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Drainage Basin Morphometric Parameters of River Lamurde: Implication for Hydrologic and Geomorphic Processes

E. D. Oruonye[1*], B. B. Ezekiel[1], H. G. Atiku[1], E. Baba[1] and N. I. Musa[1]

[1]Department of Geography, Taraba State University, P.M.B. 1167, Jalingo, Taraba State, Nigeria.

Authors' contributions

This work was done in collaboration among all authors. Author EDO designed the study, performed the statistical analysis, wrote the protocol and first draft of manuscript, did the analysis and report writing. Authors BBE, HGA, EB and NIM contributed in fieldwork observation, measurement, recording and data collection. All authors read and approved the final manuscript.

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ABSTRACT

This study has examined the drainage basin morphometric parameters of River Lamurde and its implication on hydrologic and geomorphic processes. Various morphometric parameters of the drainage basin were calculated based on literatures. Lamurde basin is a fourth stream order with dendritic pattern of drainage. The results of the study indicated that the drainage basin area is 553.9 km^2, basin perimeter 197.5 km, form factor 0.19, circulatory ratio 0.5 and drainage texture is 03. The stream frequency of the study area is 0.11 stream segments per square kilometer, drainage density (Dd) is 0.389 km/km^2, bifurcation ratio 3.85 and length of overland flow is 0.13 km. The drainage density, bifurcation ratio and circulatory ratio values indicate that the basin has a gentle slope, more elongated and highly permeable bedrock. The relief ratio of the basin is characterized by less resistant rocks. Both values of stream frequency and drainage density show that Lamurde basin has a low relief and by implication has a low response to surface runoff. This basin shape parameters indicates that the basin has a flatter peak of flow for longer duration. The

**Corresponding author: Email: eoruonye@gmail.com;*

morphometric parameters studied using GIS has helped us to understand various terrain characteristics such as the nature of the bedrock, infiltration capacity, runoff etc.

Keywords: Drainage basin; geomorphic; hydrologic; lamurde; morphometric and parameters.

1. INTRODUCTION

Drainage basin morphometry can be regarded as the topographical expression of land by way of area, slope, shape, length among others [1]. Morphometric analysis defines more clearly and precisely the general form of the basin landform as represented on a map and serve as a basis for demonstrating the effect of environmental control on fluvial system and for predicting the basin output variables such as discharge [2]. These morphometric parameters affect catchment stream flow pattern through their influence on concentration time [3].

Studies on drainage basin morphometry have been carried out in many parts of the world [4]. In Nigeria, similar studies have been carried out which include those of [5,6,7,8]. The drainage basin morphometric parameters include stream order, stream length, stream number, basin area, basin shape factor (e.g. circularity ratio, elongation ratio, form factor and compaction ratio), basin perimeter, bifurcation ratios, drainage density, stream frequency and drainage intensity.

Studies have shown that data on stream discharge and morphometric parameters of drainage basins in developing countries are either lacking or grossly inadequate where they exist [9,10]. In Nigeria, a major constrain to hydrological studies and water resources planning and management is lack of reliable hydrological data for use by water resource managers and researchers [2]. Many stream discharge gauging stations which were established in the early 1970s are no longer functional and where they function, are poorly maintained [2]. [10] asserted that this development has made hydrological research almost impossible in the country. [2] observed that the situation has made many researchers in the country to abandon hydrological studies in favor of other aspects of the study. The alternative to this is to resort to measures of appraising and evaluating the natural water resources potential of basins without stream gauge records, using series of generalized regional relationships based on morphometric parameters [2].

Morphological studies of rivers are very important to study the behaviour of a river, its aggradations/degradation, shifting of the river course, erosion of river bank etc. and to plan remedial measure for erosion, flooding and other related problems. Quantitative analysis of drainage basin morphometric parameters is of immense utility in river basin evaluation, watershed prioritization for soil and water conservation and natural resources management at micro level.

This type of study has not been carried out on River Lamurde in Jalingo town of Taraba State Nigeria. No segment of the basin is gauged and information on the drainage system is very scarce as not much research work has been carried out in this direction. Yet the basin is a major source of water in Jalingo metropolis and is characterized by hydrologic and geomorphic problems such as flooding, erosion and mass movement. Greater part of the Lamurde River basin flood annually and this flooding has increased in frequency in recent times with devastating effect on the socio-economic life of the people. The river basin is used for a variety of agricultural activities (rainfed and irrigation farming and livestock grazing) and major source of urban water supply in the town. This study is necessitated by the need to provide information on the drainage basin morphometric parameters of River Lamurde. This information would be used to describe the basin as a landform and a hydrological unit and the implication of the drainage basin morphometry on the hydrologic and geomorphic processes in the area. This will enhance the management techniques which will not only aid in the improvement of river regime by retaining greater volume of rainfall intercepted by the basin on the land, but will also help in solving problem of soil erosion, sediment generation, flooding and urban water supply in the area.

1.1 Description of Study Area

River Lamurde is the main river draining Jalingo town and environ. It forms a confluence with its major tributary, River Mayogwoi in Magami ward in the town. It took its sources from the Yorro Mountain near Gangoro and flows downhill through Yorro, Tazarang, Alkali Gwa, Bassa and

Jalingo. The basin is located between latitudes 8°40’ to 9°05’N and longitudes 11°05’ to 11°45’E (Fig. 1). The river flows for over 96km westward before emptying into the Benue River system near Tau community [11]. The basin is located in a sub humid climate zone with average rainfall of 850 mm^3. Rainfall starts in May and ends in October. The highest amount of rainfall in the basin is received in the months of July, August and September. Temperature is relatively high throughout the year but lower in the middle of the rainy season and winter months of December and January. Mean temperature is 30°C. The vegetation type is the wooded savanna characterized by short grasses interspersed with short trees. Geologically, the drainage basin consists of cretaceous rocks of the Bima sandstone formation with isolated flat-topped hills [11]. Scattered remnants of highly metamorphosed sedimentary rocks and diverse predominantly granitic and plutonic masses generally known as older granites are found all over the basin. Ferruginous tropical soils derived from crystalline acid rocks of the basement complex are dominant soil types in the basin. River Lamurde is the major source of recharge for underground water in the area with a typical minimum yield of 648,240 m^3 per year from the

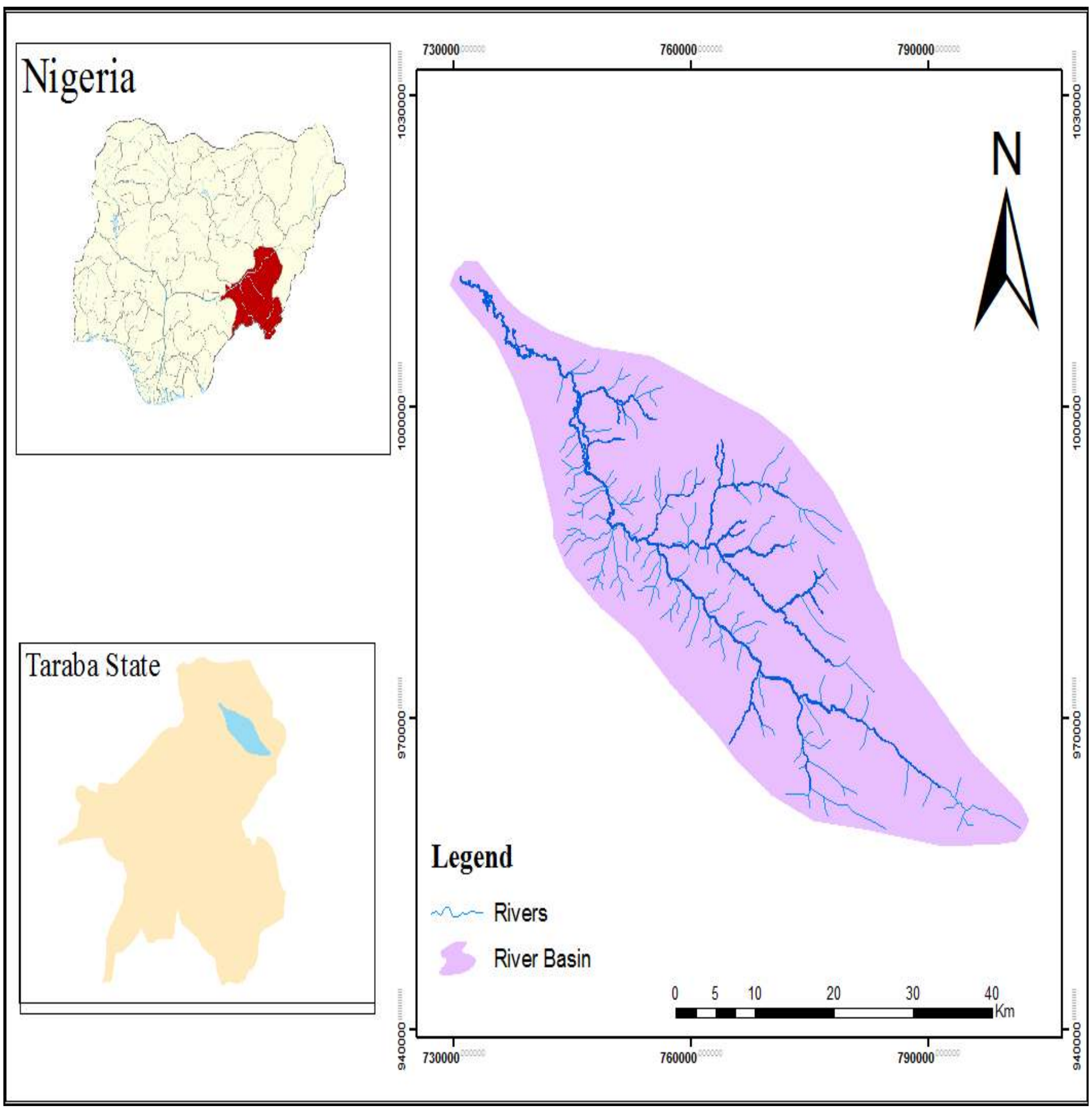

Fig. 1. Location map of the study area

boreholes located within the flood plain of the river [12]. The changes in land uses along the floodplains of the river has been a matter of great concern because of the increase in the devastating effects of flooding in recent times in the area [13,14].

2. MATERIALS AND METHODS

The data used in this study comprises of ETM+ (2015) and Shuttle Radar Topographic Mission (SRTM) digital elevation model of the basin obtained from the United State Geological Survey (USGS) online open resources. The map of the study area was obtained from the Taraba State Bureau of Land and Survey. Satellite images of Landsat 8 were used as base map for the GIS technique. The images were acquired on 15th March 2015 and the projection type is UTM and spheroid is WGS 1984. The datum is the Minna datum, UTM zone 32N and the pixel size is 15 meter. Morphometric analysis and prioritization of basin was based on the integrated use of remote sensing and GIS technique. The drainage map of the study area was prepared using geo-coded data and verified with survey of Jalingo toposheets no. 193, 194, 195, 214, 215, 216, 235, 236 and 237 of the area at 1:50000. The toposheets and satellite data were geometrically rectified and georeferenced to World space coordinate system using ERDAS IMAGINE 9.2 software package.

Morphometric analysis comprises a series of sequential steps. The drainage layer was converted to digital format through on-screen digitization from available topographic maps using ArcGIS 9.1, in the scale of 1:50000 and the attributes were assigned to create the digital database. All measurements were directly computed from the vector data that was extracted from the topographic maps. The entire drainage segments were digitized as lines separately for each order [15]. Digitization work was carried out using Arc GIS 9.2 software. The map showing the drainage pattern was prepared after detailed ground checks (fieldwork) with GPS survey on channel network. Image interpretation comprises data derivation from map analysis, map work, computation from topographical maps and satellite imageries pertaining to different components of the drainage basin morphometric parameters in the study area. The Area (A) and Perimeter (P) of the drainage basin was calculated using measurement tool option of ArcGIS version 9.2. Various morphometric parameters such as linear aspects of the drainage network: stream order (Nu), bifurcation ratio (Rb), stream length (Lu), and areal aspects of the drainage basin: drainage density (D), stream frequency (Fs), texture ratio (T), elongation ratio (Re), circulatory ratio (Rc), form factor (Rf) of the basin were computed. This morphometric parameters of the basin were calculated based on literature [16,17,15,18,19,20,21].

3. RESULTS OF THE FINDINGS

Fig. 2 shows that the basin exhibits a dendritic type of drainage network which indicate the homogeneity in texture and lack of structural control in the study area.

3.1 Stream Order (Nu)

The designation of stream order is usually seen as the first step in drainage basin analysis. Stream order has been defined as a measure of the position of a stream in the hierarchy of tributaries [22]. Hierarchical ordering of streams is necessary to assess hydrodynamic character of a drainage basin. In the present study, the various stream segments of the drainage basin have been ranked according to Strahler's stream ordering system. According to [19], the smallest fingertip tributaries are designated as first stream order. Where two first stream order meets, a second stream order is formed; where two second stream order meets, third stream order is formed and so on. The stream order of River Lamurde is presented in Table 1.

The total number of stream segments is found to decrease as the stream order increases in the basin. The study reveals that the development of 1st order streams is maximum in the basement complex area and minimum in the alluvial plains (Table 1). The number of 1st stream order in a basin of a given size is dependent upon a number of factors which include climatic, geologic and hydrologic. The trunk stream through which all discharge of water and sediment passes is therefore the stream segment of the highest order. River Lamurde, which is the trunk in the study area is of the fourth order (Fig. 2).

3.2 Stream Length (Lu)

The total length of individual stream segments of each order is the stream length of that order. Stream length measures the average (or mean) length of a stream in each orders, and is calculated by dividing the total length of all streams in a particular order by the number of streams in that order. The stream length of the various stream orders in River Lamurde is presented in Table 1. Stream length is one of the most important hydrological features of the basin as it reveals the surface runoff characteristics. Streams of relatively smaller lengths are characteristics of areas with larger slope and finer textures. Streams with longer lengths are generally the characteristics of flatter surface with low gradients. Usually, the total length of stream segments is highest in first stream orders and decreases as the stream order increases. The number of streams of various orders in the basin was counted and their lengths measured from the mouth to the divide of the drainage basin. Stream length is a revelation of the chronological developments of the stream segments including interlude of tectonic disturbances.

3.3 Mean Stream Length

The mean stream length is calculated by dividing the total stream length of given order by number of stream of that order as shown in Table 1. The value for any given order is greater than that of the lower order and less than that of its next higher order in the whole drainage basin. The mean stream length of the study area is 3.65 km.

Table 1. Stream orders, stream number, stream length in the Lamurde river basin

S_no	Stream order	Stream numbers	Total stream length (km)	Mean stream length (S.L/SN)	Bifurcation ratio
1	1^{st} order	132	382.7	2.9	5.08
2	2^{nd} order	26	105.3	4.1	4.33
3	3^{rd} order	6	53.5	8.9	6
4	4^{th} order	1	60.1		

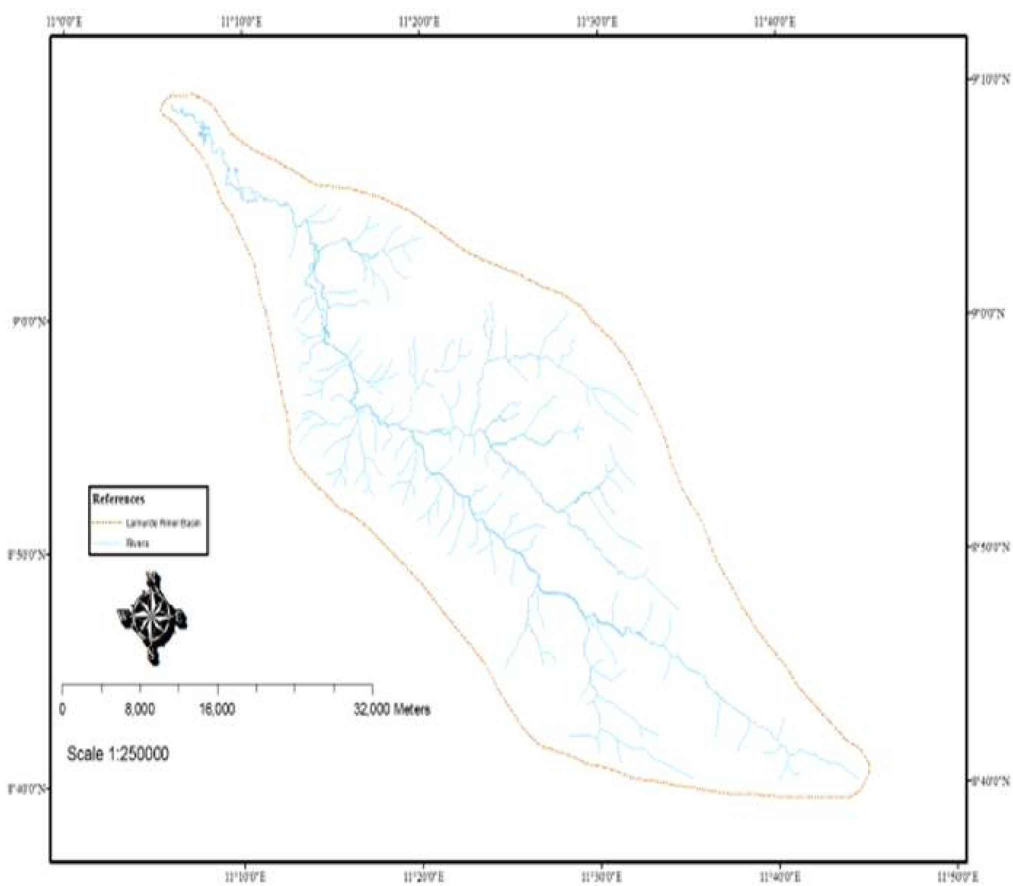

Fig. 2. Lamurde river basin

3.4 Bifurcation Ratio (Rb)

Bifurcation ratio is related to the branching pattern of a drainage network and is defined as the ratio between the total numbers of stream segments of one order to that of the next higher order in a drainage basin [20]. The sum of all the bifurcation ratios in the basin was divided by the number of bifurcation ratios to give the mean bifurcation ratio of the basin. The calculated mean bifurcation ratio for the study area is 3.85, an indication that the study area is a lowland area. This low Rb value indicates less structural disturbance in Lamurde basin. This suggests that the study area has low potentials for discharge compare to those of highland areas with bifurcation ratio of 5.0 [15]. Bifurcation ratios are controlled by basin physiographic factors especially basin relief and drainage density [23]. However, in regions where the network geometry of streams develops without pronounced lithological or structural control, bifurcation ratios between basins of different orders are stable showing little variation from one order basin to another [24,25].

Chorley [26] had noted that the lower the bifurcation ratio, the higher the risk of flooding, particularly of parts and not the entire basin. The low average bifurcation ratio of the Lamurde basin of 3.85 is an indication that parts of its segment are liable to flooding. According to [27], bifurcation ratios ranging from 3 – 5 indicate natural drainage system characterized by homogenous rock. The drainage basin of Lamurde may have been affected by human activities.

3.5 Length of Overland Flow

Length of overland flow is defined as the length of flow path, projected to the horizontal, non channel flow from point on the drainage divide to a point on the adjacent stream channel (Horton, 1945). Horton, for the sake of convenience, had taken it to be roughly equal to half the reciprocal of the drainage density. Overland flow is significantly affected by infiltration (exfiltration) and percolation through the soil, both varying in time and space [28]. In this study, the length of overland flow of the Lamurde drainage basin is 0.13 kilometers, which shows low surface runoff in the study area.

3.6 Areal Aspects

The areal aspects of drainage basin include different morphometric parameters, like drainage density (D), stream frequency (Fs), form factor (R_f), circulatory ratio (Rc), elongation ratio (Re) and length of overland flow (L_g). The values of these parameters were calculated and the results are presented in Table 2.

Table 2. Areal aspects of Lamurde river basin

S_no	Areal parameter	Computed value
1	Area (Sqkm)	1,553.9
2	Perimeter (Km)	197.5
3	Elongation ratio	0.49
4	Drainage density	0.389
5	Stream frequency	0.11
6	Length of overland flow	0.13
7	Form factor	0.19
8	Circulatory ratio	0.5
9	Drainage texture	0.3

3.7 Drainage Area (Au)

The entire area drained by a stream or system of streams such that all streams flow originating in the area is discharged through a single outlet is termed as the drainage area. In other words, the drainage area is a collecting area from which water would go to a river. The boundary of the area is determined by the ridge separating water flowing in opposite directions. The total area of the drainage basin is estimated to be 1,553.9 km^2. Basin area has been identified as the most important of all the morphometric parameters controlling catchment runoff pattern. This is because, the larger the basin, the greater the volume of rainfall it intercepts, and the higher the peak discharge that result [29,7,30,31,32,33].

3.8 Drainage Density (Dd)

Drainage density can be regarded as the total length of the streams of all orders per drainage area. Dd is expressed as the ratio of the total sum of all channel segments within a basin to the basin area i.e., the length of streams per unit of drainage area. It is a dimension inverse of length [16]. Drainage densities can range from less than 5 km/km^2 when slopes are gentle, rainfall low and bedrock permeable (e.g. sandstones), to much larger values of more than 500 km/km^2 in mountainous areas where rocks are impermeable, slopes are steep and rainfall totals are high [34]. The drainage density (Dd) of the study area is 0.389 km/km^2. Thus, in this study, the drainage density falls less than 5 km/km^2 which indicates that the area has a gentle slope, low rainfall and permeable bedrock. Low drainage densities are often associated with widely spaced streams due to the presence of less resistant surface materials (lithologies or rock types), or those with high infiltration capacities. Drainage basin with high Dd values indicates that a large proportion of the precipitation runs off. On the other hand, a low drainage density indicates that most rainfall infiltrates into the ground and few channels are required to carry the runoff. In general, low drainage density leads to coarse texture while high drainage density leads to fine texture [19].

3.9 Stream Frequency (Fs)

The stream frequency (Fs) or channel frequency or drainage frequency of a basin may be defined as the total number of stream segments within the basin per unit area [17]. It mainly depends on the lithology of the basin and reflects the texture of the drainage network. The basins of the structural hills have higher stream frequency, drainage density while the basins of alluvial has minimum. The stream frequency of the study area is 0.11 stream segments per square kilometer. The lower value indicates that the basin possess low relief and less number of streams. The existence of less number of streams in a basin indicates matured topography, while the presence of large number of streams indicates that the stream is youthful and still undergoing erosion. Both values of stream frequency and drainage density show that Lamurde basin has a low relief and by implication has a low response to surface runoff.

3.10 Drainage Texture (Rt)

Horton [17] defined drainage texture as the total number of stream segments of all order in a basin per perimeter of the basin. The drainage texture of the Lamurde basin is 0.84. This shows that the basin has a very coarse texture. Smith have classified five different drainage textures related to various drainage densities as very coarse (below 2), coarse (2 - 4), moderate (4 - 6), fine (6 - 8) and very fine (8 and above). The higher the drainage texture, the more the dissection and erosion in the basin. Drainage texture depends on a number of natural factors such as climate, rainfall, vegetation, rock and soil types, infiltration capacity, relief and stage of development. Weak rocks devoid of vegetative cover produce fine texture, while rocks which are hard and with vegetative cover produce coarse texture.

3.11 Basin Shape (Rf)

This is the measure of the elongation of a basin. As elongation increases for a given area, Rf decreases. Three parameters viz. Elongation Ratio (Re), Circulatory Ratio (Rc) and Form Factor (Rf) are used for characterizing drainage basin shape, which is an important parameter from hydrological point of view. The shape of the basin mainly governs the rate at which the water is supplied to the main channel. The basin has an elongation ratio (0.49), circularity ratio (0.5) and form factor (0.19) which indicates that the shape of the basin tends towards elongation. The elongation shape indicates that the basin will have a flatter peak of flow for longer duration. Basin shape reflects the way that runoff will bunch up at the outlet. An elongated basin having the outlet at one end of the major axis and having the same area as the circular basin would cause runoff to be spread out over time, thus producing a smaller flood peak than that of the circular basin.

3.12 Basin Perimeter (P)

Basin perimeter is the outer boundary of the drainage basin that encloses its area. It is measured along the divides between basins and may be used as an indicator of basin size and shape [20]. The basin perimeter of Lamurde basin is 197.5 kilometers.

3.13 Elongation Ratio (Re)

Elongation ratio (Re) is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length [20]. Elongation ratio determines the shape of the basin and can be classified based on these values as circular (0.9 - 1), oval (0.8 – 0.9), less elongated (0.7 – 0.8), elongated (0.5 – 0.7), more elongated (< 0.5). Regions with elongation ratios are susceptible to more erosion whereas regions with high values correspond to high infiltration capacity and low runoff. The elongation ratio of the drainage basin is 0.49 which indicates more elongation and more prone to erosion with less infiltration capacity. Circular drainage basins are more efficient in the discharge of runoff. They are at greater risk from flood hazard because they have a very short lag time and high peak flows than the elongated basins. Elongated drainage basins have low side flow for shorter duration and high main flow for longer duration and are less susceptible to flood hazard.

3.14 Circularity Ratio (Rc)

The circularity ratio is a similar measure as elongation ratio, originally defined by Miller [21] as the ratio of the area of the basin to the area of the circle having same circumference as the basin perimeter. The calculated Rc value for the study area is 0.5 which indicate that the drainage basin is between elongated and circular and is characterized by medium to low relief. The value of circularity ratio varies from 0 (in line) to 1 (in a circle). The circularity ratio (Rc) has been used as a quantitative measure for visualizing the shape of the basin and is expressed as the ratio of basin area (A) to the area of a circle (Ac) having the same perimeter as the basin [21,19]. It is affected by the lithological character of the basin. The ratio is more influenced by length, frequency (Fs), and gradient of streams of various orders rather than slope conditions and drainage pattern of the basin. It is a significant ratio, which indicates the dendritic stage of a basin. Its low, medium and high values are indicative of the youth, mature and old stages of the life cycle of the tributary basins.

3.15 Form Factor (Rf)

Form factor is the numerical index commonly used to represent different basin shapes [16]. The value of form factor ranges between 0.1 to 0.8. The form factor of the study area is 0.19. This shows that the basin is very elongated and thus has low peak flow of longer duration. Consequently, the flood flow of this type of basin is easier to manage than the circular basin [35]. The Smaller the value of form factor, the more elongated will be the basin. The basins with high form factors (0.8), have high peak flows of shorter duration, whereas, elongated drainage basin with low form factors have lower peak flow of longer duration.

3.16 Relief Aspects of the Study Area

Basin relief is an important factor in understanding the denudational characteristics of the basin. Relief is the difference between the maximum and minimum elevations in the basin. The maximum height of the Lamurde basin is 685m and the lowest is 118 m. The relief of the basin is 567 m (Fig. 3). The basin length, relative relief and relief ratio of the study area is presented in Table 3.

3.17 Relief Ratio (Rh)

This is a dimensionless measure of the overall gradient across a basin. It is calculated by dividing the relief (H) of a basin by its length (L). The maximum basin relief is obtained from the elevation difference between highest point on the basin perimeter and its confluence with the trunk stream. The maximum basin relief of the Lamurde drainage area is 567 m (685 m – 118 m). The Rh normally increases with decreasing drainage area and size of sub-watersheds of a given drainage basin [36,37]. The relief ratio of the Lamurde basin is 0.032. The relief ratio of the basin is low, which is characteristics features of less resistant rocks. The lower values may indicate the presence of basement complex rocks that are exposed in the form of small ridges and mounds with lower degree of slope [38]. Low relief ratios also indicate that the recharge capabilities of the basin are low and chances of ground water potential are good [39]. The study area lies within hilly terrain (Yorro hills) in the initial stages and further down stream in the gently or flat sloping terrain (Fig. 3).

Table 3. Relief aspects of river Lamurde

S_no	Morphometric parameters	Result
1	Basin length	89.6 km
2	Relative relief	2.78
3	Relief ratio	0.032

3.18 Relative Relief

Relative relief is defined as the differences in height between the highest and the lowest points (height) in a unit area. It is an important morphometric parameter used in the overall assessment of morphological characteristics of terrain [40]. [41] suggested to calculate relative relief by dividing the difference of height between the highest and lowest points in the basin (H) with basin perimeter (P), thus relative relief = H/P. The relative relief of the study area is 2.87. Relative relief is calculated on the basis of highest and lowest elevations and the data of relative relief so derived are tabulated and classified into three categories viz. (i) low relative relief = 0 m – 100 m, (ii) moderately relative relief 100 m – 300 m and (iii) high relative relief = above 300 m.

3.19 Basin Length (Lb)

Basin length is the longest dimension of a basin to its principal drainage channel. The longer the length of a basins, the lower the chances that such a basin will be flooded when compared with a more compact basin. Basin length (Lb) has

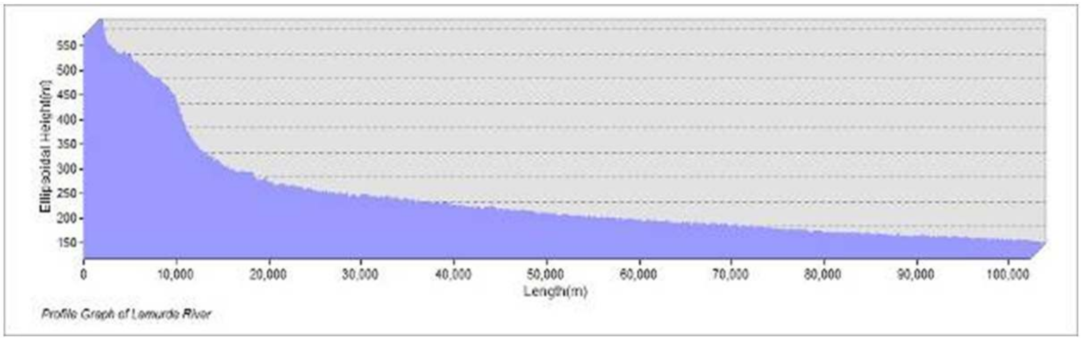

Fig. 3. Profile of river Lamurde

been given different meanings by different workers [20,42,43,44]. The Lb is the longest length of the basin, from the catchment to the point of confluence [42]. The Lamurde stream meets River Benue at the point of confluence in the north-western part of the study area. The length of the Lamurde river basin is 89.6 kilometers.

4. CONCLUSION

This study has examined the morphometric characteristics of River Lamurde basin using remote sensing image and GIS technique. These morphometric parameters studied using GIS has helped us to understand various terrain characteristics such as the nature of the bedrock, infiltration capacity, runoff etc of the study area. The results of the findings has revealed that the basin has a low relief, coarse texture, gentle slope and permeable bedrock. The elongated nature of the basin implies a high main flow for longer duration and less susceptibility to flood hazard. The result of the findings suggest that the study area will be more prone to erosion with less infiltration capacity. The findings revealed that the recharge capabilities of the basin are low and chances of ground water potentials are good. The implication of the findings of the study is that there will hardly be enough water supplies to support large scale water development project, particularly hydropower development projects except with intensive development of land and water resources of the basin.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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