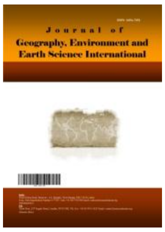

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# Evaluation of Erosion-Prone Areas in Lamurde River Basin, Nigeria Using Morphometric Prioritization Method

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***Authors' contributions***

*This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.*

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## ABSTRACT

Remote sensing and GIS techniques have been increasingly used in characterization of drainage basin and prioritization of erosion prone watershed. This study uses remote sensing and GIS to characterise drainage basin morphometry and prioritize soil erosion prone sub watershed in the Lamurde watershed in Taraba state Nigeria. The study adopted standard formulae and methods to compute the morphometric parameters. The Lamurde watershed was delineated to fifteen sub-watersheds with each coded as WS1 to WS15. The result of the findings reveals that Lamurde watershed has a dendritic to sub-dendritic drainage pattern with the smaller streams intersecting the main trunk at acute angles. The findings reveal that Lamurde is a ninth order stream with total area of 1,458.66 km$^2$ and a perimeter of 395.93 km. The basin also has 258,493 total number of streams. The main soil types in the Lamurde basin are fluvisol, lithosol, ferric luvisols and humic nitosols. The surface soil texture of the area is mainly loamy type and particle size classes are fine loamy type. Depth of soil varies from shallow to very deep and having parent material derived from sandstones, mudstones and shales. The findings of the study reveals that watershed: WS7, WS8, WS5, WS11, WS15, WS14, WS2 and WS6 in ascending order are very highly vulnerable to soil erosion. Despite inherent limitation in the use of morphometric parameters to prioritize erosion prone sub watersheds, it is most suitable in the present circumstances because of inadequate

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information and lack of functional measurement station in the basin, since they have more stable and accessible data on which prioritization of the watersheds can be based on. This study contributes to the problem of dearth of information regarding the susceptibility to erosion in the Lamurde River Basin in Taraba State Nigeria. Based on this findings, these sub watersheds should be given higher priority on any soil conservation intervention measures in the study area. This will go a long way to help address the problem of soil erosion in the area.

*Keywords: Erosion prone areas; lamurde; morphometric prioritization; river basin and soil erosion.*

## 1. INTRODUCTION

Soil erosion is increasingly becoming a major threat to farming activities in most developing countries especially in Sub Saharan Africa and Nigeria in particular. Soil erosion is broadly defined as the accelerated removal of topmost layer of the earth surface through water, wind or tillage from fragile skin of the earth [1]. Drainage basins generally are sensitive to the process of land degradation. The drainage basin analysis is important in any hydrological investigation like assessment of groundwater potential, groundwater management, pedology, soil erosion and environmental assessment [2]

Water is the most important of the several factors that influence soil erosion. Soil erosion, runoff, the evolution of rivers, sedimentation, and drainage geometry are reflections of hydrological and geomorphic processes, and are ultimately assessable using morphometric characteristics of the drainage basin [3].

Morphometric analysis of a watershed is an important first step in understanding watershed dynamics. Knowledge of the morphometry of a basin can go a long way to explain the hydrological behaviours of such basin [4]. Proper scientific planning and management of these resources of drainage basin requires immense data [5]. The drainage basin has been seen as the fundamental hydrologic and geomorphic areal unit through which the precise description of the geometry of landforms could be harnessed as data could be collected, organized and analyzed [6].

Remote sensing data can be used alongside with conventional data for delineation of ridgelines, characterization, priority evaluation, problem identification, assessment of potentials and management needs, identification of erosion prone areas, evolving water conservation strategies, selection of sites for check dams and reservoirs among others [7, cited in 8].

This analysis can be carried out through measurement of the morphometric properties of the drainage basins using the Geographic Information System (GIS). The use of Geographical Information System (GIS) techniques are much efficient, time-saving and suitable for spatial planning [1]. One of the greatest advantage of GIS, is its capability of handling large datasets and resolving many complex issues besides facilitating retrieval and querying of data.

Studies conducted by Sanware et al. [9] Prasad et al. [10] and Sharda et al. [11] revealed that remote sensing and GIS techniques were of great use in characterization and prioritization of watershed areas. For example, Sharma et al. [12] used morphometric parameters to prioritize five sub-watersheds of the Sarpha River drainage basin of Shahdol in the District of Madhya Pradesh using GIS technique.

Thus, watershed prioritization is the ranking of sub watersheds of a watershed according to vulnerability to soil erosion [13]. Prioritizing erosion-prone areas in the catchment is essential when financial resources for executing a conservation plan are limited [14]. The area most likely to contribute to a large volume of sediment, and which are susceptible to a high degree of erosion, get higher priority in treatment and control intervention.

Jalingo town has suffered from serious soil erosion and other forms of land degradation in recent times resulting in topsoil loss in the area. The basement complex nature of Jalingo town characterised by undulating topography has predisposed the town to incidence of soil erosion. Many parts of Jalingo town are seriously affected by problem of soil erosion resulting in formation of gullies that made streets not motorable. The vulnerability of the area to soil erosion makes it necessary to undertake effective soil conservation measures. This will require planning and management of soil and water resources in a sustainable manner in the

Lamurde basin to help halt further deterioration of land and increase crop productivity in the basin.

Hence, planning and management of soil and water resources in a sustainable manner in the Lamurde basin is very important. This will go a long way to halt further deterioration of land and increase crop productivity in the basin. To achieve this, proper scientific planning and management of soil resources requires comprehensive approach and historical data. The geomorphological characteristics of watersheds are commonly used for developing the regional hydrological models for solving various problems of the watersheds under inadequate data situations [15,7,16]. It is against this background that this study evaluates the drainage basin morphometry to prioritize soil erosion prone areas in the Lamurde watershed.

### 1.1 Description of Study Area

Jalingo LGA is roughly located between latitudes 8°47’N to 9°01’N and longitudes 11°09’E to 11°30’E. It is bounded to the North by Lau Local Government Area, to the East by Yorro Local Government Area, to the South and West by Ardo Kola Local Government Area. The Lamurde drainage basin is located between lat. 9°11'N to 8°35' and between longitude 11°7'E to 11°45'E. Jalingo town lies within the Lamurde River basin. River Lamurde which drains Jalingo town is a ninth stream order that took its sources from the Yorro Mountain near Gangoro and flows downhill through Yorro, Tazarang, Alkali Gwa, Bassa and Jalingo (Fig. 1). The river flows for over 96km westward before emptying into the Benue River system near Tau community. Jalingo town is made up of undulating plain interspersed with mountain ranges. These mountain ranges surrounded the town in a circular form, extending from Kona area through the border between Jalingo and Lau LGAs down to Yorro and Ardo Kola LGAs to Gongon area. The basin has only one outlet, which is the Lamurde River, to drain water from the basin to the River Benue system. Most of the agricultural farming activities are rain fed with few places along the main Lamurde river used for irrigation especially within Jalingo town.

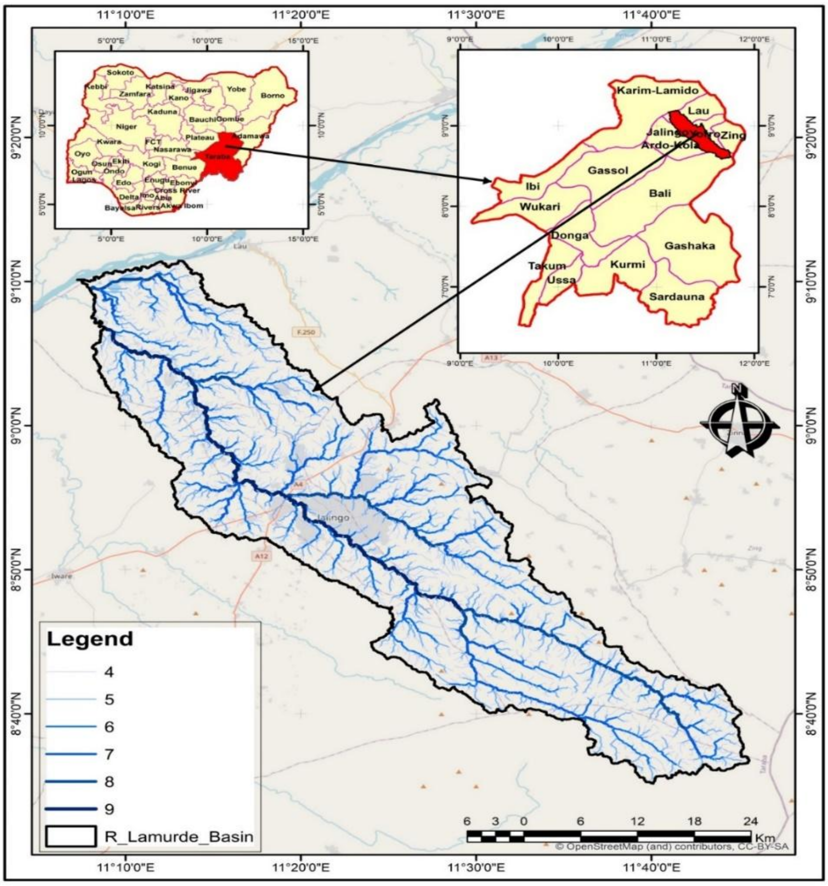


**Fig. 1. Map of the Study Area**

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 and soil erosion in recent times in the area [17,18,19]. Furthermore, Jalingo town have rugged topography and unstable slopes with highly shattered rocks. Based on these factors, the evaluation of basin characteristics from the morphometric analysis and other associated factors will help to understand the physical behaviour of the drainage basin.

## 2. MATERIALS AND METHODS

### 2.1 Sources and Types of Data

The data that was used in this study include Enhanced Thematic Mapper (ETM+) and Shuttle Radar Topographic Mission (SRTM) and digital elevation model of the basin. This was obtained from the United State Geological Survey (USGS) online open resources. It was projected to UTM and spheroid WGS 1984. The study used the Minna datum, UTM zone 32N and the pixel size was 30 meter. The processed image was used to identify the drainage pattern and perform the morphometric analysis. Topographic map of Jalingo area on toposheets: 193, 194, 195, 214, 215, 216, 235, 236 and 237 at 1:50000 scales was used in this study. The Lamurde watershed was delineated into sub-watershed for morphometric prioritization method analysis using ArcSWAT automated tool in the ArcGIS environment (Fig. 2a). Digital elevation model (DEM) was used to validate the surveyed points and toposheet contours using global positioning system (GPS) for better results.

### 2.2 Processing of Data

The drainage network of the watershed was extracted from DEM using River Tools 3.0 software. The study used software's such as ArcGIS 10.3, Global Mapper and ERDAS Imagine 9.1 in geo-registration of toposheets, georectification, image processing, digital image classification and composition of false colour composite (FCC) from satellite data. The digital elevation model (DEM) products like drainage network map, elevation map, slope map, and contour map was integrated by overlay technique in ArcGIS environment to assess their effect on the watershed behaviour. The Strahler's drainage ordering system was used in assigning orders to various streams. Soil classification map (scale 1:500,000) was resized to 1:50,000 scale by superimposing Landsat satellite data and image ratio tool. The slope map was derived from DEM (Fig. 2b). The soil map was obtained from Federal Ministry of Agriculture. Relevant linear, areal and relief parameters of drainage morphometry of the sub watershed was computed using standard formula as shown in Table 1 and the entire basin was divided into sub basins for prioritization process.

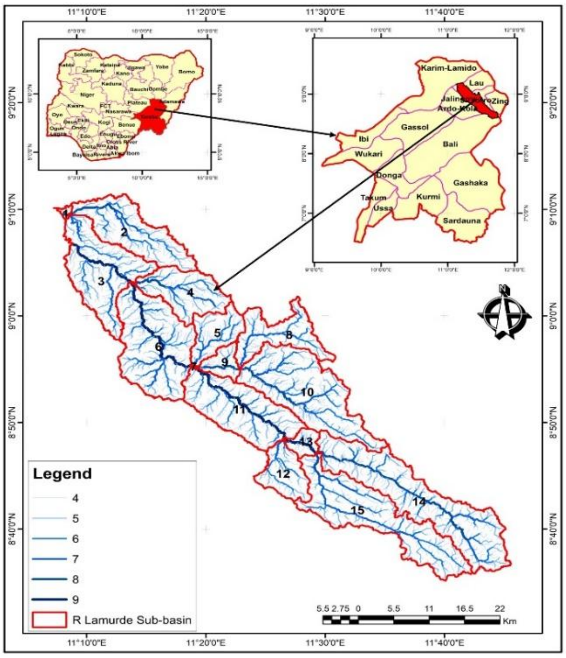


**Fig. 2a. Map of Lamurde showing the sub watershed**

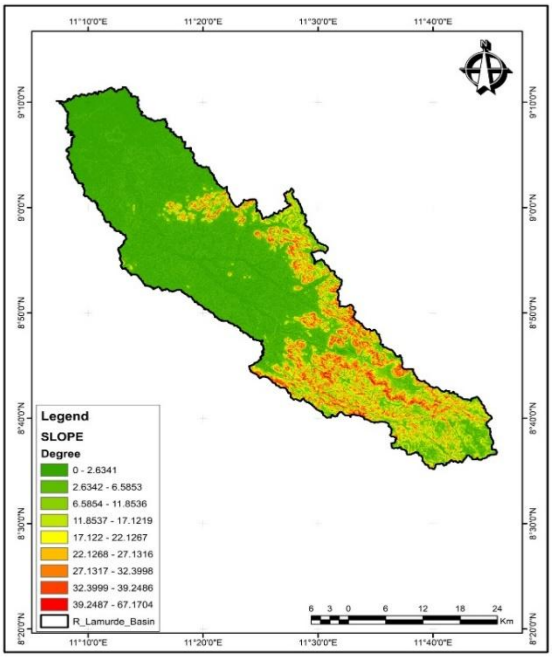


**Fig. 2b. Slope map of Lamurde watershed**

**Table 1. Formula used for computation of morphometric parameters**

| S/No | Parameter | Formula | Type of parameter | References |
|---|---|---|---|---|
| 1 | Area | A | Geometry | |
| 2 | Perimeter | P | Geometry | |
| 3 | Basin length | $L_b$ | Geometry | Nookaratnam et al. [20] |
| 4 | Stream length | L | Stream | Horton [21] |
| 5 | Number of streams of order U | $N_u$ | Stream | Strahler [22] |
| 6 | Bifurcation ratio ($R_b$) | $R_b = N_u/N_{(u+1)}$ | Morphometric | Schumn [23] |
| 7 | Drainage density ($D_d$) | $D_d = L_u/A$ | Morphometric | Horton [21] |
| 8 | Stream frequency ($F_s$) | $F_s = P\ N_u/A$ | Morphometric | Horton [21] |
| 9 | Drainage texture (T) | $T = D_d \times F_s$ | Morphometric | Horton [21] |
| 10 | Form factor ($R_f$) | $R_f = A/(L_b)^2$ | Morphometric (basin shape) | Horton [21] |
| 11 | Circularity Ratio ($R_c$) | $R_c = 4\pi A/P^2$ | Morphometric (basin shape) | Miller (1953) |
| 12 | Elongation ratio ($R_e$) | $R_e = (2/L_b) \times (A/\pi)^{0.5}$ | Morphometric (basin shape) | Schumn [23] |

*Source: Adapted from Das (2014).*

### 2.3 Prioritization of Sub-basins

To carry out prioritization of sub-basins, the highest value of linear parameters was rated as rank 1, second highest value was rated as rank 2 and so on, and the least value was rated last in rank. Also, the lowest value of shape parameters was rated as rank 1, next lower value was rated as rank 2 and so on and the highest value was rated last in rank. At the end of the study, the ranking of the sub watersheds was determined by assigning the highest priority based on highest value in terms of linear parameters and lowest value in terms of shape parameters following Nookaratnam *et al*. [20] method.

## 3. RESULT OF THE FINDINGS

The Lamurde watershed was delineated to fifteen sub-watersheds with each coded as WS1 to WS15. The result of the findings reveals that Lamurde watershed has a dendritic to sub-dendritic drainage pattern with the smaller streams intersecting the main trunk at acute angles. This drainage pattern is an indication of the presence of homogenous rocks and soil types in mountainous and hilly area such as the study area. The study adopted standard formulae and methods earlier described in Table 1, to compute the morphometric parameters. The results are presented in Table 2, and their implications discussed.

### 3.1 Basic Parameters

*Basin area (A)* is the total area projected upon horizontal plane of a watershed. It is the most important watershed characteristics as it directly reflects volume of water in a watershed. Larger basin size intercepts greater volume of rainfall, higher runoff and peak discharge. Sometimes, the smaller size has also recorded maximum flooding and sedimentation. The total area of the Lamurde watershed is 1,458.66 km$^2$. The area of the sub watersheds (WSs) varies from 0.3 km$^2$ to 220.9 km$^2$, the smallest at WS7 and the largest at WS14 (Table 2).

*Watershed perimeter (P)* is length of delineated watershed boundary. It is also regarded as the size of the watershed. The perimeter of the Lamurde basin is 395.93km, while the perimeter of sub watersheds varies between 3.8 – 147.9km; the shortest at WS7 and the longest at WS14.

*Basin length ($L_b$) is* the longest dimension of basin parallel to the principal drainage channel [23]. It indicates the main channel through which the largest volume of water flow through. The findings of the study reveals that the basin length of Lamurde basin is 93.27km. This varies across the sub watersheds with the longest basin length recorded in WS14 (35.7km) and the shortest in WS7 (1.2 km).

*Watershed relief ($B_h$)* is the height between the outlet and the highest relief on the perimeter of a watershed. The result of the study reveals that the relief of Lamurde basin ranges between 1310 – 15 m.a.s.l. The sub watershed with the highest relief is WS15 (1310m) and the lowest is WS1 (15m).

*Stream order (U)* is an indication of the position of a stream in the hierarchy of tributaries. Stream ordering is a categorization that is based on the number and the type of tributary junctions, which is the initial step in morphometric analysis. The streams are assigned different order based on Strahler [22] method. The smallest finger type stream is regarded as first stream orders; where two first stream orders meet, it result in second stream orders; where two second stream orders meet, it result in third stream orders, and so on. It increases from upstream to downstream due to geomorphology of a drainage basin, and the highest order of stream segment is the main channel in which all discharges, runoff and sediment pass through [24]. The main and highest order (9$^{th}$ order) is shown at WS3.

Using the Strahler's drainage ordering system, the result of the findings reveals that the total number of streams in the Lamurde drainage basin is 258493, out of which 203855 belong to 1$^{st}$ order, 42335 are of 2$^{nd}$ order, 9593 are of 3$^{rd}$ order, 2124 are of 4$^{th}$ order, 468 of 5$^{th}$ order, 92 are of 6$^{th}$ order, 21 are 7$^{th}$ order, and 4 are of 8$^{th}$ order. The findings of the study reveals that the highest number of streams is found in sub-basin WS14 (38963), followed by sub-basin WS15 (32621) and sub-basin WS10 (32096), whereas the smallest number of streams is found in sub-basin WS7(60), WS1(500) and WS13(3260). The first stream orders were found to be highest in number in almost all the sub-basins which decreases as the order increases and the highest order has the lowest number of streams.

*Stream length* ($L_u$) is the average lengths of streams of each of the different orders in a drainage basin that tends closely to approximate a direct geometric series in which the first term is the average length of streams of the 1st order. Stream length is highest in first stream order and subsequently decreases as stream order increases [21]. The findings of the study reveals that the longest stream length is found in WS14 (4922km) and the lowest in WS7 (7.1km).

*Stream frequency ($F_s$)* of the Lamurde sub watersheds varies from 196.03 to 168.02; the highest stream frequency is recorded in WS7 (196.03/km2), which indicated that it has the least infiltration capacity and thus highest erosion susceptibility in terms of $F_s$. The lowest stream frequency is recorded in WS2 (168.02/km2), which indicated it possesses the least erosion susceptibility.

*Bifurcation ratio ($R_b$)* - the mean bifurcation ratio of the Lamurde river basin is 4.111. Among the WSs, the highest mean bifurcation ratio is recorded in WS12 (4.892), which indicated that it is structurally complex and has low permeability and thus the highest erosion susceptibility in terms of $R_{bm}$. The lowest $R_{bm}$ is recorded in WS7 (2.269), which is an indication of least erosion susceptibility.

*Texture ratio (T)* - in the Lamurde watershed, the lowest texture ratio is recorded in WS1 (36.23/km), which indicated that it has the highest infiltration capacity among the other WSs or conversely, it has the least susceptibility to erosion if the T is taken as the basis of erosion susceptibility. The highest texture ratio was observed in WS6 (336.58/km), which indicated that it has the lowest infiltration capacity and thus highest erosion susceptibility in terms of T.

*Elongation ratio ($R_e$)* - the highest elongation ratio in the Lamurde basin is recorded in WS1 (0.855), indicating that it has the least susceptibility to erosion in terms of $R_e$. The lowest $R_e$ is recorded in WS14 (0.470), indicating the highest susceptibility.

*Circulatory ratio ($R_c$)* - the highest Circulatory ratio in the Lamurde basin is recorded in WS13 (0.34), indicating low infiltration capacity and more erosion susceptibility in $R_c$ terms. The lowest $R_c$ is recorded in WS8 and WS15 (0.12) which indicates that it possesses low relief and higher infiltration capacity, resulting in lower susceptibility.

*Form factor ($R_f$)* - the highest form factor in the Lamurde basin is recorded in WS1 (0.57), indicating that it has shorter peak flow duration and is least susceptible to erosion in terms of $R_f$. The lowest $R_f$ is recorded in WS14 (0.17), indicating highest susceptibility.

*Compactness coefficient ($C_c$)* - the highest Compactness coefficient in the Lamurde basin was recorded in WS7 and WS15 (2.93), indicating that it is least susceptible to erosion in terms of $C_c$. The lowest $C_c$ is recorded in WS2 (1.56), indicating the highest susceptibility to erosion.

The relief aspect is a three-dimensional characteristic of a watershed that is expressed in terms of the area, volume, and altitude of watershed landforms. *Relief ratio ($R_h$)* is the ratio of maximum relief of the watershed to the

**Table 2. Sub watershed morphometric parameters**

| Sub water shed No | Basin area ($Km^2$) A | Basin Perimeter (km) | Max. elevation (m) | Min. elevation (m) | Basin length | Total Relief (m) | Stream Number ($N_u$) | Stream length (Km) $L_u$ | Stream order |
|---|---|---|---|---|---|---|---|---|---|
| WS1 | 2.9 | 13.8 | 115 | 130 | 2.3 | 15 | 500 | 67.6 | 6 |
| WS2 | 111.2 | 91.2 | 117 | 252 | 22.9 | 135 | 18,676 | 2,583.1 | 8 |
| WS3 | 139.1 | 101.8 | 110 | 239 | 17.8 | 129 | 23,945 | 3,180.4 | 9 |
| WS4 | 83.9 | 68.7 | 140 | 650 | 16.1 | 510 | 14,962 | 2,051.8 | 8 |
| WS5 | 52.3 | 52.2 | 169 | 652 | 12.7 | 483 | 9,356 | 1,332.9 | 7 |
| WS6 | 171.7 | 92.3 | 141 | 479 | 22.0 | 338 | 31,062 | 3,947.1 | 8 |
| WS7 | 0.3 | 3.8 | 172 | 184 | 1.2 | 12 | 60 | 7.1 | 6 |
| WS8 | 76.8 | 91.0 | 188 | 807 | 15.4 | 619 | 13,983 | 2,127.3 | 7 |
| WS9 | 27.4 | 37.5 | 172 | 339 | 8.1 | 167 | 4,400 | 576.2 | 8 |
| WS10 | 181.5 | 109.8 | 188 | 1251 | 26.5 | 1063 | 32,096 | 4,922.5 | 8 |
| WS11 | 137.6 | 84.7 | 172 | 528 | 20.7 | 356 | 25,280 | 3,165.2 | 8 |
| WS12 | 52.6 | 49.4 | 210 | 1129 | 11.9 | 919 | 9,385 | 1,497.2 | 7 |
| WS13 | 18.3 | 26.1 | 206 | 788 | 5.8 | 582 | 3,260 | 490.5 | 8 |
| WS14 | 220.9 | 147.9 | 223 | 1470 | 35.7 | 1247 | 38,963 | 6,576.1 | 8 |
| WS15 | 184.7 | 141.2 | 223 | 1533 | 31.8 | 1310 | 32,621 | 5,663.9 | 8 |

*Source: Authors Analysis, 2021.*

**Table 3. Stream morphometric parameters**

| Sub water shed No | Bifurcation ratio ($R_b$) | Drainage density ($D_d$) | Stream frequency ($F_s$) | Circularity ratio ($R_c$) | Form factor ($R_f$) | Elongation ratio ($R_e$) | Texture ratio (T) | Compactness coefficient ($C_c$) |
|---|---|---|---|---|---|---|---|---|
| WS1 | 3.188 | 22.93 | 169.55 | 0.19 | 0.57 | 0.855 | 36.23 | 2.27 |
| WS2 | 3.629 | 23.24 | 168.02 | 0.17 | 0.21 | 0.521 | 204.69 | 2.44 |
| WS3 | 3.416 | 22.86 | 172.10 | 0.17 | 0.44 | 0.750 | 235.15 | 2.43 |
| WS4 | 3.734 | 24.45 | 178.33 | 0.22 | 0.32 | 0.643 | 217.76 | 2.12 |
| WS5 | 3.847 | 25.47 | 178.77 | 0.24 | 0.32 | 0.643 | 179.21 | 2.04 |
| WS6 | 3.804 | 22.98 | 180.86 | 0.25 | 0.36 | 0.674 | 336.58 | 1.99 |
| WS7 | 2.269 | 23.35 | 196.03 | 0.26 | 0.22 | 0.529 | 15.72 | 1.95 |
| WS8 | 4.172 | 27.69 | 182.01 | 0.12 | 0.32 | 0.642 | 153.67 | 2.93 |
| WS9 | 3.570 | 23.30 | 177.95 | 0.22 | 0.38 | 0.692 | 117.35 | 2.13 |
| WS10 | 3.836 | 27.12 | 176.86 | 0.19 | 0.26 | 0.573 | 292.39 | 2.30 |
| WS11 | 3.752 | 23.00 | 183.68 | 0.24 | 0.32 | 0.641 | 298.63 | 2.04 |
| WS12 | 4.892 | 28.47 | 178.46 | 0.27 | 0.37 | 0.688 | 189.84 | 1.92 |
| WS13 | 3.065 | 26.83 | 178.34 | 0.34 | 0.55 | 0.835 | 124.89 | 1.72 |
| WS14 | 3.898 | 29.77 | 176.40 | 0.13 | 0.17 | 0.470 | 263.36 | 2.81 |
| WS15 | 4.385 | 30.66 | 176.59 | 0.12 | 0.18 | 0.482 | 230.97 | 2.93 |

*Source: Authors Analysis, 2021.*

**Table 4. Prioritization sub-watersheds using morphological parameters**

| Sub water shed No | Bifurcation ratio ($R_b$) | Drainage density ($D_d$) | Stream frequency ($F_s$) | Circularity ratio ($R_c$) | Form factor ($R_f$) | Elongation ratio ($R_e$) | Texture ratio (T) | Compactness coefficient ($C_c$) | Compound parameter | Final priority |
|---|---|---|---|---|---|---|---|---|---|---|
| WS1 | 13 | 2 | 14 | 6 | 15 | 15 | 2 | 10 | 9.625 | 13 |
| WS2 | 10 | 5 | 15 | 4 | 3 | 3 | 8 | 13 | 7.625 | 7 |
| WS3 | 12 | 1 | 13 | 4 | 13 | 13 | 11 | 12 | 9.875 | 14 |
| WS4 | 9 | 8 | 8 | 8 | 6 | 8 | 9 | 8 | 8.0 | 9 |
| WS5 | 5 | 9 | 5 | 10 | 6 | 8 | 6 | 5 | 6.75 | 3 |
| WS6 | 7 | 3 | 4 | 12 | 10 | 10 | 15 | 4 | 7.625 | 7 |
| WS7 | 15 | 7 | 1 | 13 | 4 | 4 | 1 | 3 | 6.0 | 1 |
| WS8 | 3 | 12 | 3 | 1 | 6 | 7 | 5 | 14 | 6.375 | 2 |
| WS9 | 11 | 6 | 9 | 8 | 12 | 12 | 3 | 8 | 8.625 | 12 |
| WS10 | 6 | 11 | 10 | 6 | 5 | 5 | 13 | 10 | 8.25 | 11 |
| WS11 | 8 | 4 | 2 | 10 | 6 | 6 | 14 | 5 | 6.875 | 4 |
| WS12 | 1 | 13 | 6 | 14 | 11 | 11 | 7 | 2 | 8.125 | 10 |
| WS13 | 14 | 10 | 7 | 15 | 14 | 14 | 4 | 1 | 9.875 | 14 |
| WS14 | 4 | 14 | 12 | 3 | 1 | 1 | 12 | 13 | 7.5 | 6 |
| WS15 | 2 | 15 | 11 | 1 | 2 | 2 | 10 | 14 | 7.125 | 5 |

*Source: Authors computation, 2021.*

maximum length of watershed. This measures the overall steepness of a watershed which is an indicator of erosion process and intensity on watershed slopes [23]. The findings of the study show that $R_h$ value is higher at WS15, WS14 and WS10, whereas WS7, WS1 and WS3 have lower value of total relief at study area.

### 3.2 Ranking and Prioritization of Sub-watersheds

It has been reported that linear and relief parameters have direct relationship with soil erodibility [20,25,26]. This implies that the higher their value the more erodible the soil in that watershed. Consequently, a sub-watershed with the highest value in linear and relief parameters was rated as first rank, second higher value was rated as second rank and so on; and the least value was rated as last in the rank. On the other hand, areal and shape parameters are known to have inverse relationship with soil erodibility [27, 28]. The lower their value, the more erodible the soil in a watershed. Thus, a sub-watershed with the lowest value in areal/shape parameters was rated as first rank, the next lower value was rated as second rank and so on. Then the highest value was rated as the last in the rank. Compound method of averaging value was used in this study, because it was expected that all morphometric parameters have equal importance for final ranking [29,30]. After ranking all the sub-watersheds based on the selected parameters, the ranking values for each sub-watershed was added and divided by the number of all parameters, in this case it was divided by eight; and then arrive at compound value. By so doing, the sub watershed with the least compound value was assigned the highest priority rank which was represented by number 1, the next higher value was represented by number 2 and so on, then the sub-watershed that got the highest compound value was assigned the last priority number, in this 14 [31,32,33,24]. This implies that, the highest priority indicates the greatest degree of runoff, peak discharge and soil erosion risks in that sub-watershed. This makes it imperative to plan proper land and water management practices for each sub-watersheds as per their sensitivity ranks.

### 3.3 Soil Types of Lamurde River Basin

The soils in the Lamurde basin were classified according to the FAO/ UNESCO legend of World Reference Base (WRB) system (FAO/UNESCO, 1974). This system is one of the commonly used in Nigeria for soil classification and mapping. Thus, the study area, Lamurde basin was overlaid on soil map. The digitized map of the basin was divided into the following soil regions (Fig. 3);

**Fluvisol** is a type of soil found typically on level topography that is flooded periodically by surface waters. They are made up of recent alluvium with parent materials derived from river, lake, or marine sediments that have been deposited at regular intervals or in the recent past.

**Lithosols** – these are soils developed on crystalline acid rock and sandy parent materials at very shallow depth. The soils are limited in depth by continuous coherent hard rock within 10 cm of the surface. The soils are derived mainly from the basement complex and old sedimentary rocks. Lithosols on sandy materials are found in many parts of the basin.

**Ferric Luvisols** is an FAO soil classification group that is also referred to as Alfisols in USDA soil Taxonomy. Ferric luvisols (or sandy clay loam soils) have poor internal drainage [34]. Luvisols typically brown to dark brown surface horizon over a (greyish) brown to strong brown or red argic subsurface horizon.

**Humic Nitosols** (Nh) – these are soils rich in organic matter, also referred to as Ferralitic soils. The sedimentary rocks are dominated by sandstones but there are intervening beds of clay, shale and limestone in some places. Everywhere, the rocks have been deeply weathered and oxidized or laterized; the weathering profile consists mostly of red and yellow earths and loose, poorly sorted sands intermixed in places with clay deposits.

The predominant land use in the sub-watersheds are agricultural land and forest lands. Both the sub-watersheds and the main watershed is characterized by overgrazing, degraded forest cover and undulating topography complimented by erratic and intense rainfall. The surface soil texture of the watershed is mainly loamy type and particle size classes that are fine loamy type. Depth of soil varies from shallow to very deep and having parent materials derived from sandstones, mudstones and shales.

## 4. DISCUSSION

The use of morphometric method in prioritization of watersheds for susceptibility to erosion, has been carried out in different parts of the world

[35,36], using different prioritization methods [37]. These different techniques used have their weaknesses which include the number of limited parameters and the involvement of the expert opinion in weighting the parameters [13]. However, prioritizing the watersheds based on morphometric parameters is a necessary method for sustainable management of the watershed [13]. This is because data on drainage basin morphometric characteristics are always available and reliable due to the constant morphometric and physiographic characteristics of the watersheds. Therefore, it is possible to prioritize sub-watersheds on this basis [38]. However, the result of the present study varies from earlier morphometric analysis of the basin by Oruonye et al. [39]. All the values of the morphometric analysis differ with the present findings. In the earlier study, the entire drainage segments were digitized as lines separately using Arc GIS 9.2 software, whereas in the present study, higher version ArcGIS 10.3 and ArcSWAT automated tool in the ArcGIS environment was used.

This study contributes to the problem of dearth of information regarding the susceptibility to erosion in the Lamurde River Basin in Taraba State Nigeria. The findings of the study as shown (Tables 3 and 4) reveals that watershed: WS7, WS8, WS5, WS11, WS15, WS14, WS2 and WS6 in ascending order are very highly vulnerable to soil erosion. Based on this findings, these sub watersheds should be given higher priority on any soil conservation intervention measures in the study area. This will go a long way to help address the problem of soil erosion in the area.

Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have greater resistance to erosion. Sand, sandy loam and loam textured soils tend to be less erodible than silt, very fine sand and certain clay-textured soils.

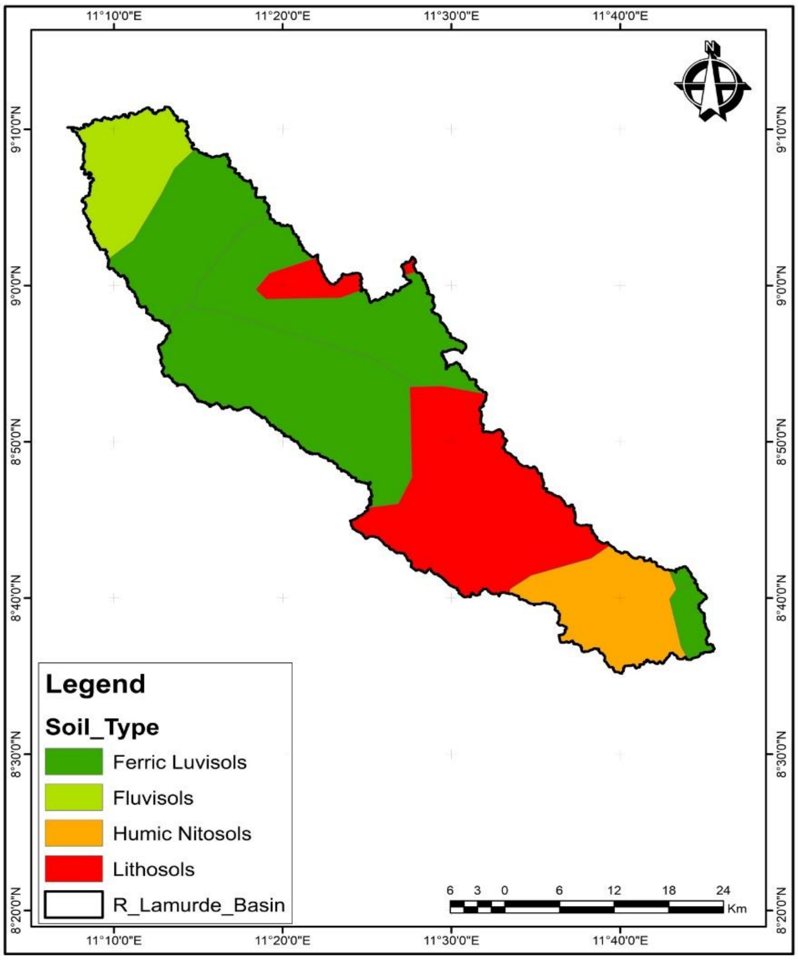


**Fig. 3. Soil Map of the Lamurde Basin**

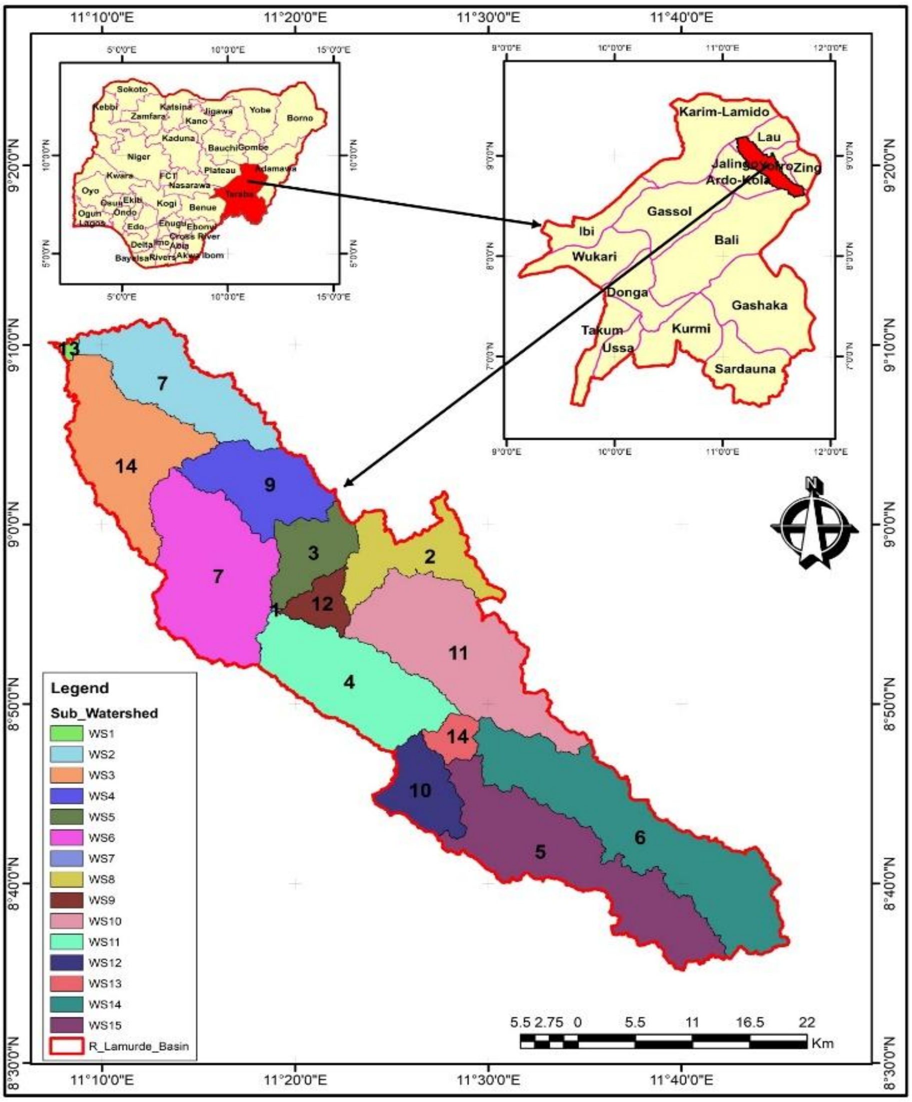


**Fig. 4. Prioritized Rank Map of Lamurde Drainage Basin**

The findings in this study is very useful as it will help to identify important sub basins where soil erosion has been found most severe as a result of the presence of responsible factors. The result therefore provides important information for planners or policy makers to take rational decision and strategies for soil and water conservation in watershed management in the basin.

## 5. CONCLUSION

This study has evaluated soil erosion-prone areas in the Lamurde River Basin, Nigeria using morphometric prioritization method. Remote sensing and GIS technique were used in evaluating the linear aspects such as stream order, bifurcation ratio, stream length and aerial aspects such as drainage density ($D_d$), stream frequency ($F_s$), form factor ($R_f$), circulatory ratio ($R_c$) and elongation ratio ($R_e$). The results of morphometric analysis show that sub-watershed WS7 and WS8 are prone to relatively higher erosion and soil loss. Therefore, suitable soil erosion control measures are required in these sub-watersheds to preserve the land from further erosion. Although there are many methods used in prioritization of drainage basin, this study used morphometric analysis because the results are closer to reality. Despite inherent limitation in the method, it is most suitable in the present circumstances because of information constraints or lack of a measurement station in the basin, since they have more stable and accessible data on which prioritization of the watersheds can be based on.

## 6. RECOMMENDATIONS

Based on the findings of the study, the following recommendations are made;

i. With the prioritization of the sub-watersheds, it is very important to prepare a comprehensive watershed management and implementation plan. This will help the state to initiate actions to forestall further erosion in the drainage basin.
ii. There will be need to employ other more integrated approach such as land use and land cover changes, estimation of surface runoff and sediment yield to achieve more effective result in erosion control in the drainage basin.
iii. Soil conservation measures such as construction of bunds, check dams, micro basins and planting of multipurpose tree species, especially economic tress in more affected location will a long way in mitigating the problem of soil erosion in the basin.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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