The Environmental Studies Journal: A Multidisciplinary Journal

Morphometric Analysis and Prioritization of Muvur Sub-Basins for Soil Erosion Vulnerability in the Muvur Watershed, Mubi, Northeastern Nigeria.

Ezekiel Yonnana[1*], Mohammed Sayd Dzarma[1], Nakama David[1], Felicity Daniel Soyi[1] and Shittu Whanda Ja'afaru.[2]

[1]*Department of Geography, Adamawa State University Mubi, Adamawa State Nigeria*

[2]*Erosion and Watershed Management Project, Environmental and Safeguard Unit, Gombe State*

Corresponding author: Dr. Ezekiel Yohanna, Mobile: +234(0)8036627553

Email: ezekiel97@adsu.edu.ng.

Received August,2020, Accepted September, published September, 2020

Abstract

Soil erosion is a major environmental and land use problem that poses serious threats to most socioeconomic productivities in many parts of the world. In this paper, the vulnerability of the Muvur Sub-Basins to soil erosion was analyzed using GIS based Watershed Morphometric Analysis and Prioritization Approach. The study aimed at identifying the most erosion-prone sub-basins in the watershed. Seven delineated Sub-Basins (MSB1, MSB2, MSB3, MSB4, MSB5, MSB6 and MSB7) of the Muvur Watershed were assessed using thirteen (13) morphometric parameters that have either direct or inverse relationships with soil erodibility. Prioritization of the Sub-Basins with respect to soil erosion vulnerability using Composite Rating (CR) values was employed. Results revealed that four of the sub-basins (MSB3, MSB4, MSB6 and MSB7) had high vulnerability tendencies to soil erosion, while MSB1 and MSB5 had moderate vulnerability. Field study results showed that rills and gullies are the most common types of soil erosion operating in the watershed area, posing serious devastation to farmlands, roads and residential infrastructure. It was recommended that urgent attention from concerned agencies towards mitigating the menace of soil erosion in the most vulnerable Sub-Basins is required. Further studies in aspects of soil loss assessment as well as assessment of morphological characteristics of soil erosion features in the watershed were equally recommended.

Keywords: *Soil Erosion; Vulnerability; Watershed Morphometric Analysis; Muvur Sub-Basins; Morphometric Parameters; Composite Rating Value.*

Introduction

A major and prominent land degradation process that commonly operates within most drainage basins is soil erosion. It is among the major environmental and agricultural problems whose impacts are felt at both local and global scales (Altaf, et al., 2014). This is because soil loss by erosion operates at faster rates than replacement by soil forming processes (Kadam, et al., 2019). Myers (1993) earlier noted that the removal of top soil from any land by the combined effects of water and wind at global scale is estimated at about 75 billion metric tons per year, with agricultural land being the most affected. About 1,903 Mha of the world's land mass are affected by water erosion (UNEP, 1997; Das 2014). In Sub-Saharan Africa, soil erosion accounts for about 77% of land degradation and threatens about 22% of arable land (Climate Home News, 2020). It is estimated that soil erosion affects over 50 million people in Nigeria and accounts for loss of resources worth over 3000 million US Dollars per year (World Bank, 1990; Thlakma, et al., 2018).

In a similar but predictive point of view, soil scientists in Nigeria assert that the Government will need about ₦194 billion for the restoration of degraded lands by 2030, in order to sustain gains made in agricultural sector in the last four and half years (Azeez, 2019). It has also been observed that Abia, Imo, Anambra, Enugu, Ondo, Edo, Ebonyi, Kogi, Adamawa, Delta, Jigawa and Gombe States are the worst hit by gully erosion in Nigeria (Azeez, 2019; Shitttu, 2019). Hence the crucial need to combat soil erosion by all possible means. Therefore, the identification of areas most vulnerable to the threats of soil erosion is very key to the task of soil erosion control and management in the country. It thus forms the backdrop of the current methodological study.

Morphometry is an aspect of geomorphology concerned with the quantitative analysis of forms; size and shapes of landforms. This is the measurement and mathematical analysis of the configuration of the earth's surface, shapes and dimensions of its landforms (Clarke 1966; Agarwal, 1998; Obi Reddy et al., 2002; Pakhmode et al., 2003). Owing to the fact that quantitative analysis of drainage system is an important aspect of assessing the characteristics of watershed (Strahler, 1964), the concept of morphometry is applied to the analysis of shapes and sizes of the fluvial forms in a drainage basin within the context of Watershed Morphometry (WM). Therefore, WM simply refers to the quantitative analysis of the physical properties of the basin, as they influence the development, characteristics and evolution of the basin as a morphological unit. The form and structure of drainage basins and their associated drainage networks are described by their morphometric parameters, which are quantitative attributes of the landscape that are derived from the terrain or elevation surface and drainage network within the drainage basin (Biswas et al., 2014).

Such an analysis can be achieved through measurements and mathematical computations of linear, aerial geometry and relief aspects of the basin (Nag and Chakraborty, 2003; Paul and Inayathulla, 2012). The characterization and analyses of Drainage basin parameters provide vital information pertaining to the development and evolution of the basin landscape as influenced by geomorphic processes operating within the watershed (Altaf et al., 2013). Therefore, Watershed Morphometric Analyses contribute immensely in such studies as assessment of basin flow behavior; flood hazards assessment and mapping of potential zones, Identification and prioritization of erosion prone zones, site suitability for dam construction, watershed management, groundwater potentials and management as well as pedology and environmental assessment among others (Avinash et al., 2011; Diakakis 2011; Javed et al., 2011; Mishra, et al., 2011; Jasmin and Mallikarjuna, 2013; Altaf et al., 2014; Biswas et al., 2014; Das, 2014; Mohammed et al., 2018; Kadam et al., 2019; Prabhakar et al., 2019).

The most common parameters 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; Eze and Effiong, 2010; Rekha, et al., 2011; Paul and Inayathulla, 2012; Altaf et al., 2013; Mohammed et al., 2018; Kadam et al., 2019; Prabhakar et al., 2019). The analyses of these parameters also contribute greatly in comprehending the drainage basin as a hydrological unit.

The Applications of Geographical Information System (GIS) techniques are much efficient, time-saving and much suitable in handling spatial analysis (Kadam et al., 2019). Such techniques are very vital for assessing various geographic and hydrogeomorphic terrain characteristics (Vijith 2006; Altaf et al., 2013; Mohammed et al., 2018; Prabhakar et al., 2019). They provide a flexible environment and powerful tools for the manipulation and analysis of spatial information, particularly for future identification and extraction of information for better understanding (Vijith 2006). The input parameters required for morphometric analysis and watershed prioritization studies can be generated by GIS.

The Muvur Watershed and its river system house and supports the livelihoods of over twenty major human settlements through water supply for consumption, domestic uses, fishing, livestock rearing and irrigation farming as well as substantial arable land for both rain fed and irrigation agriculture. However, from cursory observations, the functionality of the watershed's drainage network tends to pose some erosion threats on the basin landscape in forms of rill, gully erosion and river banks failure. These processes on temporal instances affect the socioeconomic wellbeing of the people in the area, by posing devastating effects on their farmlands, road networks and human dwellings. It is on the basis of this background that this paper examines the degree of vulnerability of the Muvur Sub-Basins (MBS) to soil erosion using Watershed Morphometric Analysis and the Prioritization Approach.

Materials and Methods

The Study Area

The Muvur Watershed is located between latitudes 10°15′00″N and 10°32′00″N of the Equator and between Longitudes13°00′00″E and 13°35′00″E of the Prime Meridian (Fig. 1). The watershed covers an area of about 462.95km^2 and lies across the Nigerian-Cameroun border in the Northern Adamawa province, covering a minute part of the Cameroun Republic (Amsa, Moudi, Choua, Guili and Bourha settlements) and larger part of Mubi North, Nigeria (Mayo Bani, Muvudi, Muvi, Muchala, Mutuba, Nyaminyami and Bourha Oango settlements among others).

The watershed is of the Tropical Wet and Dry (Aw) climate type characterized by warm to hot temperature conditions with annual means greater than 22°C. It is also marked by distinct wet and dry seasons. The wet seasons last for about Five months (May to October) with annual rainfall totals ranging between 850mm and 1100mm (Adebayo, 2004) which serve as the main source of run offs and stream flows in the basin.

The Muvur Watershed geology is mainly that of basement complex rocks, categorically of the Pan-African Granotoids with porphyritic old granites and gneisses of associated origin as the major rock types (Nigerian Geological Survey, 2004). This geologic characteristic is of great relevance to the basin's hydromorphology and pedology as reflected in its relief, hydrography and soils.

The relief is generally high (>400m above mean sea level [a.m.s.l]) with respect to Nigeria's mean sea level (Adebayo and Dayya, 2004)). However, it is further categorized into three levels; Highlands/Mountains (814 – 1,180 a.m.s.l); High plains (582 – 813 a.m.s.l); and Lowlands (483 -581 a.m.s.l) as suggested by Adebayo and Dayya (2004) and shown in the relief map (Figure 2a). The relief is of significant influence on the basin's slope which in turn affects its run off, stream flow and sediment entrainment and transport characteristics. Both geology and relief of the basin play key roles in its soil status. The basin's soil map (Figure 2c) shows the three main soil classes (Lithosols, Plinthic Luvisols and Gleyic Cambisols) that characterize the watershed. The stony, loose, shallow and embryonic characteristics of the soil classes have been well described (Ray, 1999; Yonnana, 2004; Usman, 2005).

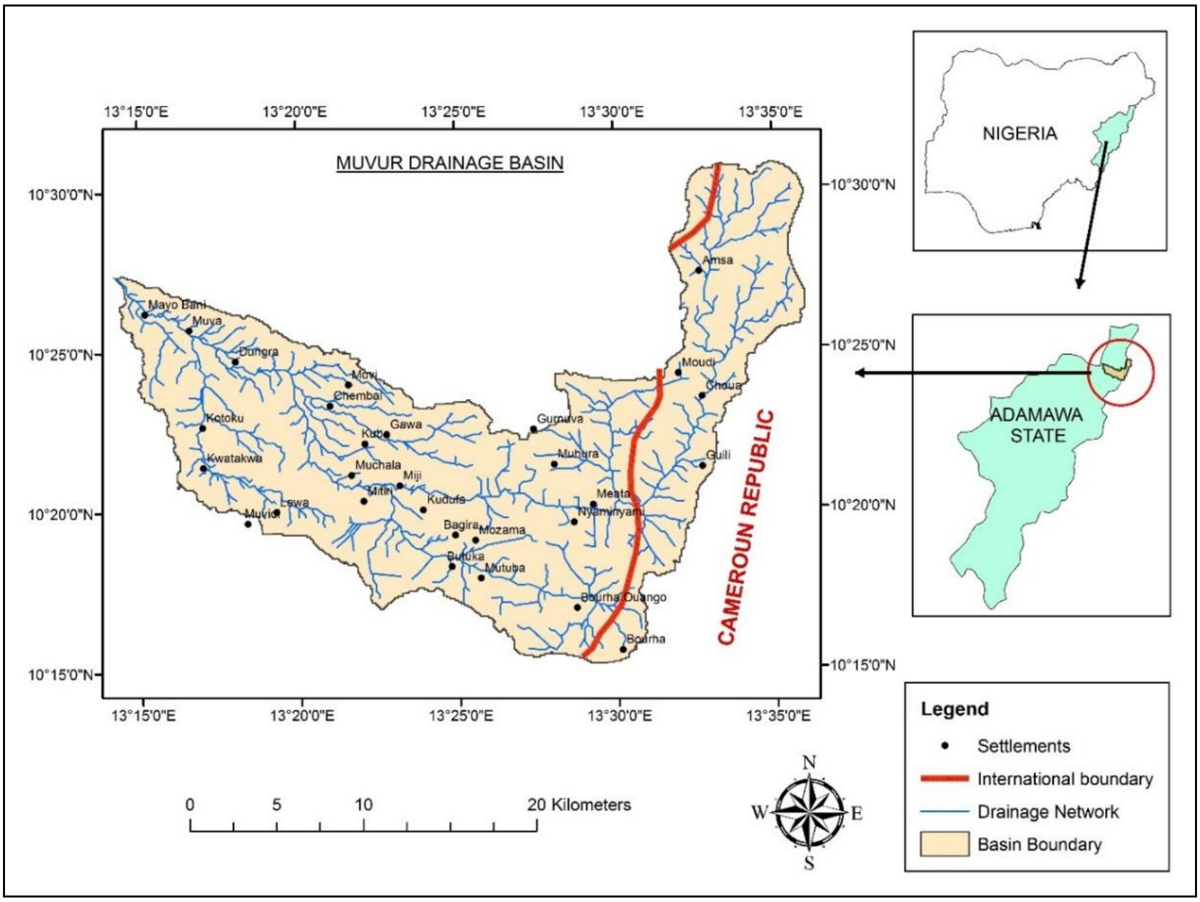

Figure 1: The study area

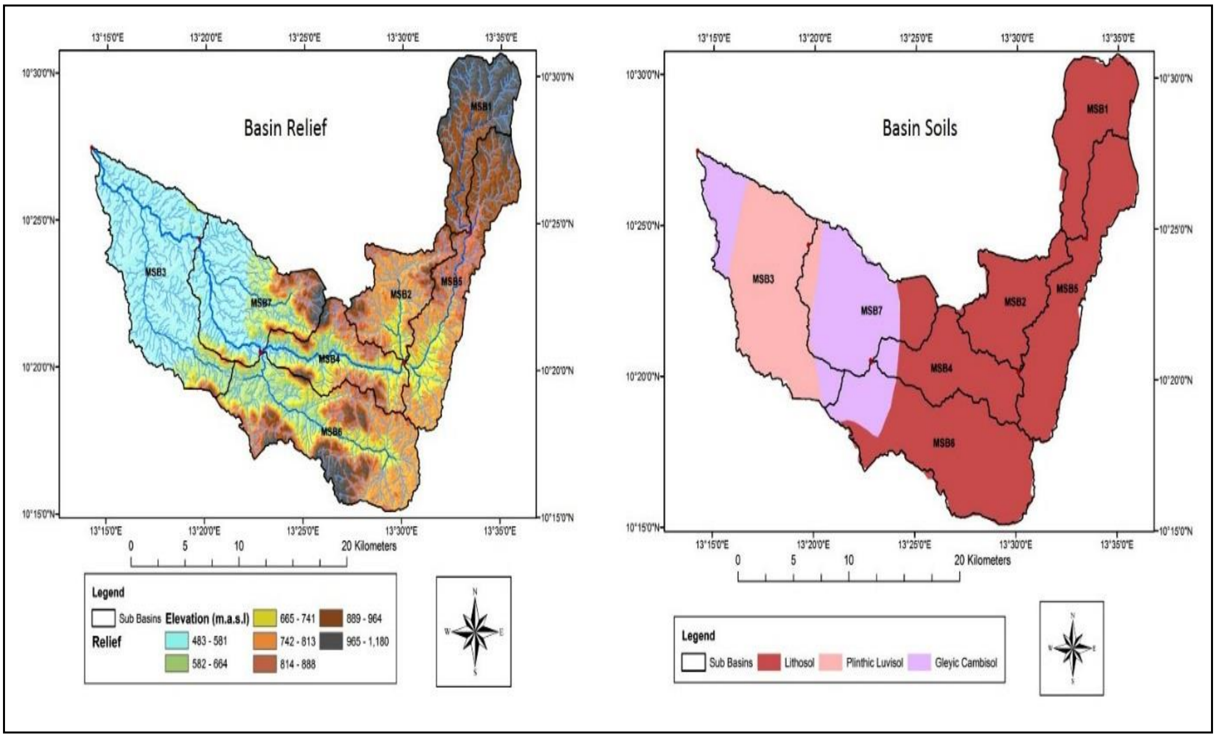

Figure 2: Relief and Soils of the Muvur Watershed

Their structural and textural characteristics make them highly susceptible to erosion conditions. The Muvur Watershed and its Sub-Basins were delineated using the 30m by 30m resolution Digital Elevation Model obtained from the United States Geological Surveys (USGS) Earth Explorer website. The delineation procedure was carried out in the ArcMap environment of ArcGIS 10.3 using appropriate tools of the Arc Toolbox. In this procedure, seven Muvur Sub-Basins (MSB1 to MSB7) were delineated and their drainage networks established (Figure 3).

Some of the Sub-Basin parameters as Stream Orders (u), Stream Lengths (L_u), Areas (A), Perimeters (P), Lengths (L_b), Minimum and Maximum Elevations (E_{min} and E_{max}), Longest Flow Paths (LFP) and Average Slope (S_m) in percentage (%) rise for each Sub-Basin were established directly by GIS manipulations using appropriate tools and procedures in the ArcGIS 10.3 Software.

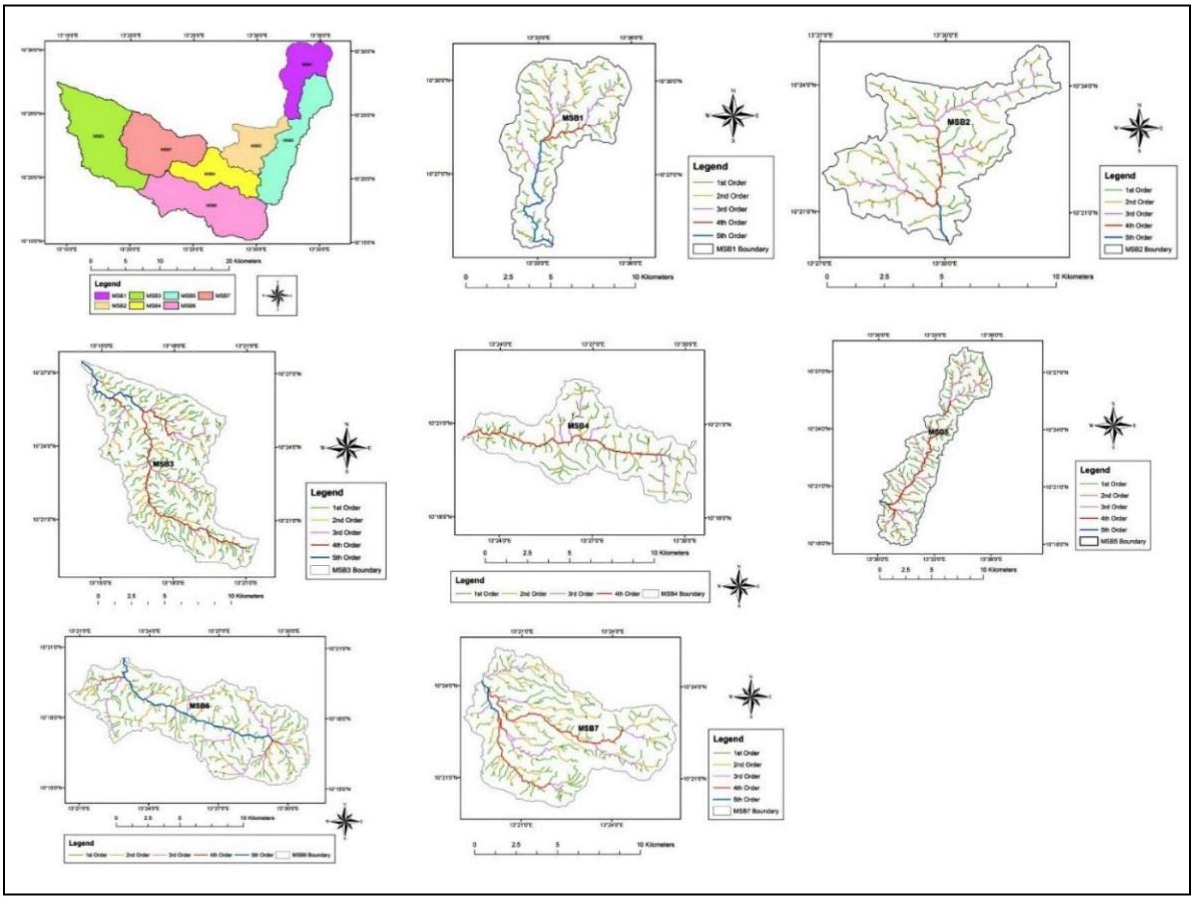

Figure 3: Delineated Muvur Sub-Basins (MSB) and their stream network patterns

Table 1: Basin Morphometric Parameters and Formulae adopted for their computations

Aspect	Parameter	Formula	Reference
Linear	Stream order (u)	Hierarchical order	Strahler, (1964)
	Stream length (L_u)	Length of the stream	Horton, (1945)
	Bifurcation Ratio (R_b)	$R_b = N_u/N_{u+1}$; where, N_u=Total number of stream segment of order'u'; N_{u+1}=Number of segment of next higher order	Schumm, (1956)
Arial	Drainage Density (D_d)	$D_d = \sum L_u/A$; where, ∑Lu=Total length of streams; A=Area of watershed	Horton, (1932)
	Stream Frequency (F_s)	$F_s = \sum N_u/A$; where, $\sum N_u$=Total number of streams; A=Area of watershed	Horton, (1932)
	Drainage Texture ratio (D_t)	$D_t = \sum N_u/P$; where, $\sum N_u$=Total number of streams; P=Perimeter of watershed	Horton, (1945)
	Form Factor (R_f)	$R_f=A/(L_b)^2$; where, A=Area of watershed, Lb=Basin length	Horton, (1932)
	Circulatory ratio (R_c)	$R_c=4\pi A/P^2$; where, A=Area of watershed, π=3.142, P=Perimeter of watershed	Miller, (1953)
	Elongation ratio (R_e)	$Re=2\sqrt{(A/\pi)}/L_b$; where, A=Area of watershed, π=3.14, L_b=Basin length	Schumm, (1956)
	Length of overland flow (Lof)	$L_{of} = 1/2D_d$; where, D_d=Drainage density	Horton, (1945)
	Compactness Coefficient (C_c)	$Cc=0.2841(P/A^{0.5})$; Where P=Watershed Perimeter, A=Watershed Area	Gravelius (1914)
Relief	Basin relief (H)	Vertical distance between the highest (E_{max}) and lowest (E_{min}) points of watershed.	Schumm, (1956)
	Relief ratio (R_{hl})	$R_{hl}=H/L_b$; Where, H=Basin relief; L_b=Basin length	Schumm, (1956)
	Ruggedness Number (R_n)	Rn=Dd*(H/1000)	Strahler, (1964)
	Shape Factor (B_s)	$Bs=(Lb)^2/A$	Horton, (1945)
	Average Slope	Lb (in meters)/H	Ghany (2015)

The Prioritization Approach

Measurement and Computation of Morphometric Parameters

Linear, Shape/Areal and Relief morphometric parameters of relevance to the study included Basin Relief (H), Mean Bifurcation Ratio (R_{bm}), Drainage Density (D_d), Stream Frequency (Fs), Drainage Texture (DT), Shape Factor (B_s), Length of Overland Flow (L_{of}), Form Factor (R_f), Circularity Ratio (R_c), Elongation Ratio (R_e), Compactness Coefficient (C_c), Ruggedness Number (R_n), Relief Ratio (Rhl) and Average Slope (S_m). These were all computed mathematically using standard formulae (Table 1).

An important procedure used in assessing the degree of watersheds susceptibility to soil erodibility is the Prioritization Approach based on computed watershed morphometric characteristics.,(Das 2014; Altaf et al., 2014; Mohammed et al., 2018; Probhakar 2019). This is leaned on the fact that, while some watershed morphometric parameters (Mean Bifurcation Ratio, Drainage Texture, Drainage Density, Stream frequency, Length of overland flow, Relief Ratio, Ruggedness Number; Average Slope etc.) are directly related to soil erodibility, others (Circularity Ratio, Elongation Ratio, Form Factor, Compactness Coefficient, Shape Factor etc.) are inversely related (Das 2014; Altaf et al., 2014; Mohammed et al., 2018; Probhakar 2019).

This implies that the high values of the directly related parameters indicate low infiltration and high surface runoff potentials which are bound to enhance soil erodibility in affected watersheds leading to the high severity of soil erosion. Conversely, high values of the inversely related parameters indicate low runoff and low soil erodibility potentials in affected watersheds. On these bases, the prioritization approach involving the ranking of thirteen (13) morphometric parameters with respect to their relation to soil erodibility, was employed in identifying the degrees of vulnerability of the Muvur Sub-Basins (MSBs) to soil erosion.

Two processes were involved in Prioritization Approach. First, ranking of each morphometric parameter across the Sub-Basins with respect to its direct or inverse relationship with soil erodibility. Second, prioritization analysis to arrive at a Composite Rating (CR) value.

Ranking of Morphometric Parameters

Sub-Basin morphometric parameters which exhibit direct relationship with soil erodibility were ranked in an order that the highest value of a parameter for a particular sub-basin was rated 1. The next higher value of the parameter for another sub-basin was rated 2, in that order until all the values of the parameter for the seven sub-basins were ranked, with the lowest rated 7. A similar ranking procedure was conducted for the parameters that show inverse relationship with watersheds soil erodibility. However, in this case of inverse relationship, the highest value of each parameter for a Sub-basin was rated 7 and next higher value of the parameter for another Sub-Basin rated was 6, in that order until all values of the parameter for all the Sub-Basins were ranked, with the lowest value of the parameter rated 1.

Prioritization Analysis

Having ranked each parameter across the Sub-Basins accordingly, the average rank value for each Sub-Basin known as the Composite Rating (CR) Value was computed using the formula suggested by Altaf et al., (2014) expressed as;

$$CR = \frac{1}{n}\left(\sum_{i=1}^{n} R_i\right) \qquad (1)$$

Where ***CR*** is Composite Rating value; $\boldsymbol{R_i}$ is rank of a Sub-Basin parameter; and ***n*** is number of parameters used for the analysis.

The Sub-Basin with the lowest CR value portrays the highest level of susceptibility and vulnerability to soil erosion. However, for emphasis and priority sake, the degree of vulnerability to soil erosion was further categorized as follows:

Table 2: Categorization of the degree of Sub-Basins' vulnerability to soil erosion

Composite Rating (CR) Value	Degree of vulnerability to soil erosion
<4.0	High
4.0 – 4.5	Moderate
> 4.5	Low

Results and Discussion

The occurrence of soil erosion by running water in a particular geographic area is to a greater extent influenced by the morphometric characteristics of the watershed or sub-watershed within which the area is situated. Therefore, provided in this section are the results and discourse on the morphometric characteristics of the Muvur Sub-Basins (MSB), as they influence the vulnerability of the entire watershed to the menace of soil erosion.

Drainage Pattern of the Muvur Watershed.

Draiange network delineation revealed that the Muvur Watershed is typically of the Dendritic Drainage Pattern; the most common drainage pattern which develops in areas where the rock or unconsolidated material beneath the stream is homogenous and has no particular fabric or structure, and as such can easily be eroded equally in all directions (Geology In., 2014). The occurrence of this type of the drainage pattern in the Muvur Watershed as seen in its Sub-Basins (Figure 3) influences the formation of rills and gullies which are bound to eventually advance into stream channels through erosion by overland flows.

Morphometric Analyses

Geometric Properties

Three vital geometric properties of much relevance to morphometric analyses of watershed are Basin Area (A), Perimeter (P) and Basin Length (Lb). They are very key to determining such other parameters as Drainage density, Stream Frequency, Circularity Ratio, Elongation Ratio, Drainage Texture, Compactness Coefficient, Form Factor and Relief Ratio among many others.

These geometric properties are measures that determine the size, shape and elevation properties of a watershed. As such the areas, perimeters and basin lengths of the seven (7) Muvur Sub-Basins (MSB) are key to this study. The results on Table 3 showed that the Sub-basin Areas ranged from 40.33km2 (MSB2) to 97.59km2 (MSB3), the perimeters ranged from 38.56km (MSB1) to 61.21km (MSB5), while the sub-basin lengths ranged from 9.51km (MSB2) to 19.76km (MSB3).

Table 3: Geometric properties of Muvur Sub-Basins

Sub-Basin	A (km^2)	P (km)	L_b (km)
MSB1	44.47	38.56	11.62
MSB2	40.33	40.85	9.51
MSB3	97.59	59.70	19.76
MSB4	45.00	43.57	13.94
MSB5	67.41	61.21	17.38
MSB6	96.86	57.89	16.86
MSB7	71.29	59.70	12.24

Linear Morphometric properties

The Linear Morphometric properties of a watershed are indicative of the contributing role of structural control in determining its drainage pattern (Kale and Gupta, 2001; Kadam et al., 2018). The only linear parameter directly employed in the prioritizations of the Muvur Sub-Basins for soil erosion vulnerability was Mean Bifurcation Ratio (Rbm). However, the roles played by other linear parameters (Stream Order, Total Number of Stream Segments, and Total Length of Streams) in computing the Bifurcation Ratios and other relevant areal parameters cannot be disregarded. Besides, high values of such linear parameters are indicative of overland water flows (surface runoffs) and discharges capable of triggering or enhancing soil erodibility. Results of the linear parameters are presented on Table 4.

All the Sub-Basins were characterized by five (5) stream orders with exception of MSB4 having four (4) orders. MSB3, MSB6 and MSB7 had significantly higher total number of stream segments (398, 396, and 352, respectively) than the other four sun-basins. This corresponded with their total lengths of streams (MSB3-238.44km; MSB6-210.68km; and MSB7-171.52km, respectively) which is an indication of higher runoff and greater potentials of vulnerability to soil erosion.

Bifurcation ratio (R_b): This is expressed as the number of streams of given order to that of the next higher order; an index of relief and dissection (Horton. 1945). 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). High values of Mean Bifurcation Ratios (Rbm) indicate hydrograph peak events with potentials of flash floods (Rakesh et al 2000; Altaf et al., 2013) as well as episodic sheet wash, rills and gully conditions. In addition, Bifurcation Ratio values 3.66 and 6.00 are characteristic of watersheds in which the drainage patterns are distorted by the geologic structure (Schumm, 1956; Hadley and Schumm, 1961; Farhan et al., 2016).

The Mean Bifurcation Ratios (R_{bm}) for the seven Muvur Sub-Basins ranged from 3.51 (MSB2) to 5.45 (MSB4) as shown on Table 4. This result indicates that the drainage patterns of almost all the seven sub-basins are distorted by the area's geologic structure with MSB4 being the most affected. Furthermore, because bifurcation ratio is directly related to soil erodibility, the higher values obtained for MSB3, MSB4, MSB6 and MSB7 signify greater chance of their vulnerability to soil erosion.

Areal Morphometric Properties

Generally, areal morphometric properties exhibit varied relationships with soil erosion. While Stream Frequency, Drainage Density, Drainage Texture, and Length of overland flow are directly or positively related to soil erosion in a watershed, Form Factor, Circularity Ratio, Elongation Ratio, and Compactness Coefficient show negative relationships. Results of the areal properties for the Muvur Sub-Basins are presented on Table 5.

Stream Frequency (F_s): This is the ratio of the total number of stream segments to area of the watershed (Horton 1932; Kadam et al., 2019). It is a morphometric parameter that denotes the surface runoff function of a drainage basin. The Stream frequency values for the Muvur Sub-Basins were relatively high, ranging from 3.35 (MSB5) to 4.94 (MSB7). These values were similar to those observed over the Hararo sub-catchments in eastern India (Das (2014), which indicated high chances of soil erosion vulnerability. The values observed for the Muvur Sub-Basins indicated the presence of high relief, low infiltration capacity of bed rock and faster runoffs, tendencies as noted by Kale and Gupta (2001) and Kadam et al., (2018) These characteristics point to greater chances of soil erosion by surface water flows.

Drainage Density (D_d): This is a measure of total length of stream segments per unit of basin area (Horton 1932; Parvez, and Inayathulla, 2019). Invariably, it is a function of climate lithology and basin slope (Kadam et al., 2018). The drainage densities of the Muvur Sub-Basins ranged from 1.82 (MSB4) to 2.44 (MSB3). This signifies that the drainage of the entire Muvur Watershed is low to moderate owing to the presence of shallow to moderately deep soils and moderate terrain ruggedness which are all capable of supporting episodic soil erosion events. By these properties, the watershed's drainage density maintains a balance between the driving force of soil erosion and the ground resistance as noted by Horton (1945), Strahler (1952) and Kadam et al., (2018).

Drainage Texture (D_t): The relative spacing of stream segments in a drainage basin is described by the basin's Drainage Texture parameter, which in turn is dependent on the area's climate, vegetation, lithology, soil type, infiltration capacity and relief among others (Smith 1950). Based on the fivefold drainage texture classification presented on Table 6, results showed variations in the drainage texture characteristics of the Muvur Sub-Basins.

While MSB2 and MSB5 exhibited coarse drainage textural characteristics possibly due to lithological, shallow soils and low infiltration capacity factors; MSB1, MSB4 and MSB7 exhibited Moderate texture owing to lithological and soil factors; and MSB3 as well as MSB6 exhibited fine textures possibly due to their moderately deep soils and considerable dense vegetation cover as observed by field study.

Length of overland flow (L_{of}): This is an independent parameter that influences both the hydrologic and the hydrographic development of a drainage system (Horton 1932; Altaf et al., 2013). High values of length of overland flow indicate high surface runoff conditions and in turn high tendencies of soil erosion. The length of overland flow values for the Muvur Sub- Basins ranged from moderate to high (0.21 to 0.30). This is an indication of gentle to moderate slope characteristics which influence longer flow paths and runoff conditions capable of influencing soil erosion tendencies in the Muvur Basin.

Table 6: Fivefold Drainage Texture Classification

Drainage texture value	**Textural Class**
<2.00	Very Coarse
2.00 – 4.00	Coarse
4.00 – 6.00	Moderate
6.00 – 8.00	Fine
>8.00	Very fine

Adopted from Smith (1954)

Form Factor (R_f): This is the ratio of the basin area to the square of its length (Horton, 1932). The Form Factor values for MSB2 and MSB7 were high, indicating conditions of short-lived episodic runoffs. Conversely, MSB1, MSB3, MSB4, MSB5 and MSB6 showcased low form factor characteristics which signified low peak runoffs over long periods, capable of enhancing prolonged soil erosion conditions in the affected areas. This finding is based on the grounds that high form factor values (>0.40) are characteristics of circular basins with high peak flows over short periods, while low values (<0.40) describe elongated basins with low peak flows of longer durations (Kachel, 1988; Youssef et al., 2011; Altaf et al., 2013; Frahan et al., 2016).

Circularity Ratio (R_c): The Circularity Ratio of a watershed is strongly dependent on its stream length and frequency as well as its geological structure, climate, relief and slope characteristics (Farhan et al., 2016).

Table 4: Linear Morphometric Properties of Muvur Sub-Basins (MSBs)

Sub-Basin	No. of streams of different orders (N_u)						Total lengths of streams of different orders (L_u)						Bifurcation Ratio (R_b)					
	1st	2nd	3rd	4th	5th	∑Nu	1st	2nd	3rd	4th	5th	∑Lu (km)	1st	2nd	3rd	4th	5th	R_{bm}
MSB1	145	29	07	02	01	184	46.24	21.21	11.59	4.75	9.23	93.02	-	5.00	4.15	3.50	2.00	3.67
MSB2	110	28	05	02	01	146	39.62	23.22	13.12	5.37	1.82	83.16	-	3.93	5.60	2.50	2.00	3.51
MSB3	301	80	13	03	01	398	129.50	60.44	17.58	23.10	7.82	238.44	-	3.77	6.16	4.34	3.00	4.32
MSB4	161	28	05	01	-	195	52.98	18.44	8.97	1.32	-	81.71	-	5.75	5.60	5.00	-	5.45
MSB5	175	36	12	02	01	226	69.76	32.60	19.22	13.53	0.75	129.09	-	4.87	3.00	6.00	2.00	3.97
MSB6	307	74	11	03	01	396	109.02	53.59	27.73	4.05	16.29	210.68	-	4.15	6.73	3.67	3.00	4.39
MSB7	273	65	10	03	01	352	86.57	43.47	19.07	19.81	2.60	171.52	-	4.20	6.50	3.33	3.00	4.26

KEY: ∑Nu =Total No. of Streams; ∑Lu =Total Length of Streams; R_{bm} =Mean Bifurcation Ratio; LFP=Longest Flow Path

Table 5: Areal Morphometric Properties of Muvur Sub-Basins (MSBs)

Sub-Basin	F_s	D_d	D_t	L_{of}	R_f	R_c	R_e	C_c
MSB1	4.14	2.09	4.77	0.239	0.33	0.376	0.65	1.64
MSB2	3.62	2.06	3.57	0.242	0.45	0.304	0.75	1.83
MSB3	4.08	2.44	6.67	0.205	0.25	0.344	0.56	1.72
MSB4	4.33	1.82	4.48	0.300	0.23	0.298	0.54	1.85
MSB5	3.35	2.02	3.69	0.261	0.22	0.226	0.53	2.12
MSB6	4.09	2.18	6.84	0.230	0.34	0.363	0.66	1.67
MSB7	4.94	2.41	5.90	0.208	0.48	0.251	0.78	2.01

KEY: F_s=Stream Frequency; D_d=Drainage Density; D_t =Drainage Texture; L_{of}=Length of overland flow; R_f=Form Factor; R_c=Circularity Ratio; R_e= Elongation Ratio; C_c=Compactness Coefficient;

Results revealed low Circularity Ratios for the Sub Basins (0.226 for MSB5 to 0.376 for MSB1). The low values are indicative of elongation, moderate to high relief, impermeable surfaces and structural disturbances which influence low peak flows over longer time, thus signifying strong vulnerability to soil erosion.

Elongation Ratio (R_e): The Elongation Ratio values for the Sub-Basins ranged from 0.53 (MASB5) to 0.78 (MSB7) indicating less elongation with strong relief and steep ground slopes as noted by Strahler (1964) and Kadam et al., (2019). This signifies that Sub-Basins exhibit moderate to high efficiencies in the discharge of their run offs, which are capable of supporting substantial fluvial erosion processes.

Compactness Coefficient (C_c): This is an important indicator of basin shape used for expressing the relationship between the hydrological basin and a schematic circular basin of the same aerial characteristics (Prabhakar et al., 2019). It is also employed in interpreting the infiltration capacity of the watershed (Altaf et al., 2014). A Compactness Coefficient of 1.00 indicates that the basin is circular, while values > 1.00 indicate degrees of deviation form of circularity (Kadam et al., 2019). The implication is that, Low values or values closer to 1.00 signify high runoff discharge efficiencies with low infiltration tendencies and as such influence high degrees of vulnerability to soil erosion.

On the other hand, high values or values greater by far from 1.00 are indicative of elongated basins with increased infiltration tendencies hence less vulnerable to soil erosion.

Compactness Coefficient values for the studied Sub-Basins ranged from 1.64 (MSB1) to 2.12 (MSB7) indicating moderate elongation of the Sub- Basins, moderate run off discharges and moderate infiltration capacities.

Relief Properties

Relief Ratio, Ruggedness Number, Basin Shape Factor and Average Slope are morphometric properties that provide better accounts of the relief characteristics of a watershed. Their interpretation values for the Muvur Sub-Basins are presented on Table 7.

Relief Ratio (Rhl): This is a parameter that provides information on the overall steepness of a watershed as well as an indicator of erosion over the basin slop (Farhan et al., 2016). Therefore, high values indicate greater possibilities of soil erosion (Schuum, 1956; Parvez, and Inayathulla, 2019; Kadam et al., 2019). Results from the current study showed that the Relief Ratio values ranged from 0.022 (MSB5) to 0.048 (MSB7) with MSB2, MSB4 and MSB7 portraying greater soil erosion vulnerability tendencies (Table 7).

Table 7: Relief Morphometric Properties of Muvur Sub-Basins (MSBs)

Sub-Basin	**h_{max} (m)**	**h_{min} (m)**	**H (m)**	**Rhl**	**R_n**	**B_s**	S_m
MSB1	1180	868	312	0.027	0.65	3.04	37.2
MSB2	1044	663	381	0.040	0.79	2.24	25.0
MSB3	996	483	513	0.026	1.25	4.00	38.5
MSB4	1108	572	536	0.038	0.97	4.32	26.0
MSB5	1045	664	381	0.022	0.77	4.48	45.6
MSB6	1103	572	531	0.031	1.15	2.93	31.8
MSB7	1113	526	587	0.048	1.41	2.10	20.9

KEY: H_{max}=highest Elevation; h_{min}=Lowest Elevation; H=Sub-Basin Relief; Ratio; Rhl=Relief Ratio; R_n=Ruggedness Number; Bs=Shape Factor; S_m=Average Slope.

Ruggedness Number (R_n): This is the product of Drainage Density and Basin Relief divide by 1000 (Strahler, 1964). Higher values (1.0 and above) of this parameter indicate land degradation conditions mostly influenced by soil erosion or mass wasting processes, while lower values (<1.0) signify smooth and subdued land morphologies (Farhan et al., 2016). Values of R_n for the studied Sub-Basins ranged from 0.65 (MSB1) to 1.41 (MSB7) indicating the soil erosion vulnerability in all the sub-basins, with MSB3, MSB4, MSB6 and MSB7 under sharp eroded land morphology conditions.

Shape Factor (B_s): This is the ratio of the square of the basin length to its area (Horton 1945; Farhan et al., 2016; Parvez, and Inayathulla, 2019). The shape factor alongside the basin length and relief determine the rates of stream flow and sediment yield of the watershed (Altaf, 2014). Results for the Studied Sub-Basins ranged from 2.20 (MSB7) to 4.48(MSB5) all indicating varied elongations in the Sub-Basins. In terms of vulnerability to soil erosion, the influence of the shape factor is similar to that of the form factor. Lower values indicate higher degrees of elongation in basin shape with prolonged lower peak flows capable of sustaining greater soil erosion tendencies. On this basis, and MSB2 and MSB6, were found to be more vulnerable with MSB7 being the most vulnerable (Table 7).

Average Slope (S_m): This computed as the ratio of the basin length (in meters) to the basin relief as an expression of mean basin steepness from the upstream to the pour point (Ghany, 2015). Since the velocity of a stream is a strong determinant of discharge, which in turn influence sediment entrainment and transport (Charlton, 2008), the average slope of the watershed has a significant direct influence on its vulnerability to soil erosion. Therefore. High value of basin average slope signifies high soil erosion tendencies. Average Slope values of the Muvur Sub-Basins ranged from 25.0 (MSB2) to 45.6 (MSB5). The high values portrayed by MSB1. MSB3, MSB5 and MSB6 are tied to relief characteristics of the sub-basins and signify high vulnerabilities to soil erosion, while the lowest value exhibited by MSB2 (25.0) point to a low relief characteristic as well as low vulnerability to erosion.

Prioritization and vulnerability of Muvur Sub-Basins to soil erosion

Results of the Prioritization Analysis showing the parametric values, rankings and composite ranked values for the Muvur Sub-Basins are presented on Table 8. Based on the results, composite ranked values for the sub-basins ranged from 3.5 to 4.8, indicating Low through moderate to high vulnerabilities to soil erosion. The vulnerability of MSB2 to soil erosion was found to be low. MSB1 and MSB5 Showed moderate vulnerabilities, while MSB3, MSB4, MSB6 and MSB7 exhibited high vulnerabilities to soil erosion. The vulnerability map of the Muvur Watershed on the basis of its sub-basins is presented in Figure 4. These findings are in consonance and further confirmed the assertion by Ray (1999) and Musa (2004) that most parts of Mubi are among areas with high soil erosion vulnerability in Adamawa State.

Table 8: Ranking and Prioritization of the morphometric parameters and the Sub-Basins degrees of vulnerability to soil erosion

Parameters	Relationship with soil erodibility	Muvur Sub-Basins (MSB)						
		MSB1	MSB2	MSB3	MSB4	MSB5	MSB6	MSB7
Mean Bifurcation Ratio	Direct	3.67*(6)*	3.51*(7)*	4.32*(3)*	5.45*(1)*	3.97*(5)*	4.39*(2)*	4.26*(4)*
Drainage Density	Direct	2.09*(4)*	2.06*(5)*	2.44*(1)*	1.82*(7)*	2.02*(6)*	2.18*(3)*	2.41*(2)*
Stream Frequency	Direct	4.14*(3)*	3.62*(6)*	4.08*(5)*	4.33*(2)*	3.35*(7)*	4.09*(4)*	4.94*(1)*
Drainage Texture	Direct	4.77*(4)*	3.57*(7)*	6.67*(2)*	4.48*(5)*	3.69*(6)*	6.84*(1)*	5.90*(3)*
Length of Overland Flow	Direct	0.239*(4)*	0.242*(3)*	0.205*(7)*	0.300*(1)*	0.261*(2)*	0.230*(5)*	0.208*(6)*
Form Factor	Inverse	0.33*(4)*	0.45*(6)*	0.25*(3)*	0.23*(2)*	0.22*(1)*	0.34*(5)*	0.48*(7)*
Circularity Ratio	Inverse	0.376*(7)*	0.304*(4)*	0.344*(5)*	0.298*(3)*	0.226*(1)*	0.363*(6)*	0.251*(2)*
Elongation Ratio	Inverse	0.65*(4)*	0.75*(6)*	0.56*(3)*	0.54*(2)*	0.53*(1)*	0.66*(5)*	0.78*(7)*
Compactness Coefficient	Inverse	1.64*(1)*	1.83*(4)*	1.72*(3)*	1.85*(5)*	2.12*(7)*	1.67*(2)*	2.01*(6)*
Ruggedness Number	Direct	0.65*(7)*	0.79*(5)*	1.25*(2)*	0.97*(4)*	0.77*(6)*	1.15*(3)*	1.41*(1)*
Relief Ratio	Direct	0.027*(5)*	0.040*(2)*	0.026*(6)*	0.039*(3)*	0.022*(7)*	0.031*(4)*	0.048*(1)*
Shape Factor	Inverse	3.04*(4)*	2.24*(2)*	4.00*(5)*	4.32*(6)*	4.48*(7)*	2.93*(3)*	2.10*(1)*
Av. Slope	Direct	37.2*(3)*	25.0*(6)*	38.5*(2)*	26.0*(5)*	45.6*(1)*	31.8*(4)*	20.9*(7)*
Composite Rating Value		4.3	4.8	3.6	3.5	4.4	3.6	3.7
Vulnerability to Soil Erosion		Moderate	Low	High	High	Moderate	High	High

Priority ranks italics and parenthesis ()

Further findings based on field observation revealed rills and gullies as the most common soil erosion features in the watershed.

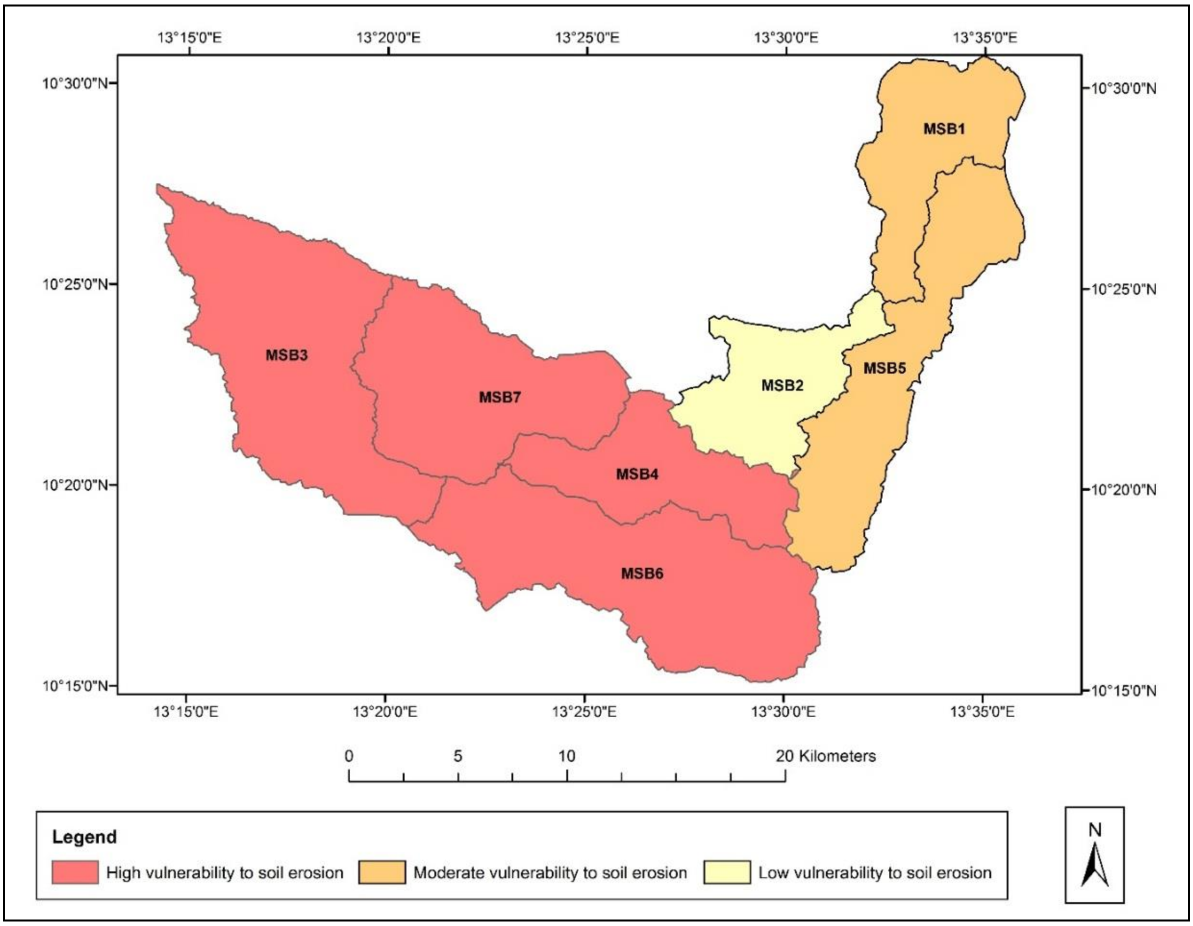

Figure 4: Soil erosion vulnerability map

Conclusion

Soil erosion is a major land degradation phenomenon that poses adverse effects to human dwellings, roads and most especially farmlands. Its occurrence by water action within a drainage basin is highly influenced by the basin's morphometric characteristics. In the current study, a prioritization approach was employed in identifying the most vulnerable sub-basins to soil erosion in the Muvur Drainage Basin. Results showed that the vulnerability of the sub-basins to soil erosion ranges from moderate to high at a larger scale. This portrays soil erosion as a major environmental problem in the Muvur Watershed. However, the findings were mainly limited to the analysis of thirteen (13) morphometric variables that relate to soil erosion.

Therefore, it is recommended that attention (by concerned bodies or authorities) be given to the moderate and most vulnerable areas in terms of soil conservation practices as well as sound technical approaches to erosion control and abatement. Further studies in aspects of soil erosion vulnerability based on land use activities, assessment of watershed soil loss to erosion and morphometric assessment of soil erosion features in the watershed are also required for effective erosion control and management in the area.

References

Adebayo, A. A. (2004). Climate: in Adebayo, A. A. (ed). *Mubi Region, A geographical synthesis.* Yola, Paraclete Publishers.

Adebayo, A. A. and Dayya, S. V. (2004). Relief and Drainage: in Adebayo, A. A. (ed). *Mubi Region, A geographical synthesis.* Yola, Paraclete Publishers.

.Agarwal, C. S. (1998). "Study of drainage pattern through aerial data in Naugarh area of Varanasi district, U.P.," *Journal of the Indian Society of Remote Sensing*, 26(4): 169–175.

Altaf, F., Meraj, G. and Romshoo, S. A. (2013). Morphometric Analysis to Infer Hydrological Behaviour of Lidder Watershed, Western Himalaya, India. *Geography Journal.* Hindawi Publishing Corporation, http://dx.doi.org/10.1155/2013/178021

Altaf, S, Meraj G, Romshoo S A. (2014). Morphometry and land cover based multi-criteria analysis for assessing the soil erosion susceptibility of the western Himalayan watershed. Environ Monit Assess. 186(12):8391–8412. doi:10.1007/s10661-014-4012-2.

Avinash, K. Jayappa, K. S. and Deepika, B. (2011). "Prioritization of sub-basins based on geomorphology and morphometric analysis using remote sensing and geographic information system (GIS) techniques," *Geocarto International,* 26(7); 569–592,

Azeez, B. (Dec 5, 2019). Soil Erosion: Nigeria needs N194b to restore degraded soil by 2030. Nigerian Tribune News.

Biswas, A., Majumdar, D. D. and Banerjee, S. (2014). Morphometry Governs the Dynamics of a Drainage Basin: Analysis and Implications. *Geography Journal.* http://dx.doi.org/10.1155/2014/927176

Clarke, J. J. (1966). *Morphometry from maps, Essays in geomorphology* New York, NY: Elsevier: 235–274.

Climate Home News (2020). Erosion crisis swallows homes and livelihoods in Nigeria. Retrieved April 12, 2020 from www.climatehomenews.com.

Das D. (2014). Identification of Erosion Prone Areas by Morphometric Analysis Using GIS. *Journal of Institution of Engineers (India): Series A.* 95(1): 61-74.

Diakakis, M. (2011). A method for flood hazard mapping based on basin morphometry: application in two catchments in Greece, *Natural Hazards,* 56(3): 803–814.

Eze, B. E. and Efiong, J. (2010). Morphometric Parameters of the Calabar River Basin: Implication for Hydrologic Processes. *Journal of Geography and Geology* 2(1): 18-26. www.ccsenet.org/jgg

Farhan, Y., Anaba, O., Salim, A., (2016). Morphometric Analysis and Flash Floods Assessment for Drainage Basins of the Ras En Naqb Area, South Jordan Using GIS. *Journal of Geoscience and Environment Protection,* 4; 9-33

Geology In., (2014). *Types of Drainage Patterns.* Retrieved May 22, 2020 from www.geologyin.com

Ghany, M. K. A. (2015). Quantitative Morphometric Analysis of Drainage Basins between Qusseir and Abu Dabbab Area, Red Sea Coast, Egypt using GIS and Remote Sensing Techniques. *International Journal of Advanced Remote Sensing and GIS,* 4(1); 1295-1322, Article ID Tech-478 ISSN 2320 – 0243.

Gravelius, H. (1914). Grundriss der gesamten Gewasserkunder. Flusskunde, 1, *Berlin and Leipzig,* viii-179.

Hadley, R. and Schumm, S. (1961). Sediment Sources and Drainage Basin Characteristics in Upper Cheyenne River Basin. *US Geological Survey Water-Supply Paper* 153-B, Washington DC, 198.

Horton, R. E. (1932) Drainage Basin Characteristics. *Trans. Amer. Geogr. Union.* 13; 350-361.

Horton, R. E. (1945). Erosional Development of the Stream and Their Drainage Age Basins, Hydrological Approach to Quantitative Morphology: *Geol. Soc. Amer. Bull.* 56; 275-370.

Jasmin, I. and Mallikarjuna, P. (2013). Morphometric analysis of Araniar river basin using remote sensing and geographical information system in the assessment of groundwater potential, *Arab Journal of Geosciences,* 6(10); 3683–3692

Javed, A. Khanday, M. Y. and Rais, S. (2011). Watershed prioritization using morphometric and land use/land cover parameters: a remote sensing and GIS based approach, *Journal of the Geological Society of India,* 78(1); 63–75, 2011.

Kadam, A. K., Jaweed, T. H. Kale, S. S. Umrikar B. N. and Sankhua, R. N. (2019). Identification of erosion-prone areas using modified morphometric prioritization method and sediment production rate: a remote sensing and GIS approach, *Geomatics, Natural Hazards and Risk,* 10:1, 986-1006, DOI:10.1080/19475705.2018.1555189

Kadam A. K., Karnewar A. S., Umrikar B., and Sankhua R. N. (2018). Hydrological response-based watershed prioritization in semiarid, basaltic region of western India using frequency ratio, fuzzy logic and AHP method. Int J Environ Dev Sustain. 15(5):1387–1585. doi:10.1007/s10668-018-0104-4.

Kale, V. S. and Gupta, A. (2001). *Introduction to geomorphology*. New Delhi: Academic (India) Publishers (Chapter 3).

Kochel, R. C. (1988). Geomorphic impact of large floods: review and new perspectives on magnitude and frequency," in *Flood, Geomorphology*, New York, JohnWiley & Sons, pp. 169–187,

Miller, V. C. (1953). A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain area, Virginia and Tennessee, *Tech. Rep. 3,* Columbia University, Department of Geology, ONR, New York. Project. 389-402.

Mishra, A. Dubey, D. P. and Tiwari, R. N. (2011). Morphometric analysis of Tons basin, Rewa District, Madhya Pradesh, based on watershed approach, *Earth Science India*, 4(3); 171–180, 2011.

Mohammed, A. Adugna, T. and Tukala, W. (2018). Morphometric Analysis and Prioritization of Watersheds for soil erosion Management in Upper Gibe Catchment. *Journal of Degraded and Mining Lands Management,* 6(1); 1419 – 1426.

Musa, A. A. (2004). Land Degradation; in Adebayo, A. A. (ed). *Mubi Region, A geographical synthesis.* Yola, Paraclete Publishers.

Myers, N. (1993) *Gaia: An Atlas of Planet Management.* Anchor/Doubleday Garden City, NY

Nag, S. K. and Chakraborty, S. (2003). Influence of Rock Types and Structures in the Development of Drainage Network in Hard Rock Area. *J. Indian Soc. Remote Sensing*. 31 (1) 25-35.

Nigerian Geological Survey (2014). Geological Map of Nigeria.

Obi Reddy, G. E. Maji, A. K. and Gajbhiye, K. S. (2002). "GIS for morphometric analysis of drainage basins," *GIS India*, 11(4): 9–14,

Pakhmode, V. Kulkarni, H. and Deolankar, S. B. (2003). "Hydrological drainage analysis in watershed-programme planning: a case from the Deccan basalt, India," *Hydrogeology Journal*, 11(5): 595–604.

Paul, J. M and Inayathulla M., (2012). Morphometric Analysis and Prioritization of Hebbal Valley in Bangalore, (Department of Civil Engineering, University Visvesvaraya College of Engineering, J.B. campus, Bangalore University, Bangalore-560056, India). *Journal of Mechanical and Civil Engineering (IOSRJMCE),* 2(6): 31-37

Parvez, M. B., and Inayathulla M. (2019).Geomorphological Analysis and Prioritization of Subwatershed of Raichur City Karnataka Using Weighted Sum Approach. *International journal of Scientific Research in Multidisciplinary Studies,* 5(9); 33-46.

Prabhakar A. K., Singh, K. K., Lohani, A. K. and Chandniha, S. K. (2019). Study of Champua watershed for management of resources by using morphometric analysis and satellite imagery. *Applied Water Science,* 9:127. http://doi.org/10.1007/s13201-019-1003-z

Ray, H. H. (1999). Soils: in A. A. Adebayo, & A. L. Tukur, (eds). *Adamawa State in Maps*. Yola, Paraclete Publishers.

Rekha, V. B., George, A. V. and Rita, M. (2011). Morphometric Analysis and Micro-watershed Prioritization of Peruvanthanam Sub watershed, the Manimala River Basin, Kerala, South India. *Environmental Research, Engineering and Management,* 3(57): 6 – 14

Rakesh, K. Lohani, A. K. Sanjay, K. Chatterjee,C. and Nema, R. K. (2000). GIS based morphometric analysis of Ajay river basin upto Srarath gauging site of South Bihar, *Journal of Applied Hydrology*, 14(4); 45–54.

Schumm, S. A. (1956). Evolution of Drainage System and Slopes in Badlands at Perth Amboy, New Jersey. *Geol. Soc. Amer. Bull.* 67; 597-646.

***Shittu, H. (11 Dec. 2019). Nigeria: 'Soil Erosion Greatest Threat to Food Security'.* This Day News. *Retrieved April 12, 2020 from www.allafrica.com*.**

Smith, K. G. (1950). Standards for grading textures of erosional topography. *Am J Sci* 248:655–668

Strahler, A. H., (1964). *Quantitative Geomorphology of Drainage Basins and Channel Networks; Handbook of Applied Hydrology,* New York, McGraw Hill Book Company, 4-39/4-76.

Strahler, A. N. (1952). Hypsometric (Area-Altitude) Analysis of Erosional Topography. *Geol. Soc. Amer. Bull.* 63; 1117-1142.

Thlakma, S. R., Iguisi, E. O., Odunze, A. C. and Jeb, D. N. (2018). Estimation of Soil Erosion Risk in Mubi South Watershed, Adamawa State, *Nigeria. Journal of Remote Sensing & GIS,* 7(1); 2-10. DOI: 10.4172/2469-4134.1000226

Usman, B. H (2005). Soils of Adamawa State North Eastern Nigeria: In Igwe, E.C; Meshelia, S.I and Jada M.Y. (eds). *Agriculture in Adamawa State.* Yola, Paraclete Publishers: 67-68

Vijith, H. and Satheesh, R. (2006) GIS based morphometric analysis of two major upland sub-watersheds of Meenachil River in Kerala. *Journal of Indian Society of Remote Sensing.* 34(2): 181- 185

UNEP, (1997). Soil degradation, Map, World Atlas of Desertification, *International Soil Reference and Information Centre* (ISRIC), UNEP/GRID-Arendal.

World Bank (1990) Towards the Development of an Environmental Action Plan for Nigeria. West Africa Department.

Yonnana, E. (2004). Soil and Vegetation in Adebayo, A. A. (ed). *Mubi Region, A geographical synthesis.* Yola, Paraclete Publishers.

Youssef, A. M. Pradhan, B. and Hassan, A. M. (2011). Flash flood risk estimation along the St. Katherine road, southern Sinai, Egypt using GIS based morphometry and satellite imagery, *Environmental Earth Sciences*, 62(3); 611–623.