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MORPHOMETRIC AND VULNERABILITY ANALYSIS OF GADA RIVER BASIN TO EROSION AND SEDIMENT YIELD

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ABSTRACT
This study is on morphometric analysis of River Gada using Geographical Information System (GIS) techniques. The aim of the study is to establish a relationship between surface morphometry and the hydrogeomorphic characteristics of the basin. This is crucial for analyzing the vulnerability of Gada river basin to erosion and sediment yield. For detailed measurement and analysis, Digital Elevation Model (DEM), high resolution imageries, and thematic maps were employed for basin delineation, slope characterization, channel network extraction and stream ordering in order to derive the linear, areal, and relief aspects of morphometric parameters of the study basin. The findings of the study revealed that a total number of 67 streams joined the 4^{th} order stream in which 52 streams were 1^{st} order, 11 streams were 2^{nd} order, 4 streams were 3^{rd} order and the major trunk was 4^{th} order stream, occupied an area of 2,790.72km^2. The drainage pattern of the stream network was dendritic pattern. The results further indicate that the values for stream frequency, bifurcation ratio, drainage density, drainage texture, constant channel maintenance, circularity ratio, elongation ratio, length of overland flow, relief ratio, dissection index, ruggedness number, and gradient ratio are 0.02, 3.83, 0.23km/km^2, 0.005km per km^2, 0.35sqft, 0.51, 0.83, 0.71km, 1.15, 0.38, 0.063 and 0.43 respectively. The observed values of both linear, areal and relief parameters were generally low. For linear parameters, low values indicate higher unit area sediment yield and low erosion vulnerability, while for areal and relief parameters, low values represent a symptom of youthful stage of river landscape development with high vulnerability to erosion and sediment yield and thus, measures to minimize the risk of sedimentation would be needed.

Keywords: Morphometric Analysis, Gada River Basin, Digital Elevation Model (DEM), Geographical Information System (GIS)

INTRODUCTION
The surface of the earth that supplies rain water to a particular stream along with the tributaries resulting in its being well demarcated by a well-defined perimeter on the basis of water divides is referred to as drainage basin (Singh, 2007). Basin morphometry is the measurement and mathematical analysis of the drainage forms, networks, and other characteristics ("Drainage Basin", n.d). The quantitative analysis of morphometric parameters is of immense importance in understanding drainage basin dynamics, watershed prioritization and management in terms of soil erosion studies, water and natural resources conservation at micro level (Hajam; Hamid; Naseer; and Bat, 2013; Biswas, Majumdar; and Banerjee; 2014, Kotei; Agyare; Kyei-Baffour; and Atakora; 2015). Morphometric analysis of drainage system also plays a significant role in expressing the prevailing climate, geological setting, geomorphology, and structural antecedent of the catchment area (Kulkarni, 2013). Such studies have relevance in prehistoric investigation as they help in reconstruction of terrain types which were of significance to pre -historic communities, and thereby for understanding of man land relationship during the pre-historic time ("Drainage Basin," n.d).
The attributes normally examined in the quantitative evaluation of drainage basin include relief, linear, and areal aspects which are mostly derived from topographic maps using manual methods. Remote sensing and Geographic information system techniques are increasingly being used as a tool for quantitative evaluation of drainage basin dynamics. Such techniques have been attempted by different researchers (Pareta and Pareta; 2010, Iqbal; Sajjad; and Bhat; 2013, Biswas *et.al* 2014; Withanage; Dayawansa; and Desilva; 2014, Kanchoul and Saaidia, 2017) in evaluating the influence of watershed geomorphic characteristics on basin hydrological behavior.

Additionally, avalanche of literature have documented the influence of controlling factors of underlying geology, climate, and vegetation on hydro- geomorphic responses of runoff, soil erosion, sedimentation, morphology dynamics, and flooding (Horton, 1932; Horton, 1945; Strahler, 1952; Schumm, 1956; Melton, 1957; Faniran, 1968; Pareta and Pareta 2010, Biswas et.al, 2014; Mandi and Soren, 2014). However no major work attempt has been made in carrying out the morphometric analysis of Gada River. The only work conducted on the study river (see Hassan, 2018) concentrated on the suspended and dissolve sediment flux within the channel. Thus, information on morphometric characteristics of the study river is anecdotal. This paper aimed at carrying out the morphometric analysis of Gada River Basin using remote sensing and GIS technique. This is with the view to establish a relationship between surface morphometry and vulnerability of the basin to erosion and sediment yield for watershed prioritization, management, and conservation of natural resources.

STUDY AREA

Gada River is found between latitude $12^0$20' and $12^0$30' North of the Equator, and Longitude $08^0$00 and $08^0$30' East of the Greenwich Meridian (Figure 1). The river is the second longest in Katsina state after Karadua, covering a total area of approximately 2,790.72 km^2. The climate of the study area is characterized by single regime of rainfall that occurs between the months of May and September with an average amount of 700mm per annum (Abaje; Sawa; and Ati, 2014). The area has a maximum day temperature of about 38^0C usually in the months of March, April and May and a minimum day temperature of about 22^0C mostly in the months of December and January (Ruma and Sheik, 2010). Additionally, Zayyana (2010) observed that relative humidity in the study area ranges between 20 and 25% mostly in the months of December and March. The relief as a whole is virtually flat, though from ground level scattered low table lands or steeply rising low hills strike the eye (Sombroek, and Zonneveld, 1971). The study area is underlain by Precambrian basement complex rock mostly of granite, gneiss, quartzite and different types of transitional metamorphic rocks (Obaje, 2009). The river is a 4^{th} order stream flowing in the northwest direction with a longitudinal stretch of 129 km from Gidan Mutum Daya village in Kankia town to Jibiya reservoir in Jibiya town. Moreover, the river is among the few ephemeral rivers of the state with an average monthly discharge of 325m^3/sec usually in the rainy season (Hassan, 2018). The study river lies in an area covered by flood plain soils locally known as Fadama soils. These soils are highly weathered, markedly lateritic, and slightly acidic due to low organic matter content (Abubakar, 2006). The river's entire basin is situated in Sahel savannah ecological zone characterized by very short grasses and schrubs with very thick bark (Chukwujekwu, 2010). However, increasing anthropogenic pressure on this sparse vegetation has exposed the surface to serious soil erosion and release of excess sediment in to the study river.

MATERIALS AND METHODS

Morphometric analysis of drainage basin requires delineation of all existing streams (Iqbal; Sajjad; and Bhat, 2013). In this study, drainage basin boundary and network characteristics (see Figure 2) were respectively delimited and extracted from the Digital Elevation Model that was generated from the Landsat imageries of the study area downloaded from www.earthexplorer.usgs.gov with Katsina NW Topographic map on a scale of 1:50,000 serving as a base map. For detailed measurement and analysis, various basin morphometric parameters of linear, aerial, and relief aspects were computed using the following formula:

Table 1: Description of Morphometric Parameters adopted in the Study

S/N	Parameters	Formula	Reference
Linear Aspect			
1	Stream order	Hierarchical rank	Strahler 1952
2	Stream number (Nu)	Nu=N1+N2+………….Nn	Horton 1945
3	Stream length (Lu)(Km)	Length of the stream	Strahler 1964
4	Stream length ratio (Lur)	Lur=Lu/(Lu-1)	Strahler 1964
5	Mean stream length (Lsm) (Km)	Lsm=Lu/Nu	Strahler 1964
6	Bifurcation ratio (Rb)	Rb=Nu/Nu+1	Strahler 1964
Aerial Aspect			
1	Basin area (A) (Km^2)	GIS Software Analysis	Schumm 1956
2	Stream frequency (Fs)	Fs=Nu/A	Horton 1932
3	Drainage density (Dd)	Dd=Lu/A	Horton 1932
4	Drainage texture (Dt)	Dt=Nu/P	Horton 1945
5	Form factor (Ff)	$Ff=A/Lb^2$	Horton 1932
6	Circularity ratio (Rc)	$Rc=12.57x(A/P^2)$	Miller 1953
7	Elongation ratio (Re)	$Re=1.128\sqrt{A}/Lb$	Schumm 1956
8	Length of overland flow (Lg)	Lg=A/2*Lu	Horton 1945

9	Texture ratio (Rt)	Rt=N1/P	Schumm 1956
10	Basin Shape Index (Ish)	Ish= 1.27 A / LB2.	Hagget and Chorley 1969
Relief Aspect			
1	Absolute ratio (Ra)m	GIS Software Analysis	
2	Relative relief (Rhp) m	Rhp=H*100/P	Melton 1957
3	Relief relief (Rhl)m	Rhl=H/Lb	Schumm 1956
4	Dissection index (Di)	Di=H/Ra	Sreedevi *et.al* 2004
5	Gradient ratio (Rg)	Rg=(Z-z)/Lb	Sreedevi *et.al* 2004
6	Ruggedness number (Rn)	Rn=Dd*(H/1000)	Patton & Baker 1976

RESULTS AND DISCUSSION

Linear Aspects of Gada River

The linear aspects of the Gada River Basin were quantitatively evaluated using the formula described above in the Arc GIS 10.1 environment and the observed values of the morphometric variables were summarized and presented in Table 2 below:

Table 2: Linear Parameters of River Gada

Basin	Stream Order	No. of streams	Stream length (Km)	Mean stream length	Stream length ratio	Values	Bifurcation ratio	Mean bifurcation ratio
Gada River	1^{st}	52	395.97	7.61	$2^{nd}/1^{st}$	0.29	4.73	3.83
	2^{nd}	11	116.3	10.57	$3^{rd}/2^{nd}$	0.25	2.75	
	3^{rd}	4	29	7.25	$4^{th}/3^{rd}$	3.21	4	
	4^{th}	1	93.1	93.1				
Total	4 orders	68	634.37			-	-	-

Source: Authors' computation (2018)

From Table 2 above, a total number of 67 streams joined the 4^{th} order stream in which 52 streams are 1^{st} order, 11 streams belong to the 2^{nd} order, 4 streams fall under the 3^{rd} order and the major trunk is the 4^{th} order stream. The drainage pattern of the stream network in the basin has been observed to be dendritic pattern. This according to Hamisu and Ettiah (2012) is an indication of the lack of homogeneity in texture and structural control. For the Stream Number (Nu), Findings of the study (Table 2) indicated that Gada River basin has a total number of 68 streams from the sum of all orders. A high number of frequencies in the first order stream has been observed and is decreasing with increasing order. This is in conformity with the Horton's (1945) law of stream number which states that the numbers of streams of different orders in a given drainage basin tend closely to approximate an inverse geometric series. High number of stream frequency in a small basin like that of the study river heightens runoff potential and soil erodibility.

The total length of stream of different orders in the study basin was 634.37km. The length of the 1^{st} order is 395.97km, while 2^{nd} streams occupied a total of 115.3km, 3^{rd} order streams have 29km and 4^{th} order have a total length of 93.1km as indicated in Table 2. This further shows that the total length of the streams segments is more in first order and decreases with increasing order except in the 4^{th} order. From the foregoing, the law of stream length has been closely obeyed for the lower order streams. However, for the 4^{th} order streams, Horton (1945) concluded that in order that the watershed area should be drained, the main stream should have a length possibly equal to that of the drainage basin and this requires that the length of the main stream should be much greater than it ordinarily would be for a drainage basin of the same order of normal form. Other reason deduced by Moges and Bhole (2015) is the slope of the watershed because streams do exhibit longer in size when the slopes of the area over which they drain become gentler. The mean stream length ratio of the study river among its successive orders shows that 1^{st} order streams has a mean length of 7.61km, 2^{nd} order streams has 10.57km, while 3^{rd} order streams has a mean length of 7.25km and the 4^{th} order streams has 93.1km as shown in Table 2. This variation may be attributed to differences in slope gradient, lithology, and soil permeability in the study basin.

Furthermore, the stream length ratio of River Gada is found to be between 0.29 and 3.2, indicating a youthful stage of landscape development which is in agreement with the finding of Moges and Bhole (2015) that high variation in stream length ratio indicates the late youthful stage of the landscape development. The bifurcation ratio for the study basin ranges between 2.75 and 4.73 with a mean value of 3.83. The highest bifurcation ratio (4.73) is found between 2^{nd} /1^{st} order streams indicating a highly impermeable underlying geology coupled with hilly slope configuration. The lowest Rb (2.75) is found between 3^{rd} /2^{nd} order streams and is ascribed to flat foot hill nature of the area. This generally suggest that the vulnerability of the basin to erosion is low but however, the basin is at youthful stage of landscape development, thus there is possibility that further erosional activities may occur.

Areal Aspects of Gada River

Table 3 below shows the aerial parameters of Gada River Basin that were computed and generated from the ArcGIS 10.1 environment.

Table 3: Results of Areal Parameters of Gada River

S/No.	Areal Parameters	Values
1	Basin area	2790.72
2	Stream Frequency	0.02
3	Drainage Density	0.23
4	Drainage texture	0.005
5	Constant of Channel Maintenance	0.35
6	Form factor	0.007
7	Circularity ratio	0.51
8	Elongation ratio	0.83
9	Length of overland flow	0.71
10	Texture ratio	0.50

Source: Authors' Computation (2018).

The Table above shows that the basin under investigation occupies an area of 2,790.72 km^2 with a very low stream frequency of 0.02 that decreases with increases in stream order. The lower values of stream frequency indicating a scatter network is a pointer to the fact that the Gada River is at youthful stage of development and thus, erosion and sediment yield processes are expected to be high at this stage (Charlton, 2008). Additionally, drainage density of the study basin is found to be $0.23km/km^2$ which is an indication of low relief as observed by Strahler (1964) that low drainage density value favored by low basin relief while high drainage density triggered by high basin relief. For drainage texture, the result further indicates that the basin under investigation has a drainage texture value of 0.005km per km^2 area. This signifies coarse drainage texture that is favored by the presence of massive, resistant and highly impermeable underlying rocks capped by bare surfaces mostly covered by grasses and schrubs. The study further discovered that the maintenance coefficient for River Gada is 0.35sqft and this low value according to Altaf; Meraj; and Romsho (2013) indicates the influence of highly resistant impermeable underlying rock, capped by very low resistant soils, and sparse vegetation.

The form factor for Gada River Basin is 0.007 which corroborates with Horton (1945) findings that value of Form factor will always be less than 0.754.This signifies that the basin is more elongated in shape and have lower peak flows for longer duration. Flood flows of such elongated basin are easier to manage than those of the circular basin (Altaf; Meraj; and Romsho, 2013). The circularity ratio of the basin under examination is found to be 0.41, which indicates that the basin is elongated in shape and this according to Hamisu and Ettiah (2012) shows the dominance of low relief and impermeable underlying materials. The elongation ratio of the river under investigation is observed to be 0.83 which indicates that the basin is more elongated. Similarly, Singh and Singh (1997) observed that basin with high ratio has high infiltration capacity, low runoff coefficient, and hence low erosion vulnerability. The calculated length of overland flow of the study river is 0.71km which is an indication of gentle slope and longer flow paths. This may not be unconnected with the gentle nature of the basin slope as observed by Altaf *et.al* (2013) that gentle slopes have longer flow paths. The findings of the study further revealed that the texture ratio of Gada river is 0.50 and this suggests that the basin experience long basin lag time, low runoff coefficient and thus low erosion vulnerability. Generally, the observed values of areal parameters were low and lower values of shape parameters give higher unit area sediment yield (Gajbhiye, Mishra, and pandey, 2014).

Relief Aspects of Gada River

The relief parameters of Gada River Basin were computed in ArcGIS software and the findings are presented in Table 4 below:

S/No.	Parameters	Values
1	Basin relief	275
2	Relative relief	262.7
3	Relief ratio	1.15
4	Dissection index	0.38
5	Ruggedness number	0.063
6	Gradient ratio	0.43

Source: Authors' Computation (2018)

Table 4 indicates that the highest relief in the study area is calculated to be 730m while the lowest relief is 455m above mean sea level. Thus, overall basin relief is discovered to be 275m above mean sea level with a relative relief of 262.7. The result further revealed that the relief ratio of the study basin is found to be 1.15. The low value of relief ratio in the study basin is attributed to the gentle nature of the basin slope underlain by impervious basement complex rocks. This is in conformity with the findings of Pareta and Pareta (2010) that areas with low to moderate relief and slope are characterize by moderate values of relief ratios which are mainly due to resistant basement complex rocks of the basin and low degree of slope. The result also shows that the index value of the study river is found to be 0.38 which indicates that the river is moderately dissected. This is another pointer to the fact that Gada basin is at youthful stage of landscape development and thus, may carry out further erosional activities. The ruggedness number of the basin is observed to be 0.063 which indicates that the basin is less vulnerable to erosion and has inherent structural complexity in association with relief and drainage density while the gradient ratio is 0.43 which reflects very moderate relief in the study basin.

CONCLUSION

The observed values of areal parameters were generally low and lower values of these morphometric parameters give higher unit area sediment yield and hence low vulnerability of the study basin to erosion. Similarly, the values of linear parameters especially stream frequency, drainage density and texture and some values of relief parameters specifically gradient ratio and dissection index were generally low. However, low values of these parameters revealed that the basin is at youthful stage of landscape development and hence, erosion and sediment yield processes are expected to be high. This is apparent as Yusuf and Yusuf (2013) reported that Jibia reservoir at the downstream reaches of the study basin is rapidly silting up, with an initial depth of 21m reduced to 13.43m indicating that 7.57m has been lost to sediment accumulation. This represents 36% loss of storage capacity leaving only 65.9% and by the year 2046 the reservoir will be completely silted up.

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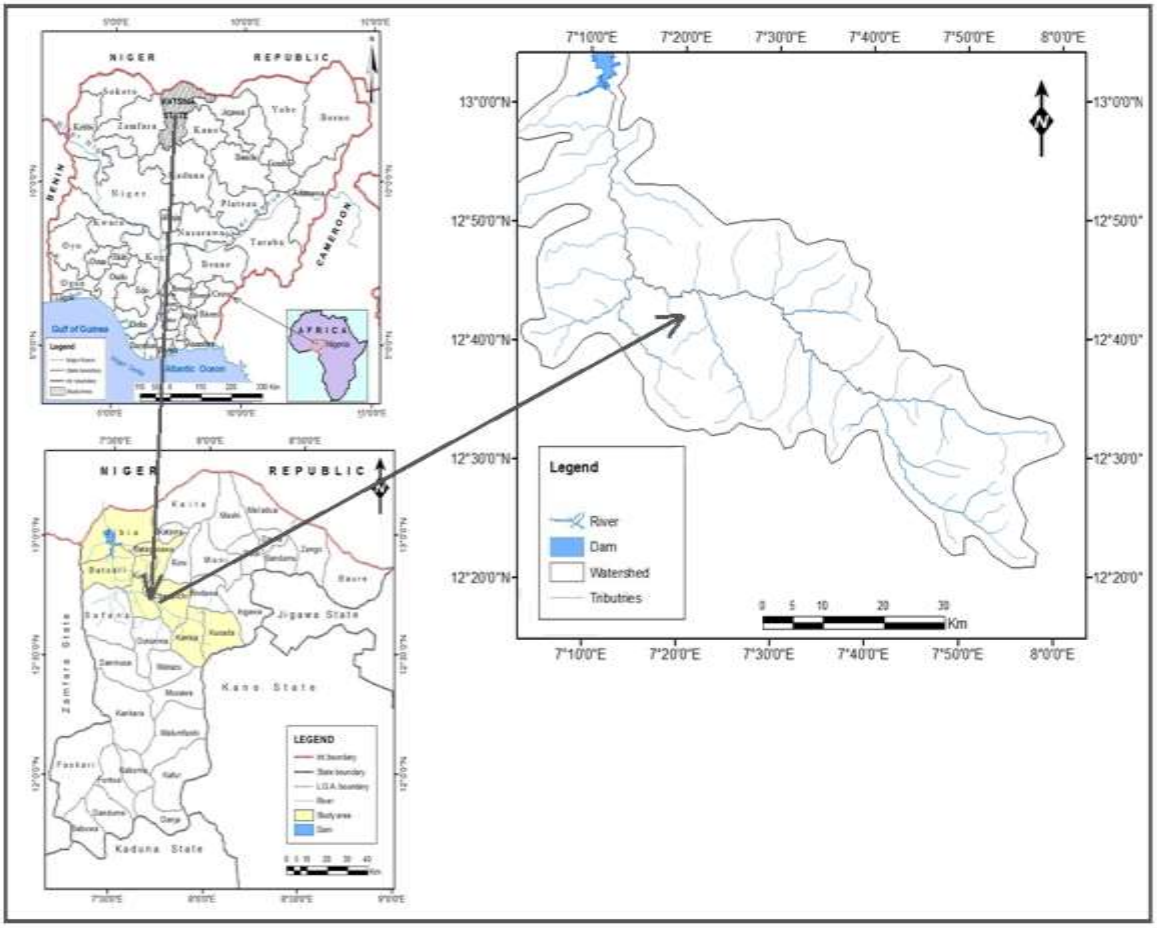

Fig. 1: The Study Area
Source: Survey Department, Katsina State (2008).

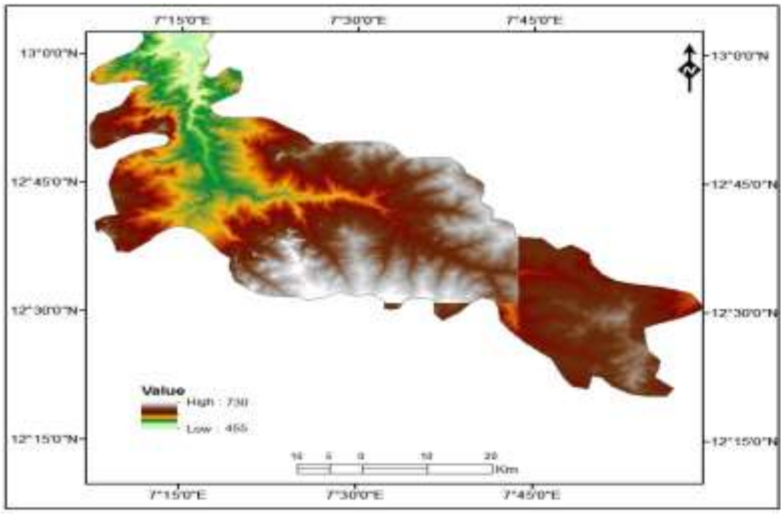

Fig. 2: Digital Elevation Map of River Gada
Source: www.earthexplorer.usgs.gov

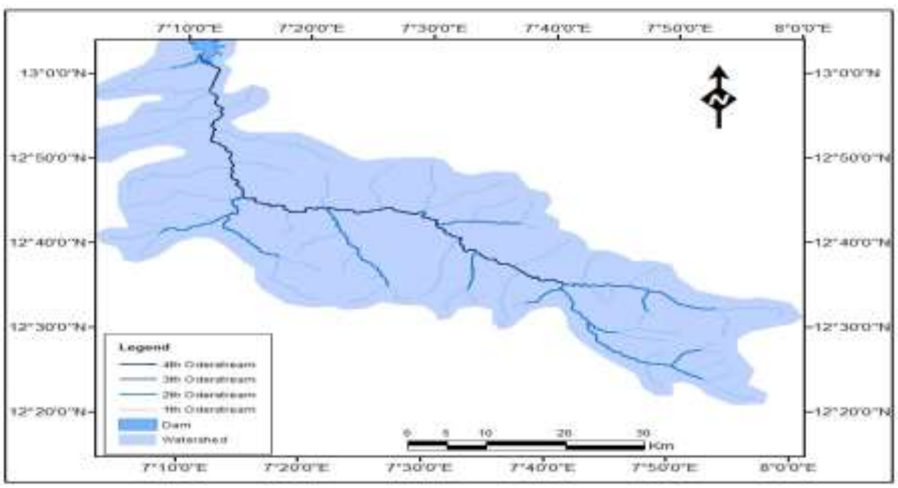

Fig. 3: Extracted Drainage Network of River Gada
Source: www.earthexplorer.usgs.gov