (D_i) be computed as the ratio of the stream frequency to the drainage density. The infiltration number (I_f) of a watershed has defined as the product of drainage density and stream frequency. The high infiltration number indicates low runoff in the watershed. Center of gravity (C.G.) of the watershed was estimated as the length of the channel measured from the outlet of the watershed to a point on the stream nearest to the center of the watershed. The center of the watershed was determined as follows. Initially a cardboard piece was cut out in the shape of watershed. Then the center of gravity was located on the watershed shaped-cardboard piece using point balance standard procedure. The cardboard piece marked with center of gravity was superimposed over the watershed plan while pressing a pin at the center of gravity of the cardboard. This point was marked on the watershed plan as the center of gravity. Formulae adopted for computation of basin geometry include:

Length area relation (Mallo (2001) $$L = a \times A^b \quad (4)$$

Lemniscate's (Yadav and Sawant 2014) $$K = \frac{L_b^2}{A} \quad (5)$$

Form factor ratio (Pawar and Raskar 2011) $$F_f = \frac{A}{Lb^2} \quad (6)$$

Elongation ratio (Nageswara et al., 2010)	$R_L = \dfrac{\sqrt{\frac{4A}{\pi}}}{L_{LM}}$	(7)
Texture ratio (Jangle and Patil (2010)	$R_t = \dfrac{N_1}{P}$	(8)
Drainage texture (Nageswara et al., (2010)	$D_t = \sum \dfrac{N_u}{P}$	(9)
Watershed eccentricity (Mallo 2001)	$\tau = \sqrt{[L^2 - w^2]/w}$	(10)
Stream frequency (Pawar and Raskar 2011)	$F_s = \sum \dfrac{N_u}{\text{Area of trunk system}}$	(11)
Drainage density (Yadav and Sawant 2014)	$D_d = \dfrac{\sum_{i=1}^{k} \sum_{i=1}^{N} L_u}{A}$	(12)
Drainage intensity (Chopra (2005)	$D_i = \dfrac{F_s}{D_d}$	(13)
Infiltration number (Jangle and Patil 2010)	$I_f = F_s \times D_d$	(14)
Area Ratio, R_a (Pareta and Pareta (2012)	$A_u = A_1\ Ra^{u-1}$	(15)

3. RESULTS AND DISCUSSION

3.1. Analysis of Linear Aspects

As evaluated in Table 1, the Orammiriukwa River System is a 4th order stream. The maximum frequency is in the 2nd order streams. The evaluation of mean stream length in Table 2 shows that stream frequency decreased as the stream order increased. As indicated in Table 3, $\sum \log N_U = \sum (k-u) \log R_b \leftrightarrow$ 2.4595= $6.0 \log R_b$. Thus, bifurcation ratio, $R_b = 2.569$. This low value of the bifurcation ratio indicates that the watershed is not affected by the structural disturbances (Vikrant et al., 2012). Amangabara et al. (2015) reported similar result in their study in which they used Arch GIS for the investigation.

Table 1: Evaluation of stream order

Stream order (U)	Stream number (N_u)
1	6
2	8
3	6
4	1
Total	21

Table 2: Evaluation of mean stream length

U	N_u	L_u (km)	$\bar{L}_u = L_u/N_u$ (km)
1	6	7.35	1.225
2	8	28	3.5
3	6	44.1	7.35
4	1	14	14

Table 3: Evaluation of bifurcation ratio

U	N_u	Log N_u	K-u LogR_b
1	6	0.7782	3.0 Log R_b
2	8	0.9031	2.0 Log R_b
3	6	0.7782	1.0 Log R_b
4	1	0.000	0.0 Log R_b
Total	21	2.4595	6.0 Log R_b

A.O. Ibeje et al. / Nigerian Research Journal of Engineering and Environmental Sciences
3(2) 2018 pp. 724-730

Table 4: Evaluation of stream length ratio

U	L_u	N_u	$\acute{L}_u$	$\text{Log}\acute{L}_u$	Log L_1	u-1
1	7.35	6	1.225	0.0881	0.0881	0
2	28	8	3.5	0.5441	0.0881	1
3	44.1	6	7.35	0.8663	0.0881	2
4	14	1	14	1.146	0.0881	3
Total	93.45	21	26.075	2.6445	0.3525	6

Using Equation 2, the stream length ratio was obtained as $R_L = 2.410$ while the length of main channel was measured as $23.5 \times 3.5\text{km} = 82.25\text{km}$. Length of overland flow was obtained from Equation 3, as $Lg = \frac{1}{2(0.1097)} = 4.558km$. This implies high surface runoff in the catchment.

3.2. Analysis of Areal Aspects

The basin area (A) of Orammiriukwa watershed was measured as 919.979 km^2. As shown in Table 5, the basin perimeter (P) of the basin was obtained as $49.2cm = 49.2 \times 3.5km = 172.2km$. In Table 6, the length of the Orammiriukwa river basin was evaluated as 93.45 km.

Table 5: Evaluation of basin area (A)

Tributary stream	Perimeter, $p = 2\pi\, r(cm)$	$r = \frac{p}{2\pi}(cm)$	$r\ (km)$	$\pi r^2 (km^2)$ Catchment area
Mba	8.5	1.353	4.735	70.43
Okitankwu	15.7	2.499	8.746	240.284
Orammiriukwa	25	3.979	13.927	609.265
Total	49.2	7.831	27.408	919.979

Table 6: Evaluation of length-area relation

U	L (km)	Log L	A (km^2)	Log A
1	7.35	0.8663	62.389	1.795
2	28	1.4472	238.838	2.378
3	44.1	1.6444	390.662	2.591
4	14	1.1461	160.333	0.4136
Total	93.45	5.1040	852.222	7.1776

Using regression analysis, the length-area relation was obtained from Equation 4, as $L = 8.308A^{0.1987}$. The computation is also indicated in Table 6. Thus, the Lemniscate's was evaluated from Equation 5, as $k = \frac{93.45^2}{919.979} = 9.493$. The lemniscates (k) value shows that the watershed occupies the maximum area in its region of inception with large number of streams of higher order (Yadav and Sawant, 2014). Amangabara (2015) reported similar findings in the study he conducted. From Equation 6, Form factor (F_f)$= \frac{919.979}{93.45^2} = 0.12$. This indicates that the watershed is elongated in shape and has high peak flow for longer duration (Pawar and Raskar, 2011). This is because the form factor is less than 0.754 (for a perfectly circular watershed).

The diameter of the circle of same area as the basin, $D_c = \sqrt{\frac{4\times 919.979}{\pi}} = 34.23\text{km}$. From Equation 7, elongation ratio, $R_L = \frac{34.23\text{km}}{75.25\text{km}} = 0.455$. This indicates that the watershed is very elongated (Mallo, 2001). Texture ratio was calculated as $R_t = \frac{6}{172.2} = 0.035$ using Equation 8. Drainage texture was evaluated from Equation 9, as $D_t = \frac{21}{172.2} = 0.12$ and this indicates that the watershed is very coarse (Nageswara et al.,

A.O. Ibeje et al. / Nigerian Research Journal of Engineering and Environmental Sciences
3(2) 2018 pp. 724-730

2010). From Equation 10, the watershed eccentricity, $\tau = \sqrt{\frac{17.5^2-5.8^2}{5.8}} = 2.85$. The center of gravity of the watershed was measured as $5°33^1$N, $7°8^1$E. From Tables 1 and 5, Stream frequency, F_s was obtained using Equation 11, as $F_s = \frac{21\text{km(from Table 1)}}{609.265\text{ (from Table 5)}} = 0.0345\text{km}^{-1}$. Also, using Equation 12, the drainage density was determined as $D_d = \frac{93.45}{919.979} = 0.102$, which suggests a very low drainage density. This indicates a very less permeable sub-soil and spare vegetative cover (Nag, 1998). Drainage intensity was calculated from Equation 13, as 0.34. According to Jangle and Patil (2010), this low drainage intensity for the Orammiriukwa river system implies that the watershed is susceptible to flooding, gully erosion and landslides. This is because surface runoff is not easily removed from the watershed. This finding is consistent with the study conducted by Amangabara (2015) in the catchment using remote sensing and satellite imagery. Infiltration Number was obtained from Equation 13, as $I_f = 0.0345 \times 0.102 = 0.000352$. The low infiltration number in the watershed suggests the high runoff in the watershed, thus implying flooding. Table 7 indicates the computation of area ratio is 0.999 using Equation 14.

Table 7: Evaluation of area ratio (R_a)

U	$\bar{A}_u$ (km^2)	Log A_u^1	Log $\bar{A}_1$	u-1
1	62.389	1.795	1.795	0
2	238.838	2.378	1.795	1
3	390.662	2.591	1.795	2
4	160.333	0.4136	1.795	3
Total	852.222	7.1776	1.795	6

4. CONCLUSION

The Orammiriukwa river basin appears to have no strong geological control in the development of the drainage area. The drainage area has low permeable subsurface lithology. The elongation ratio and form factor reveal that the river system is highly elongated and flood flows are difficult to manage. The basin is subject to erosion. The watershed indicated a high surface runoff. It is recommended that the morphometric data generated through this study are used to prioritize the watershed. This study has strengthened an understanding of the hydrological, geological, geomorphological characteristics of the Orammiriukwa drainage basin through geometric computations. No doubt there could be some marginal errors in the measurement carried out by this study, however, it is believed that the approach adopted in this study will help in the planning and development of the basin. This work can serve as a baseline study for further research in the management of water resources as well as the control of flood and erosion.

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6. CONFLICT OF INTEREST

There is no conflict of interest associated in this work.

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