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Morphometric analysis of Jiberu drainage basin and its implications on sediment loading into lake Gwakra in Gerei, Adamawa state, Nigeria

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ABSTRACT

Morphometric analysis of a drainage basin describes its characteristics based on quantitative evaluation of different parameters. In this study, the morphometric characteristics of the Jiberu Drainage Basin has been analyzed using geospatial techniques with the aim of ascertaining their implications on sediment loading into the Lake Gwakra. SRTM image was used to create DEM of the basin and the linear, aerial and relief morphometric properties of the drainage basin were determined using relevant GIS and mathematical procedures. The results revealed that the stream of the basins is of 5th order with a total of 259 stream segments, a total stream length of 428.52 km and a mean Bifurcation Ratio of 3.83. The aerial and relief properties of the basin showed low-moderate morphometric behaviors owing structural distortions, land use disturbance and changes in climatic characteristics which in turn result to moderate runoffs, soil erosion and sediments loading into the Gwakra Lake Basin. Controlled land uses activities as well as further temporal hydrological and sediment studies over the Jiberu Basin and the lake were recommended.

KEYWORDS
morphometric analysis; jiberu drainage basin; lake gwakra; soil erosion; sediment load

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INTRODUCTION

The channel network's morphometric analysis, which expresses the current climate, geology, geomorphology, structural, and other antecedents of the catchment, is crucial for understanding the drainage basin's geo-hydrological behaviour (Nanda et al 2014). Morphometry is a quantitative description and analysis of the landform of a basin or water-shed. The landform has been shown to have a significant effect on water output from a watershed (Doad et al., 2012; Ezemonye & Emeribe, 2013). A number of metrics that accurately capture the physical characteristics of the basin are used to quantify the landform. Among others, these include the basin's size (Area, Perimeter), shape parameters, drainage density and intensity, bifurcation ratio, and stream density (Pal et al., 2012). The morphometric analysis of drainage basin has been carried out by so many scholars around the world with varying degree of accuracy (Nan-da et al., 2014; Gadiga & Shittu 2018; Asfaw & Workineh 2019). The most common parameters used in analyzing the drainage basin include Basin Area, Basin Perimeter, Basin Relief, Stream Order, Stream Length Ratio, Bifurcation Ratio, Drainage Density, Stream Frequency, Texture Ratio, Form Factor, Circulatory Ratio, Elongation Ratio, Length of Overland Flow and Constant Channel Maintenance among others (Horton, 1945; Strahler, 1964; Mohammed et al., 2018; Kadam et al., 2019; Prabhakar et al., 2019). Understanding the Drainage basin as a hydrological unit is substantially improved by the analysis of these factors. Over the past two decades, the morphometric parameters has been increasingly derived from digital representation of topography, generally called the Digital Elevation Model (DEM). Remote sensing and Geographic Information System (GIS) applications are more effective, quicker, and more suited to handle spatial analysis (Kadam et al., 2019). These methods are essential for analyzing different aspects of the hydrogeomorphic and geographical landscape (Vijith 2006; Altaf et al., 2013; Mohammed et al., 2018; Prabhakar et al., 2019). Vijith 2006 opined that they offer a flexible environment and strong tools for the analysis and manipulation of spatial data, especially for the identification and extraction of data in the future for improved comprehension. Therefore, Remote sensing and GIS techniques have been used in the current work to assess a variety of topography and drainage basin morphometric parameters.

The hydro-morphological functionality of the entire Jiberu watershed is highly dependent on its morphometric behavior as influenced the linear aerial and relief morphometric properties. Interestingly, it was discovered from recent field studies the Jiberu drainage basin which formerly empties into the River Benue (Federal Surveys, 1971) now drains completely into the Gwakra Lake (Google Earth Imagery 2021), thus posing siltation threats to the lake basin. It is against this backdrop that the current study focuses on examining the morphometric characteristics of the Jiberu drainage Basin and their implications on sediment loading into Lake Gwakra.

Study Area

The Jiberu drainage basin under study is situated in the upper portion of the Benue trough located between latitudes 09˚ 20' 30"N and 09˚ 25' 30"N of the equation and between longitudes 12˚ 21' 00"E and 12˚ 25' 00"E of the prime (Greenwich) meridian, covering a total area of about 338.71 km2 (Federal Surveys, Nigeria 1971). The area has a humid tropical climate with distinct wet and dry seasons controlled by the yearly fluctuations of the Inter-Tropical Convergence Zone (ITCZ). The dry season which makes up the irrigation farming period runs from December to May. The lake area and its entire irrigable land is characterized by the Gleyic cambisols (FAO) or Typic topoqualfs (USDA)-213 soil type. This is a mineral hydromorphic and juvenile soil of recent riverine and lacusterine alluvium (Areola 1983). Its colour ranges from dark brown (10yr3/2) to very dark grey (10yr3/1) with loamy, sandy-loam and silty loam textural characteristics. The soil type is also of low to high cation exchange capacity with pH values ranging from 5.9 to 4.9 indicating slightly acidic to very strongly acidic conditions (Usman, 2005). Being characterized by high water-holding capacity and nutrients content (Usman, 2005) the soil type is naturally fertile enough to support substantial agricultural productivity. The major sources of water for the lake are the Jiberu Drainage System and episodic inundations from the River Benue during flood periods. With a surface area of about 1.41Km2 and a mean depth of 1.46m (Yonnana et al., 2015), the lake basin is capable of storing over 2.0mcm of water annually. which could support substantial irrigation agriculture and other socioeconomic activities as fishing and recreation.

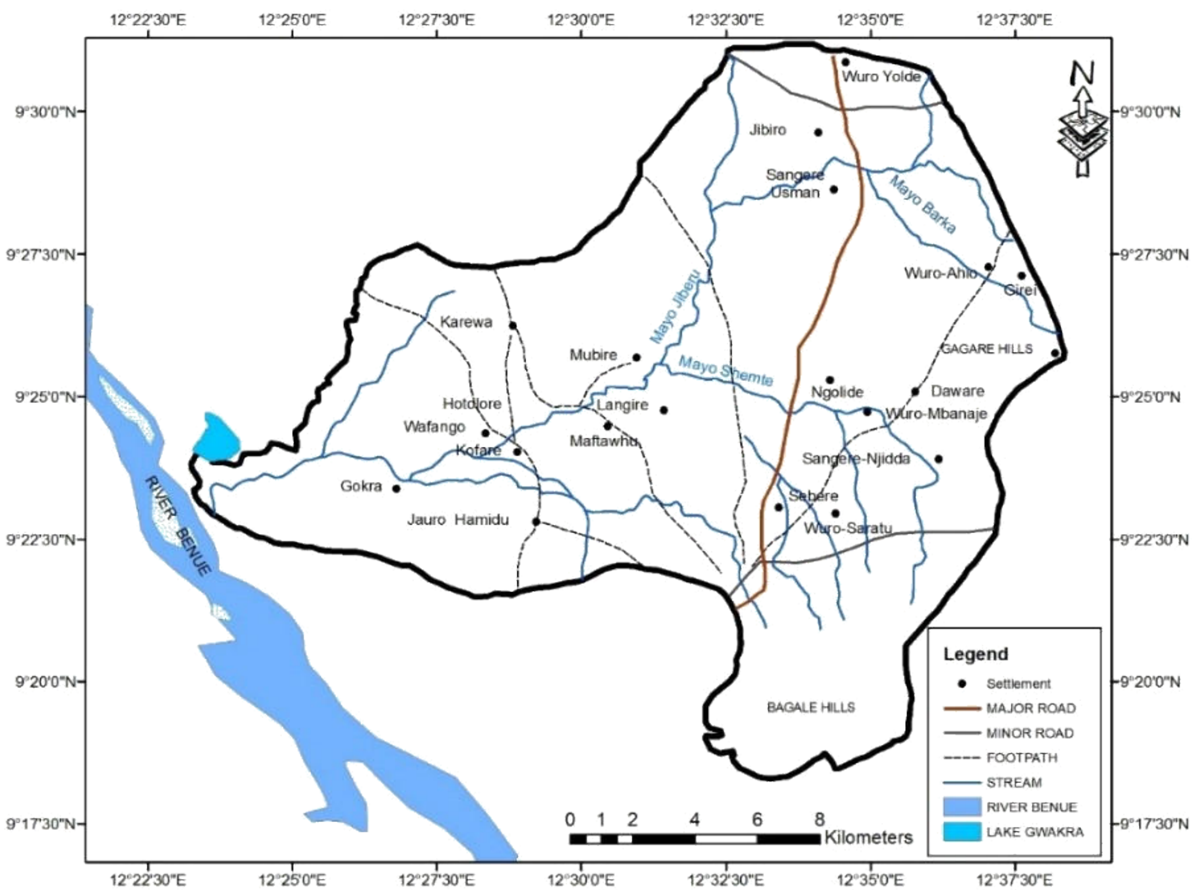

FIGURE 1: The Study Area
Sources: Federal Surveys, Nigeria (1971)

Methodology

The materials used for this study which is the *Shuttle Radar Topography Mission* (SRTM) image was downloaded from the website of USGS earth explorer and the drainage basin shape was delineated from it. Arcgis 10.3 and its extensions was used in processing and analyzing the data collected from the terrain and hydrologic analysis. The Digital Elevation Model (DEM) of the drainage basin was used to carry out the Morphometric and Geomorphic analysis for linear, aerial and relief features of extracted basin. Additionally, the Measurement and Computation of Morphometric Parameters were done from the formula presented in Table 1.

TABLE 1: Methods of calculating Morphometric parameters

Morphometric Parameters	Formula	References
Linear Aspects		
Stream order (U)	Hierarchical order	Strahler,1952
Stream Length (Lu)	Length of the stream	Horton, 1945
Mean stream length (Lsm)	Lsm=Lu/Nu; Where, Lu=Mean stream length of a given order(km), Nu=Number of stream segment.	Horton, 1945
Stream length ratio (RL)	RL= Lu / Lu-1 Where, Lu= Total stream length of order (u), Lu-1=The total stream length of its next lower order	Horton, 1945
Bifurcation Ratio (Rb)	Rb = Nu / Nu+1 Where, Nu=Number of stream segments, present in the given order, Nu+1= Number of segments of the next higher order	Schumm, 1956
Areal Aspects		
Drainage density (Dd)	Dd=L/A Where, L=Total length of stream, A= Area of basin.	Horton, 1945
Stream frequency (Fs)	Fs=N/A Where, L=Total number of streams, A=Area of basin	Horton, 1945
Infiltration Number (If)	If=Dd*Fs Where Dd=Drainage Density; Fs=Stream Frequency	
Texture Ratio (Dt)	T=N1/P Where, N1=Total number of first order stream, P=Perimeter of basin.	Horton, 1945
Form factor (Rf)	Rf=A/(Lb)^2 Where, A=Area of basin, Lb=Basin length	Horton, 1945
Elongation ratio (Re)	Re=√(Au/π)/ Lb Where, A=Area of basin, π=3.14, Lb=Basin length	Schumm, 1956
Circulatory ratio (Rc)	Rc=4πA/P^{2}Where A= Area of basin, π=3.14, P= Perimeter of basin.	Miller,1953
Length of overland flow (Lg)	Lg=1/2Dd Where, Drainage density	Horton, 1945
Constant channel maintenance(C)	C=1/Dd Where, Dd= Drainage density	Horton, 1945
Relief Aspects		
Basin area (A) (km^2)	Area from which water drains to a common stream and boundary determined by opposite ridges.	Strahler,1969
Basin perimeter(P) (km)	P=Outer boundary of drainage basin measured in kilometers.	Schumm, 1956
Basin length (Lb) (km)	Lb = Is the longest dimension of a basin to its principal drainage channel	Schumm, 1956
Basin relief (Bh)	$R=H-h$, Where, H is maximum elevation and h is minimum elevation within the basin.	Schumm, 1956
Relief Ratio (Rh)	Rh = Bh / Lb Where, Bh=Basin relief, Lb=Basin length	Schumm, 1956
Ruggedness Number (Rn)	Rn=Bh×Dd Where, Bh= Basin relief, Dd=Drainage density	Schumm, 1956
Mean Bifurcation Ratio (Rbm)km	Rbm = Average of bifurcation ratios of all orders.	Horton, 1945

Source: Adopted from Sandeep, 2020

RESULTS AND DISCUSSION

Morphometric characteristics of the Drainage Basin

Results of the of the linear, areal and relief characteristics of the Jiberu drainage basin are discussed in this section.

Linear Morphometric parameters of the Jiberu Drainage Basin.

These are one dimensional parameters. Drainage network and drainage texture parameters in linear aspects are significant indicator of the process of landform development in a watershed. The results are presented in Table 2.

TABLE 2: Result of linear parameters of the Jiberu drainage basin

Stream Order(U)	Total number of stream segments (Nu)km	Stream Length (Lu)km	Mean Stream length (Lsm)	Mean Stream Length Ratio (Rl)	Mean Bifurcation ratio (Rbm)
1^{st}	206	246.50	1.18		
2^{nd}	39	94.27	2.37	0.38	5.28
3^{rd}	11	50.80	4.50	0.54	3.55
4^{th}	02	22.52	10.89	0.44	5.50
5^{th}	01	14.44	14.22	0.64	2.00
Total Mean	**259**	**428.52**	**2.34**		**(Rbm)3.83**

Source: Researcher's work, 2022

Stream Order (Nu)

Table 2 presents the Streams Order classification in the Jiberu Basin. In the present study, the channel segment of the drainage basin has been ranked according to the method of stream ordering system proposed by Strahler, 1964. The study area is of a 5th order drainage basin as depicted in Figure 2. The maximum stream order frequency is observed in case of first-order streams and then for second order. Hence, it is noticed that there is a decrease in stream frequency as the stream order increases and vice versa.

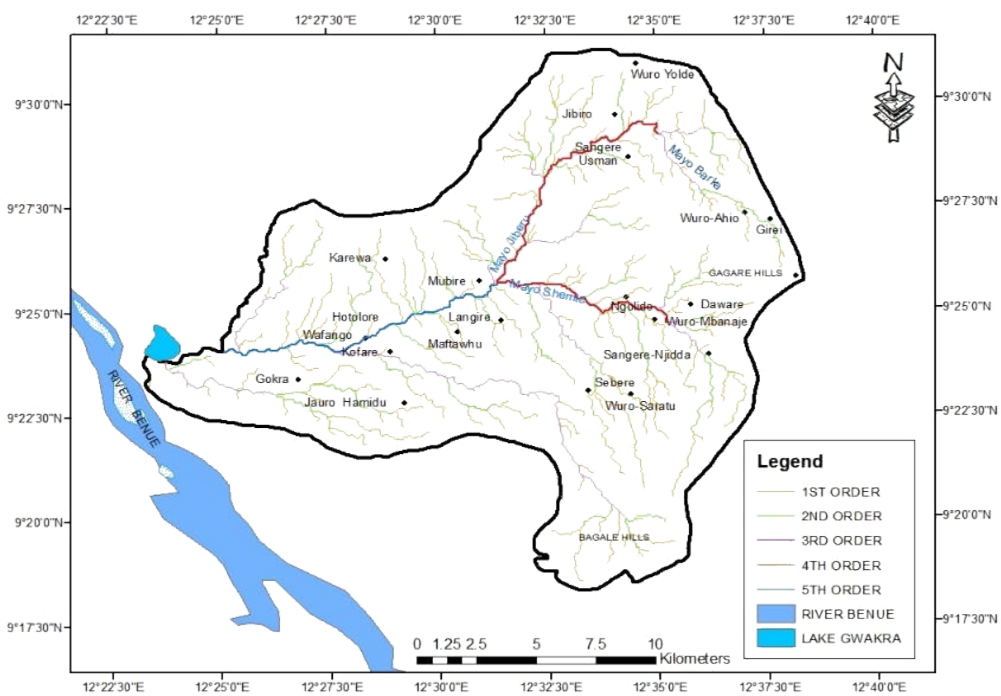

FIGURE 2: The Stream Order
Sources: Researcher's work

Stream number (Nu)

As per Horton's law (1945) of Stream Numbers, ''the number of streams of different orders in a given drainage basin tends closely to approximate as inverse geometric series of which the first term is unity and the ratio is the bifurcation ratio''. As indicated in Table 2 that the number of streams gradually decreases as the stream order increases; the variation in stream order and size of tributary basins is largely depends on physiographical, geomorphological and geological condition of the region. 259 number of stream were identified in the whole basin, out of which 79.54 % (206) is 1st order, 15 % (39) 2nd order, 4.25 % (11) 3rd order, 0.8 % (2) 4th order and 0.39 % (1) 5th order

Stream Length (Lu)

Stream Length reveals surface runoff characteristics in the basin for hydrological interpretation (Doad et al. 2012). Generally, the maximum length of stream segments is in first order and decreases as the stream order increases. The result of the stream length in the basin is shown in Table 2. It is clearly identified that the cumulative stream length is higher in first-order streams and decreases as the stream order increases.

Mean Stream Length

Mean Stream Length (Lsm) reveals the characteristic size of components of a drainage network and its contributing surfaces (Strahler 1964). It is obtained by dividing the total length of stream of an order by total number of segments in the order (Lakshmamma et al., 2011). The Lsm values for the Jiberu basin range from 1.18 to 14.22 km (Table 2) with a mean stream length (Lsm) value of 2.34 km. It is noted that Lsm value of any stream order is greater than that of the lower order and less than that of its next higher order in the basin. The Lsm values differ with respect to different basins, as it is directly proportional to the size and topography of the basin.

Stream Length Ratio (Rl)

Horton' law (1945) of Stream Length Ratio states that the mean stream length segments of each of the successive orders of a basin tends to approximate a direct geometric series with stream length increasing towards higher order of streams (Table 2). The values of Stream Length Ratio indicate increasing trends in surface flow and discharge characteristics (Ansari et al, 2012; Horton, 1945). Besides, changes in Stream Length Ratio from one order to another in a watershed indicate the late youth to mature stage of geomorphic development in its river system (Singh and Singh, 1997).

Bifurcation Ratio (Rb)

It is a dimensionless property and shows the degree of integration prevailing between streams of various orders in a drainage basin. Values of 2 are characteristics of flat or rolling basins while 3, 4 and above indicate basins of mountainous and highly dissected terrains (Farhan et al., 2016). The Rb for the Jiberu basin varies from 2 to 5.29 (Table 2). The mean Bifurcation Ratio result value of 3.83 (Table 2) indicates that the drainage pattern of the basin is distorted by the geologic structure of the area. More to this is that bifurcation ratio is directly related to soil erodibility, the value obtained signify high chance of vulnerability to soil erosion.

Aerial Morphometric parameters of the Jiberu Drainage Basin.

These are two dimensional parameters. It deals with the total area projected upon a horizontal plane contributing overland flow to the channel segment of given order and includes all tributaries of lower order (Waikar et al., 2014). The aerial aspects of the drainage basin such as Drainage Density (Dd), Stream Srequency (Fs), Infitration Number (If), Texture Ratio (T), Elongation Ratio (Re), Circularity Ratio (Rc) and Form Factor (Rf), Ruggedness Number (Rn), Length of Overland Flow (Lof) and Constant Channel Maintenance (c) were calculated and results have been given in table.

TABLE 3: The result of aerial parameter of the Jiberu drainage basin

Morphometric parameters	Result
Basin Area (A) (km^2)	
Basin Perimeter (P) (Km)	
Drainage Density (Dd) (km^2)	1.27
Stream Frequency (Fs) (km^2)	1.35
Infiltration Number	1.71
Texture Ratio (T) (km)	4.99
Form Factor (Rf)	0.74
Circulatory Ratio (Rc)	0.51
Elongation Ratio (Re)	0.48
Length of overland flow (Lof) (km)	0.39
Constant channel maintenance (C) (km)	0.79

Drainage density (Dd)

In humid regions, Drainage Densities vary between 0.55 and 2.09 km/km2 with an average of 1.03 (Langbein, 1947; Ramaiah et al., 2012). Therefore the 1.27 km/km^2 Drainage Density value of the study basin (Table 3) which is slightly above average is considered moderate and indicates the occurrence of moderately resistant lithology, average permeable subsurface material, less dense vegetation cover and low to moderate relief. Consequently, surface runoff is moderate and in episodic events influence sheetwash, rill and gully erosion as well as flooding. Figure 3 provides a complementary description of the basin's Drainage Density characteristics.

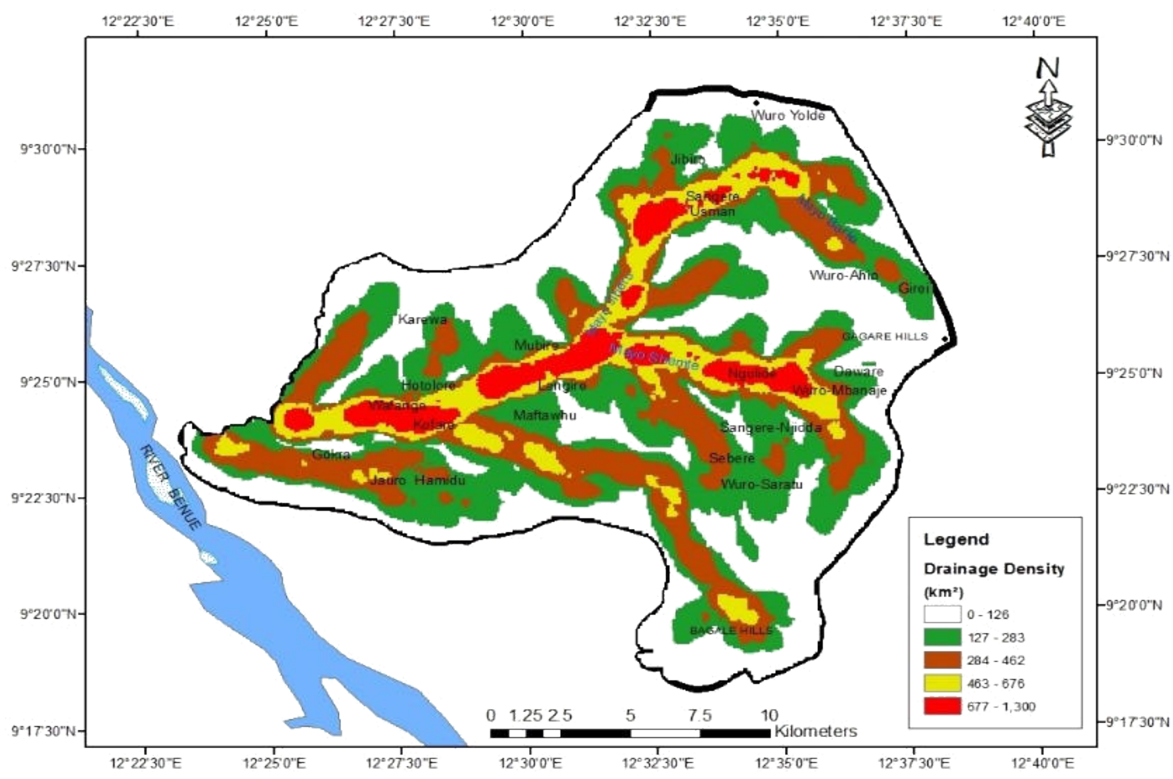

FIGURE 3: The Drainage Density of Jiberu Basin
Source: Researcher's work

Stream Frequency (Fs)

Stream frequency (Sf) is the total number of stream segments of all orders per unit area (Horton 1932). Stream frequency (Fs) is also related to permeability, infiltration capacity and relief aspect of the terrain (Rekha et al. 2011).

Reddy et al. (2004) stated that low values of stream frequency indicate presence of a permeable subsurface material and low relief. The channel segment numbers for unit areas are difficult to be enumerated (Singh 1980), but an attempt has been made to determine those of Jiberu Basin using relevant ArcGIS tools. The stream frequency of the basin was found to be 1.35 (Table 3). This low to moderate stream frequency (Fs)value exhibits positive correlation with the drainage density value of the area indicating the increase in stream population with respect to increase in drainage density as opined by Praveen et al., (2017). Just as in the case of Draiange Density, such a low to moderate Stream Frequency value signifies averagely permeable lithology and vegetation cover suggesting moderate infiltration, low to moderate runoff, as well as soil erosion and sediment load yielding tendencies,

Infiltration Number (If)

Infiltration number of a drainage basin is the product of Drainage Density and Stream Frequency of the basin. This parameter gives an idea of the infiltration characteristics of the basin (Ansari et al, 2012). Higher values indicate low infiltration and high runoff characteristics as controlled by hard and low permeability characteristics of the basin's lithology. A low to moderate Infiltration Number of 1.71 was computed for the Jiberu Basin indicating that the basin is of mild lithology and permeability, thus susceptible to moderate runoff, soil erosion and sediment load generation tendencies. Under such moderate conditions, severe soil erosion and sediment yields are associated with episodic rainfall and runoff occurrences.

Drainage Texture /Texture ratio (Dt)

Drainage Texture is expression of relative spacing of drainage lines in a river basin which is obtained by dividing the total number of stream segments of all orders by perimeter of watershed. It is important aspect of fluvial geomorphology affects the underlying lithology, infiltration capacity and relief aspect of the basin. Smith, (1950) has classified the drainage texture into five different textures viz. very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). More is the texture more will be the dissection and leads to more erosion. The Drainage Texture calculated is 4.99km (Table2). This implies that the basin is of a moderate texture category owing to lithological and soil factor. This signifies moderate runoff and soil erosion possibilities in the basin.

Form Factor (Rf)

Horton (1932) declared that form factor is the ratio of basin area to square of basin length. Form Factor is the numerical index (Horton, 1932) commonly used to represent different basin shapes. There are some different value ranges of Form Factor. The range values for Form Factor are <0.78 (elongated) and >0.78 (circular) (Rai, et al., 2017). An elongated watershed means it has low peak flows for longer duration while a circular watershed means it has high peak flows for a shorter duration. The form factor under study is 0.74 (Table 3) which implies that the basin is elongated with low peak flow for a longer duration (Frahan et al., 2016). Flood flows of such elongated basin are easier to manage than from the circular basin (Zende et al., 2012).

Circularity Ratio (Rc)

Circularity Ratio (Rc) is influenced by the length and frequency of streams, geological structures, land use/ land cover, climate, relief and slope of river basin (Zende et al., 2012). (Miller, 1953). Miller (1953) noted that basins with circularity ratios between 0.4 and 0.5 are highly elongated and permeable with homogenous geologic material. The higher the circularity ratio value the more the circularity in shape of the basin and vice-versa. It has also been observed that Low, medium and high values of circulatory ratio indicate young, mature, and old stages of the life cycle of the tributary watershed (John et al., 2012). The 0.51 circularity ratio value (Table 3) calculated for the study basin portrays its moderate circularity and more elongated shape characteristic.

Elongation ratio (Re)

It is a measure of the shape of the river basin and it depends on the climatic and geologic types. A circular basin is more efficient in runoff discharge than an elongated basin (Singh and Singh 1997). Strahler (1964) observed that the ratio runs between 0.6 to 1.0 over a wide variety of climatic and geologic types. Values closer to 1.0 are typical of regions of low relief while values in the range of 0.6 to 0.8 are generally associated with strong relief and steep ground slopes. As such, higher values of elongation ratio show high infiltration capacity and low runoff, whereas lower Re values indicate high run offs and high susceptibility to erosion and sediment load (Reddy et al.2004).

Ansari et al., (2012) noted that these values are further categorized as (a) circular (>0.9), (b) oval (0.9-0.8), (c) less elongated (<0.7). Therefore, the elongation ratio (0.48) obtained for Jiberu Basin indicates that the basin is moderately elongated with average relief and ground slopes characterized by moderate to high susceptibility to erosion and sediment load production. This is among the major factors responsible for the gradual and continual siltation of Gwakra Lake basin which the Jiberu Basin empties into in recent times,

Length of Overland Flow (Lof) (km)

This is It is one of the most independent variables which affect both hydrological and physiographical development of drainage basin (Schumm, 1956). The Length of Overland Flow (Lg) is the length of water over the ground surface before it gets concentrated into definite stream channel (Horton, 1945). High values of length of over flow indicate high surface runoff conditions and in turn high tendencies of soil erosion. The length of overflow value of the Jiberu basin is 0.39km (Table 3). The high value means gentle slopes and long flow paths, more infiltration, and reduced runoff

Constant Channel Maintenance (C)

The Constant Channel Maintenance represents how much of the drainage area is required to maintain one unit of channel length; hence, it is a measure of watershed erodibility. Schumn (1954) proposed the use of the reciprocal of drainage density for calculating the Constant Channel Maintenance, and the same method has been adopted for the present study. Regions of resistant rock type or with the surface of high permeability or with good forests cover should have a high Constant Channel Maintenance and a low drainage density. Similarly, regions of weak rock types or region with little or no vegetation and low soil infiltration and permeability should have low Constant Channel Maintenance and high drainage density. The Constant Channel Maintenance value calculated is 0.79km (Table 3) which reflect the higher infiltration and permeability of the materials, fairly good vegetal cover and relatively resistant rock type.

Relief Morphometric Parameters of the Jiberu Drainage Basin.

The relief is a three-dimensional parameter of a drainage basin which is expressed in terms of area, volume and altitude of watershed landforms Sahu et al. (2016). The relief morphometric parameter of the study basin includes basin area, basin length basin relief, relief ratio, basin parameter and ruggedness number.

TABLE 4: The result of relief parameter of the Jiberu drainage basin

Morphometric parameters	Result
Basin area (A)(km^2)	338.71
Basin perimeter(P) (km)	91.34
Basin length (Lb) (km)	27.46
Basin relief (Bh) (km)	0.494
Relief ratio Rh= Bh/Lb	0.02
Ruggedness number (Rn)	0.66
Mean Bifurcation Ratio (Rbm)km	3.83

The Basin Area (A), Perimeter (P) and Length (Lb)

Relief aspect of river basin plays an important role of computing surface and subsurface flow, permeability, landform development. The relief aspects were studied using the methods of Strahler (1952). The basin area was delineated on the basis of water divides, and the basin area extents was measured at 338.71km^2 as shown in Table 4. Morisawa (1962) has observed that the mean annual runoff and catchment area to be directly related to each other. Considering the above views, it can be said that for the basin, the mean annual runoff is relatively higher.

Basin Perimeter is the total boundary length of the basin along the divides. It is one of the important factors that determine the shape and size of the drainage basin Schumm (1956). The Jiberu Basin Perimeter was measured at 91.34 km (Table 4).

The Basin Length (Lb) is the longest length of the basin, from the catchment to the point of confluence (Gregory and Walling, 1973). The length of the study basin was found to be 27.46km (Table 4).

Basin relief (Bh) (km)

Basin relief is an important factor in understanding the geomorphic processes and landform characteristics. Difference in the elevation between the highest point of a basin (on the main divide) and the lowest point on the valley floor is known as the total relief of the river basin (Lakshmamma et al., 2011). Basin relief is an index of the potential energy available in the drainage basin; the greater the relief, the greater are erosional forces acting on the basin and vice versa (Patton1988). The computed Basin Relief value of the study basin was 494m (Table 4). Figure 4 shows the relief map of the Jiberu drainage basin.

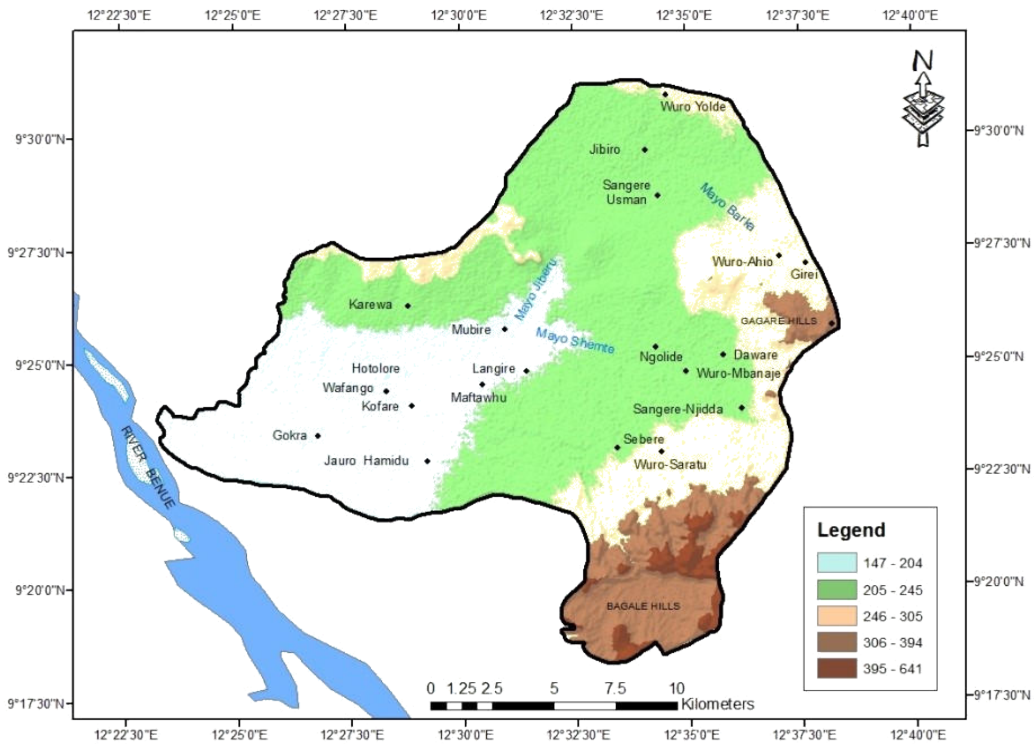

FIGURE 4: The Relief of the Jiberu basin

Relief Ratio (Rh)

According to Schumm (1956), it is a dimensionless height length ratio equal to the tangent of the angle formed by two planes intersecting at the mouth of the basin, one representing the horizontal, the other passing through the highest point of the basin. It denotes the overall steepness of a drainage basin and is an indicator of the intensity of degradation processes operating on slopes of that basin. Low value of Relief Ratios is mainly due to the resistant basement rocks of the basin and low degree of slope (Mahadevaswamy et al. 2011, Parvez and Inayathulla, 2019). The Rh normally increases with decreasing drainage area and size of a given drainage basin (Gottschalk 1964). The calculated Relief Ratio of the Jiberu Basin was 0.02 (Table 4) which indicates that the basin is composed of resistant rocks, and the basin is under intense relief and steep slope. The possibility of a close correlation between Relief Ratio and hydrologic characteristic watersheds is the sediment loss per unit is directly related with relief ratio (Schumn,1954).

Ruggedness number (Rn)

Ruggedness number, the product of relief and drainage density is an index which reflects slope steepness and length as suggested by Hart (1986). According to Farhan et al., (2016), Higher values greater than 1 of this parameter indicate land degradation conditions mostly influenced by soil erosion or mass wasting process, while lower values of less than 1 is an indication of smooth and subdued land morphologies. The 0.63 ruggedness number obtained for Jiberu drainage basin indicates slightly rugged land morphologies with moderately soil erosion possibilities.

CONCLUSION

This study showcased that digital geospatial techniques are more suitable than analogue methods of evaluating drainage basin morphometric parameters and their impact on landform and land features. To identify the morphometric properties of the specific basin area, the measurement of linear, areal, and relief aspects based on DEM is extremely helpful. As a result of low drainage density, the Surface runoff is not rapidly removed from the basin making it highly susceptible to flooding and gully erosion and the elongation ratio of the basin is 0.48 which also indicates high susceptibility to erosion and sediment load. To avoid high risk of erosion it is therefore recommended that human activities that could impact negatively on the drainage network should be discouraged.

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