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GIS-BASED SEDIMENT YIELD ESTIMATION IN MUBI SOUTH WATERSHED, ADAMAWA STATE, NIGERIA

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ABSTRACT

In recent times, soil erosion becomes very critical environmental problems which causes severe range of land degradation. Sediment yield caused by deterioration process of soil by which occurred due to the physical movement of soil particles on land surface. This study aimed at estimation of sediment yield in Mubi South Watershed, with the aid of geospatial technology. The following data were used for the research; soil, rainfall, ASTER, sentinel 10 m satellite of the year 2016. Factor maps were generated for all the data which served as input layer for the SLEMSA model in estimation of sediment yield in the study area. It was found that, the magnitude of the soil loss was about 4.033 tons/ha/year. Also, the sediment yield was about 148.43 tons/ha/year. The research recommended a good soil loss management so as to reduce land degradation, soil loss and sedimentation within the watershed for planning and implementation of watershed management, degraded land restoration.

Keywords: Watershed, Sediment Yield, SLEMSA and GIS.

INTRODUCTION

Soil erosion is a major challenge confronting land and water resources in many parts of the world and the problem may get worse in the future due to population growth and potential climatic and land use changes (Kakembo *et al*., 2009; Tibebe and Bewket, 2011). Watershed is a surface area from which runoff which is resulting from rainfall is collected and drained through a common outlet. Most of the time the term is similar with a drainage basin or catchment area. Socioeconomically a watershed includes people, their farming system and interactions with land resources, cropping strategies, social and economic activities and cultural aspects (MOARD, 2005).

Given the increasing threat to land resources, especially due to population growth and potential climatic changes, it is important to provide information that can help to target policy to focus on the areas of greatest need (Gobin *et al*., 2003). Estimation of sediment yield, however, is complicated by complex physical processes that involve interaction of a large number of spatial and temporal factors, regional differences and scale dependency (Vanmaercke *et al*., 2011; Parsons, 2012). Soil erosion occurs over many spatial scales including the site of impact from a single raindrop to large watershed, as well as over a large variety of timescales such as a single storm to many decades (Stocking and Murnaghan, 2001).

Literature shows that sediment yield from soil erosion, which is a critical component of land degradation, comprising of water and wind erosion, chemical degradation, excessive salts, physical and biological degradation (Luleva *et al.,* 2012) and is one of the serious global environmental challenges (Wessel *et al.,* 2007) often threatening agriculture, water resources and biodiversity. For instance, the world loses approximately 75 billion tons of fertile soil from world agricultural systems each year (Eswaran *et al.,* 2001). In Africa for instance, 40% of the land area is degraded, affecting food production and leading to soil erosion, which in turn contributes to desertification (Thompsell, 2017). Also, several studies indicate that over 50% of Mubi south watershed area has been affected by varying intensities and types of soil erosion (Richard *et al.,* 2018). This environmental scourge has resulted in international governments, environmental activists, soil scientists and hydrologists embarking on soil conservation trainings, awareness programs and research across the world, in a bid to curb further loses.

Since the 1930's, soil scientists and decision-makers have been developing and using models extensively in order to calculate soil loss from a field, a hillslope, or a watershed (Wischmeier and Smith, 1978). In recent years, researchers have proved that the application of SLEMSA model is wide spread and used in soil erosion sediment yield related areas (Beskow *et al.,* 2009). Sediment yield by water erosion is normally estimated with empirically and physically-based models (Jha and Paudel, 2010). But in this research, empirically based models such as SLEMSA (Soil Loss Equation Model of Southern Africa), was used to estimate the sediment yield. Different models are used to estimate erosion hazards such as SLEMSA developed by Elwell and Stoking (Ramesht, 1997). The combination of

SELMSA models and remote sensing techniques within a Geographical Information System (GIS) framework is commonly utilized for soil erosion sediment yield (Gao, 2008). Also, Luleva *et al.*, (2012) noted that, the most commonly used remotely sensed satellite data in soil erosion by water monitoring come from Landsat data imagery. Hence, the need to estimate sediment yield in Mubi South Watershed, with the aid of geospatial technology.

THE STUDY AREA

Mubi south Local Government Area is located in Northeastern Nigeria between latitudes 10º 4′ 30"N - 10º 15′ 0" N, and Longitudes 13º 20′ 0" E - 13º 27′ 0"E of the Greenwich Meridian (watershed is located 10º 4′ 30"N - 10º 15′ 30" N, and Longitudes 13º 16′ 30" E - 13º 25′ 30" E). The study watershed area covered about 148.43 km^2 (sq km). The study area is bordered by Lamurde from North-East, Gella Local Government Area to the East, WuroBobbowa and Girgi in the South-West (Richard *et al.,* 2018). The map and location of study area is shown in Figure 1.

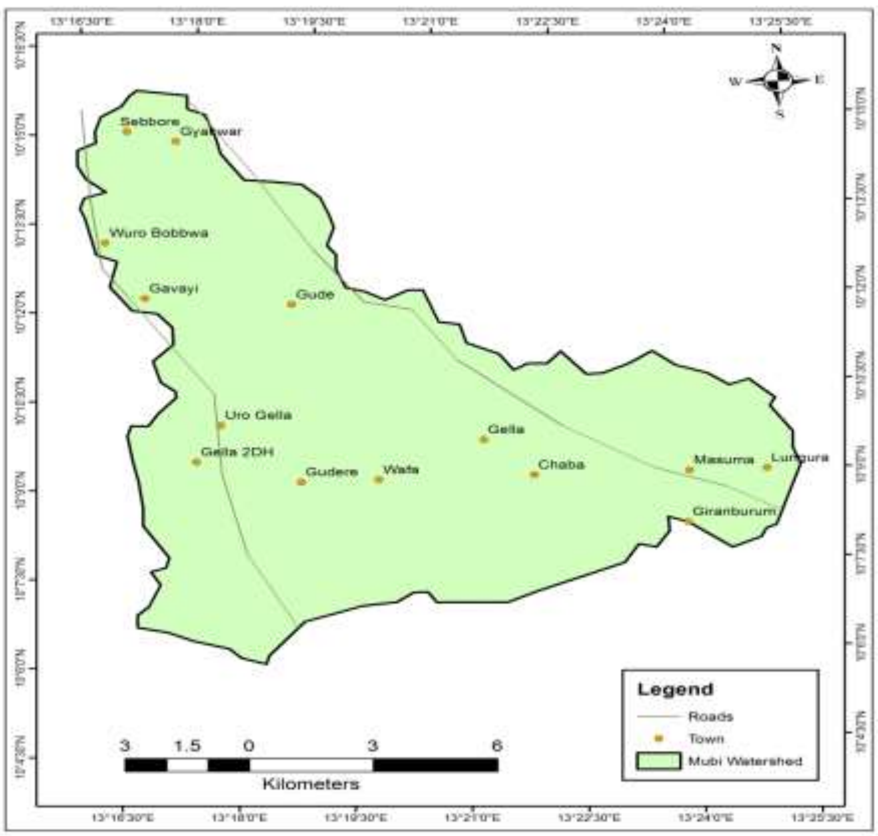

Fig. 1: Map of the Study Area

Source: Modified from the Administrative Map of Adamawa State (2015)

MATERIALS AND METHODS

Data Type and Sources

The following data types were used.

i. Rainfall data from 2005-2013 of Mubi South was sourced from meteorological office, Adamawa State University Mubi, Nigeria.

ii. Soil data of the study area, 80 soil samples were collected from the study sites using grid method, and test for four major soil parameters then subsequently the soil map was generated.

iii. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) was used to generate a digital elevation model (DEM), where the slope length (L) and thus the slope gradient (S) were calculated.

iv. Land-use/Land-cover map was generated from Sentinel satellite imagery of 10m spatial resolution of the year 2015 of the study area was obtained from www.usgs.gov.

Soil Sample Collection to Estimate Soil Erodibility Index (K)

Subsurface Soil Sampling was collected using soil hand auger equipment to collect shallow subsurface soil samples. Auger holes are dogged until the sample depth was reached. When the sample depth was reached, the bucket used to advance the hole was removed and a clean bucket is attached. The clean auger bucket is then placed in the hole and filled with soil to make up the sample and removed. These was repeatedly done for all the sampled areas. A hand auger was used based on the soil properties and depth of investigation. In sand, augering is usually easily performed, but the depth of collection is limited to the depth at which the sand begins to flow or collapse. Hand augers was also found to be limited used in tight clays and cemented sands.

Procedure of sample collection: Soil samples was collected from 80 spots within in the study area; the soil samples was mixed in a clean plastic bucket using hand auger. Sample from soil surface was collected between 0 to 6 inches depth of tillage. For pastures, sample from 0 to 4-inch depth. The collected soil samples were spread on clean paper to air dry the soil. The dried soil was mixed and placed about one pint of soil in a labeled sample bag and test for the following parameters: Percentage organic matter, soil textural classes, soil permeability classes, percentage very fine sand (clay content). The value of F was calculated using in SLEMSA model; which was the sum of a bare soil erodibility value (Fb) and correction factors based largely on practice (p) factor, which account for cultivation practice, previous cropping condition and other factors.

Data Processing

Image Geo-referencing: The datasets along with Topographic map were georeferenced to a geographic coordinate system. The images were imported into ArcGIS 10.5 environment and rectified Projection coordinate system to Universal Traverse Mercator (UTM). This helped to define the existence of those data sets in physical space as well as establish their location in the real world.

Image sub-setting: Landsat 8 imagery was used for the study. The portion of interest was subset from each of the larger scenes using ArcGIS 10.5 since the satellite images covers a large area.

Image Classification: In classifying the images into various classes, supervised classification technique was performed, using maximum likelihood classification (MLC) algorithm. This technique enables analysts to generate training classes based on the actual land-use/land-cover themes present within the study area and helps in curtailing ambiguity that is associated with the unsupervised technique of image classification. The MLC is the most widely and commonly used with remotely sensed data, and is proven to yield the best classification result. Anderson, et al., (1976) were adopted for this study. The classification scheme utilized six (5) classes thus Urban/Built-up, vegetation, cropland, bare surface and water body. In this study however, the classification scheme was modified to present Built-up land, vegetation land, agriculture land, water and barren ground.

Digital elevation model: The ASTER was used to generate a digital elevation model (DEM) of the study area, where the slope length (SL) and consequently the slope gradient (SS) were calculated to generate the extent of the topographic factor.

Rainfall and Kinetic Energy: The rainfall data were used to calculate the mean seasonal energy (E). This was achieved by applying the method of Wischemier and Smith (1978) to estimate the rainfall kinetic energy which is one among the parameter used in the SLEMSA equation for estimating the average amount of soil loss. So many scholars developed models for rainfall erosivity factor empirically, Wischmeier and smith (1978), Morgen, (1995) and Renard *et al* (1997). The rainfall-runoff erosivity factor is defined as the mean annual sum of individual storm erosion index value EI_{30}, where E is the total storm kinetic energy and I_{30} is the maximum rainfall intensity in 30 minutes. For areas where charts for automatic rain gauges are not available, like in Nigerian situation, the mean seasonal energy (E) may then be estimated from regression equations:

For areas prone to drizzle:

$$E = 17.37 \times P \quad (1)$$

For normally aggressive climates:

$$E = 18.84 \times P \quad (2)$$

Where E =kinetic energy in joules/m^2/yr, the mean seasonal energy (E) will be estimated from the equation (Wischmeier and Smith, (1978) and applied by Igwe, (1997) Using rainfall data of the study area. See appendix 1

$$E = 18.84 \text{ x } P \quad (3)$$

Where

P = mean annual rainfall in mm

E = kinetic energy in joules/m^2/year.

$$R=\frac{p2}{P}\,\frac{p2}{P} \quad (4)$$

Where p^2 is the mean annual rainfall and P is rainfall of the wettest month.

Determining Soil Erodibility Index (K): The soil data was processed to produce a Soil Erodibility Index (K) using Wischemier and Smith (1978) sensitivity equation, and to produced soil map using GIS environment which is also another parameter used in the SLEMSA equation for estimating the average amount of soil loss.

Soil laboratory analysis:

Collected soil samples were analysed in laboratory to generate soil database, which was used in determining soil erosion factors. Soil analyses for the following parameters were carried out; i) soil organic matter analysis ii) Soil Structural classes iii) soil permeability class iv) percentage very fine sand clay content.

i. Analysis of Soil Texture: Method (Hydrometer Method by Gee and Bauder, 1986). Reagent Calgon; Sodium Hexametaphosphate Solution was used. Soil weigh 50 gram of < 2mm air dried soil samples was put into a 250mls plastic bottle and immediately add 100mls of Calgon solution (Sodium Hexametaphosphate solution) and cover the bottle very tight.

The bottle was transferred and its content into a mechanical shaker and shake for 20mins. After 20mins, the samples were transferred into a 1000mls measuring cylinder and rinsed the bottle very well and also make it up to mark with water. The temperature of the sample was taking and recorded using thermometer. A blank was prepared, which those not contain soil sample, but contain only the Calgon solution (100mls) and make it to mark with water. The soil samples were disturbed using a plunger until the soil particles in the cylinder were fully disturbed. The plunger was removed and the 40sec reading was taking and recorded using the hydrometer. The cylinder was allowed to remain undisturbed for about 2hrs and finally the 2hrs reading was taking and recorded.

Calculation

The corrected hydrometer readings C (g/L) are obtained by subtracting the blank reading R_L (g/L) from the hydrometer reading in the soil suspensions R (g/L) and adding 0.36g/L for every degree above 20^{o}C.

$$C = R = R_L + (0.36T)$$

Where T = Room Temperature minus 20,

The percentages by weight of the SILT + CLAY and SAND fractions are given by:

% Clay = Corrected 8 Hrs Reading – Blank x 100
Wt of soil taken

% Silt = Corrected 40 Sec Reading – Blank x 100 -% Clay
Wt of soil taken

% Sand = 100 - % Clay + % silt.

The sample can now be classified according to the USDA or International system of Textural classification. USDA Soil Textural Triangle to determine the soil texture. See appendix 2

ii Soil Organic matter (Carbon wet Oxidation method using Walkley Black as described by Nelson and Sommers (1982).

iii Soil permeability analysis: The hydraulic conductivity was measured by the constant method, using the I C W laboratory permeameter (EijikelkampAgrisearch No. 09 02). The equipment operates on the principle that water is caused to flow through a saturated soil column by the pressure difference on both sides of a well saturated soil sample. The caps from the ring were removed and the samples were saturated overnight in a basin of water. This was done by first of all covering the blunt end of the ring with a piece of nylon cloth (approximately 5cm in diameter) which was held in place by means of a rubber band, to disallow soil loss. A specially meshed container was used to hold the ring which was in turn placed inside a plastic container. The container containing the sample was then inserted into the permeameter after establishing a constant head. A tube previously filled with water was used as a junction connecting the inside of the ring holder and the water in the permeameter. This ensured flow of water into a burette. Depending on the ease with which water flows through the sample, the time at which a conveniently chosen volume is attained in the burette is taken using a stop watch. The height of water inside the ring holder and outside was measured and the saturated hydraulic conductivity (Ks) was calculated from the formula;

$$Ks = \frac{V.L \quad V.L}{AT(DH)AT(DH)} \quad (5)$$

Where, V = volume of water collected (cm^3)

L = Lengh of soil column (cm)

A = Cross sectional area of the sample (equivalent to area of core ring) (cm^2)

T = Time in seconds

DH = Hydraulic head difference (cm)

iv Sand Separation Analysis: the sand was separated using 212 micron sieve, 250 micron sieve.

The reagent used were dispersing agent (Calgon) and (Sodium hexametaphosphate solution) in some cases. About 50 grams weight of < 2mm air dried soil sample into a 250mls plastic bottle and add 100mls Calgon solution (Dispersing Agent), cover the bottle very tight and shake for 20min using a mechanical shaker. The content of the bottle was transferred into a 1000ml, (1 litter) measuring cylinder, rinse the bottle and make it up to the marked using water. The sample was plunged in the cylinder in order to obtain a proper separation of the soil particles. The separating sieves was arranged in the order of 250micro on top of the 212 micro sieve all of them been placed on top of the sieve receiver. The disturbed samples were poured into the series of sieve under a clean flowed tap water and wash out the clay add the salt separate. Finally, the coarse medium and fine sand separate would be retained on each sieve. Finally weigh the sand. This will give the coarse sand fraction

v Estimation of soil Erodibility Index: Soil erodibility index (g / J) is the weight of soil detached from the soil mass per unit of rain fall energy. It is integrated effect of the processes that regulate rainfall acceptance and the resistance of the soil to particle detachment and subsequent transport. These processes are influenced by soil particle, of which soil texture is an important factor that influences erodibility. It was estimated based on the characteristics of the soils using the following formula developed by Wischemier and Smith (1978).

$$K = [2.1 \times 10^{-4} \times (12\text{-OM}) \times M^{1.14} + 3.25 (S-2) + 2.5 (P-3)] / 759 \quad (6)$$

K= erodibility factor (in ton/mj/mm)

Where:

OM = % Organic matter content

T = Soil textural class

S = Soil permeability class

M = Clay content

Data Analysis

1. To estimate the magnitude of soil loss in the watershed using SLEMSA MODEL.

Elwell (1978) method of estimating soil loss using South Africa Equation (SLEMSA) was adopted. To calculating the magnitude of erosion hazards (Z): After determining all parameters used in estimating the erosion hazards in SLEMSA model, the whole erosion of the watershed was achieved by the following equation:

$$Z=K*C*X \quad (7)$$

Z is the estimation of long-term average annual soil loss in hazard units.

K is the soil loss sub-model and combines soil erodibility (F), which is a unit less Index of the susceptibility of soil to erosion under a standard condition, and rainfall erosivity (E), which accounts for the energy and intensity of rainstorms, and C is the crop or cover and management sub-model, which estimates soil loss from a vegetated plot compared to that from a bare soil plot by estimating the amount of energy intercepted (i) by the percent vegetation cover. C factor was estimated using maximum likelihood classification (MLC) algorithm in Arc GIS 10.5 environment. The parameter was, build up land were assigning a value of 0.58, Vegetated Land 0.006, Farm Land 0.17, Bare Land 0.038 and Water Body 0. Adopted from Anderson, *et al* (2001).

X is the topographic sub-model, which combines slope steepness (SS) and slope length (SL) from a plot with a given percentage slope and slope length in meters compared to the soil loss from a standard plot with 4.5% slope and 30 m slope length. When all these factors defined were obtained and multiplied as shown in equation (7) the estimated amount of soil loss was calculated. The input parameter of SLEMSA model were integrated into ArcGIS 10.5 environment after integration.

2. To estimate the sediment yield in the watershed.

The ratio of sediment delivered at a given catchment area in the stream system to the gross soil erosion is the sediment delivery ratio for that drainage area. Thus, the annual sediment yield of a watershed is defined as follows:

$$SY = (A)\ (SDR) \quad (8)$$

RESULTS AND DISCUSSION

Generated Factor Map Layers for the Parameter for the Models

The results for the factor map layer are show on Figure 2 to 4

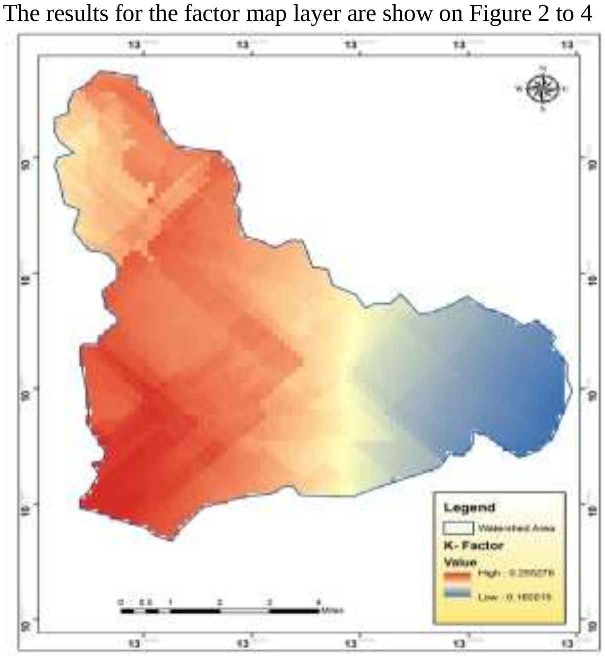

Fig 2: K-Factor

Source: Author's Analysis (2019)

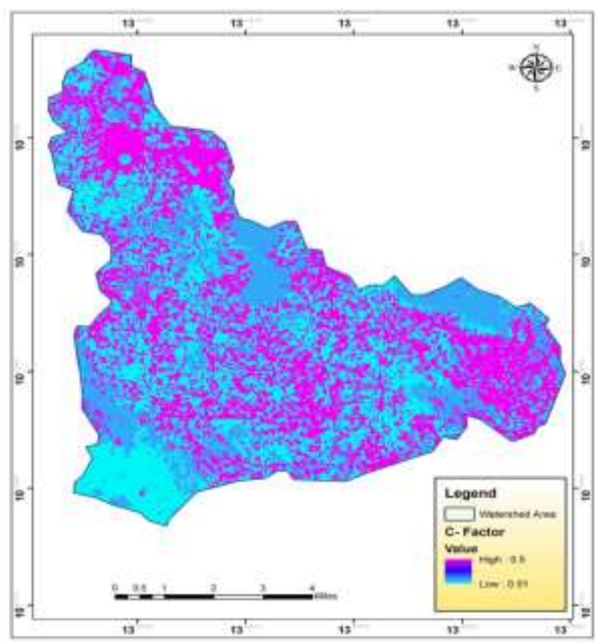

Fig. 3: C-Factor

Source: Author's Analysis (2019)

As shown in Figure 2, the value of K factor is mainly varying between 0 to 1, where 0 is for least susceptibility or sensitivity of soil for erosion and 1 represents High soil susceptibility or soil sensitivity to get erode erosion by the water. The result show that the watershed has the low value of about 0.16 organic matter which indicated that the area is characterized by Fine sand textural class while the high value of 0.25 organic matter indicated that the area is characterized by Silty clay textural class. The value for the soil erodibility factor (K – factor) for Different Textures in the study area reveals that most of the study area was found to erodible due to the large area of silty clay in the watershed. Also, the result of cover management factor (c-factor) is presented in Figure 3 show spatial distribution of cover management factor which ranges from higher value of 0.5 to lower value of 0.01 in the watershed. High cover management factor was observed around mountainous area of the watershed. This finding shows that land use slope and hillshade plays vital role in determining cover management practices in the study area.

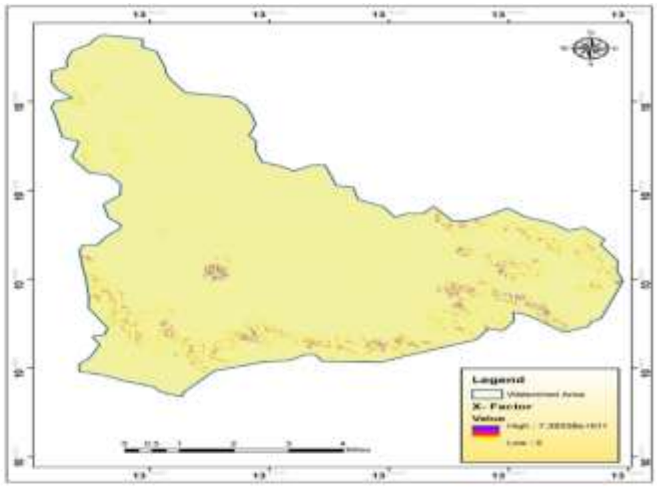

Figure 4: X-Factor
Source: Author's Analysis (2019)

The result of X-factor (Ls-factor) shows even distribution of slope steepness along each watershed. Research by Tay *et al.* (2002) shows susceptibility of soil sediment yield to water erosion depends on soil length and is more prevalent in sloping area. Also, the result of these studies suggests a curvilinear relationship between soil loss and slope steepness, with erosion initially increasing rapidly as slope increases from gentle to moderate, reaching a maximum on slopes of about 7° and then decreasing with further increase in slope. Such a relationship would apply only to erosion by rain splash/sheet and surface runoff. It would not apply to landslides.

Also reported that greater sensitive of slope had effects on soil loss due to differences in rainfall. Areas having about 7.4m length of cell slope length and steepness in the watershed as show on Figure 4, will have greater soil loss as supported by Toy *et al*. (2002), than those areas having 3m and 0m length of cell slope length.

Estimated Magnitude of Soil Loss

The result for the magnitude of soil erosion loss in the watershed is presented on Figure 5.

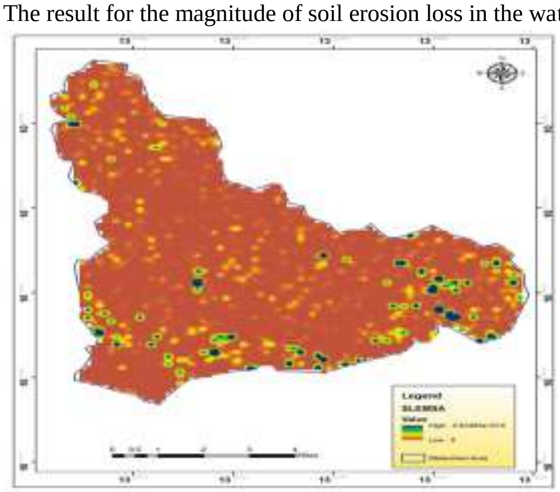

Fig. 5: Magnitude of Soil Erosion Loss
Source: Author's Analysis (2019)

It was found that, the magnitude of the soil loss was about 4.033 tons/ha/year. This result shows that the high magnitude of soil erosion loss was found to be around the mountainous areas (hilly area). This further reveal that the topography of an area plays a major role in soil erosion loss of an area. This was so because the hilly areas were characterized with less vegetal cover and presents of sandy soil which are easily eroded as the rainfall splash the ground. More so, this result show that the rate or magnitude of soil loss is higher in the hilly areas that the peneplain of the watershed and the slope play a major role as a determinant factor.

Estimated Sediment Yield

The result for the estimated sediment yield in the watershed is shown on Figure 5.

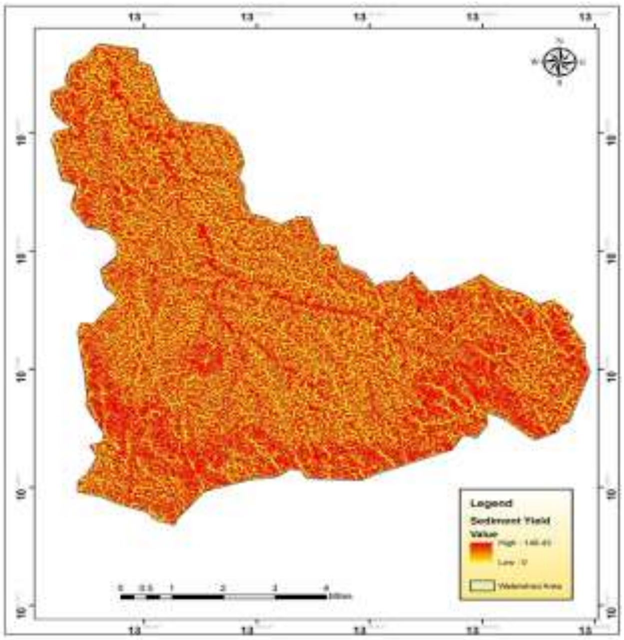

Figure 6: Soil Sediment Yield
Source: Author's Analysis (2019)

Result of Figure 6 reveals that the sediment yield in the watershed was about 148.43 tons/ha/year as at the time of this research. The high value of the sediment yield was found to be in the watershed tributaries and this was as the results of downfall movements of the sediments from the highlands to the lowland area of the watershed.

CONCLUSION

Based on the outcome of this research, it was revealed that, the magnitude of the soil loss was about 4.033 tons/ha/year and the sediment yield was 148.43 tons/ha/year as at the time of this research. It was also found that, the topography of the study area played a major determinant role in results found. This also show that the combination of existing SLEMSA model and remote sensing techniques within a Geographical Information System (GIS) framework played a vital role in estimating the magnitude of soil erosion loss and sediment yield within a watershed.

The findings from this research will be useful as sources of data and information for researchers in this field of study and documents for policy decision making especially in the fields of disaster risk managers, water resources managers, urban planners and soil conservationists. It will also be a valuable input for decision makers and other institutions who are working on environmental protection, watershed management and soil conservatives measures.

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