ESTIMATION OF POTENTIAL SOIL EROSION RISK IN A TYPICAL GUINEA SAVANNAH AGRICULTURAL WATERSHED OF NIGERIA

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The present study conducted in the Oyun River watershed (Ijagbo, Kwara State, Nigeria) was aimed at estimating and mapping its potential annual soil loss using primary and secondary data. Soil loss was estimated using the Universal Soil Loss Equation (USLE) with its parameters analyzed and integrated into the raster calculator in the geoprocessing tools of the ArcGIS 10.5 environment. The results showed an increase in erosivity from 70.07 MJ mm ha–1 per year in the period 1997–2001 to 83.48 MJ cm ha^{-1} per year within 2012–2017 representing a ca. 19 % increase. Rainfall erosivity has been projected to reach 94.17 MJ cm ha^{-1} per year in the next decade. Strong slopes of 15–30% and 30–45% gradient covering 19.77 % (13.05 ha) and 0.82 % (0.54 ha) of the watershed, respectively, and soil management practices applied there have been found the major soil loss determinants. Soil loss ranged from 0 to 35 t ha^{-1}per year with the mean annual value of 3.39 t ha^{-1}. Total annual soil loss in the watershed was calculated to be 254.25 t. Contouring, the dominant erosion control practice in the watershed, was substantially ineffective; however, its substitution with stripping and terracing indicated a 50% and 80% reduction potential in soil loss, respectively. About 11.62% of the watershed (erosion hotspots) recorded soil loss above the maximum tolerable limit of 12 t ha–1 per year set by FAO.

arable land, soil loss, USLE, ArcGIS, erosion hotspot, Kwara State

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INTRODUCTION

Land degradation through the development of agriculture has led to greater destruction of the natural resources upon which humans build a basis for survival (Pimentel, 1993). Soil loss, which contributes majorly to land degradation, is being associated with uncontrolled cultivation techniques, unplanned land use, uncontrolled urban development and deforestation (Biard, Baret, 1997). Soil loss is activated by an amalgamation of factors arising from slope length-steepness, climate change, land cover patterns, management practices and the properties of a soil which makes the soil particles more prone to erosion (Gelagay, Minale, 2016). The World Bank's collection of world development indicators reported a reduction in the amount of agricultural land in Nigeria by 4.4% within 1994–2012 (The National Bureau of Statistics, 2012). The watersheds in Nigeria represent 2.2 % of the total agricultural land (FAO, 1997). The estimation of soil loss in watersheds is very critical because of the watersheds importance for crop production, land conservation, management of water bodies etc. The universal soil loss equation (USLE) developed by Wischmeier (1959) has been generally accepted as a soil erosion model for estimating maximum potential average annual soil loss. This methodology is well adapted to Ultisols and Alfisols (USDA classification) which are predominant in West Africa (Roose, 1977; Mbagwu, Salako, 1985). The USLE was combined with ArcGIS and Remote Sensing (RS) technique to estimate potential annual soil loss in the fairly large watershed of the Oyun River. With the increase in the population of Nigeria

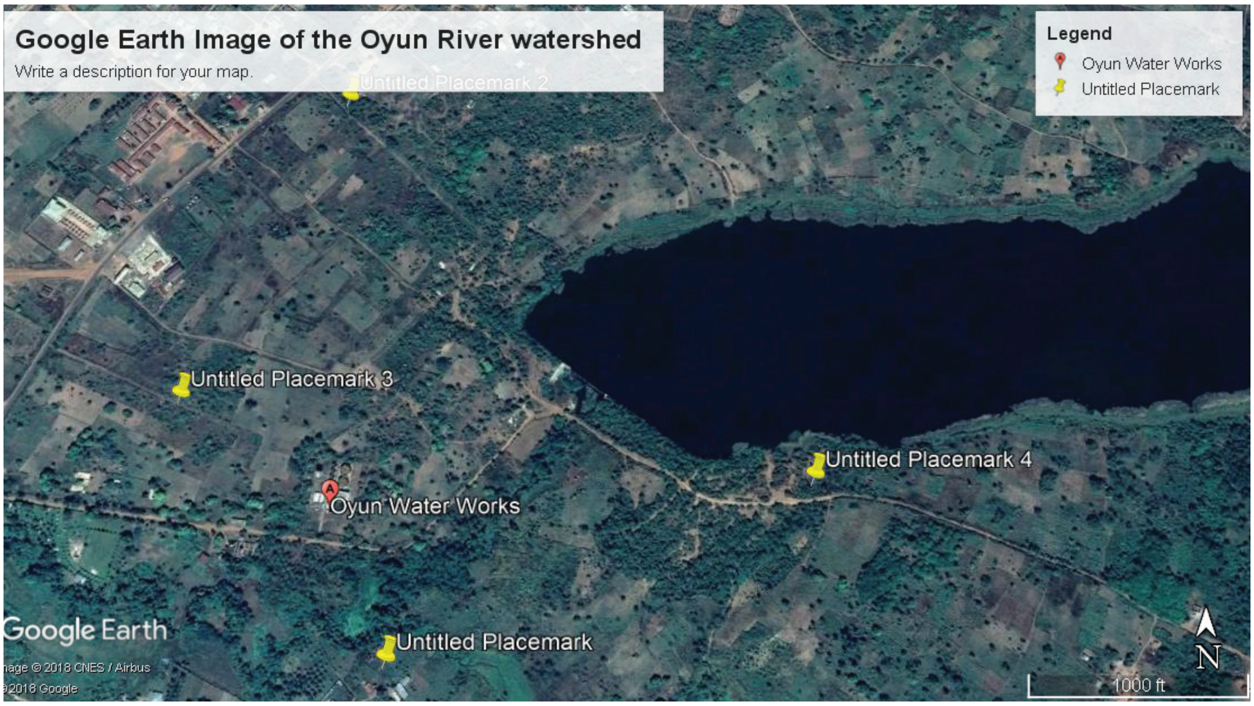
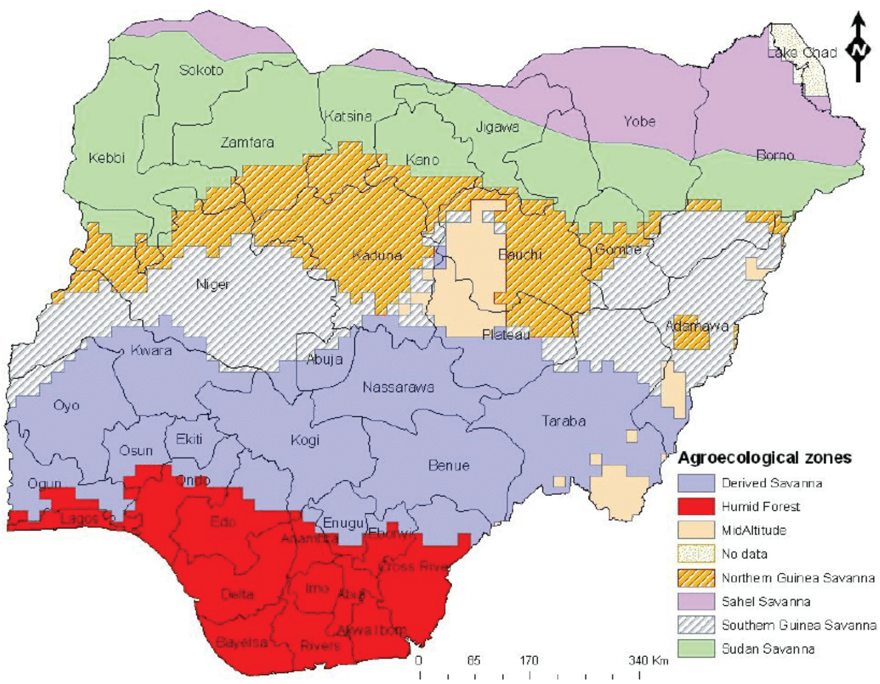


Plate 1. Google Earth image of the Oyun River watershed, Ijagbo, Nigeria

and the decrease in the cultivable area of agricultural land, there was a need to estimate soil loss especially in the agricultural watershed because of its importance in environmental management.

The objectives of this study were to determine soil loss with reference to the tolerable limit of soil loss set by the Food and Agriculture Organization (FAO), derive soil erosion hazard map for the area, and suggest best management practices that can reduce soil loss in the area, map the factors responsible for soil loss in the area, locate the erosion hotspots for conservation prioritization. The result of this study should help farmers plan on land use for purposeful and high yield agricultural activities, assist environmental protection agencies and river basin development authorities with information on soil

Fig. 1. Map of Nigeria showing various agroecological zones



loss of this area for the purpose of soil conservation and land use programmes.

MATERIAL AND METHODS

Study area

This study was carried out in the 70-hectare watershed of the Oyun River in Ijagbo, Kwara State, Nigeria (Plate 1). The soil of the area belongs to the USDA soil order Alfisol (Onwualu, Ahaneku, 2001). The land is open undulating with occasional rocky outcrops in its north-western part with varying slopes. The area falls into the derived savannah area of Kwara State (Fig. 1). Its estimated terrain elevation is 361 m a.s.l. and it is located between latitude 08° 11′ 26″ and 08° 11′ 57″ N and longitude 4° 44′ 40″ and 4° 44′ 40″ E of the Equator. The Oyun River originates at an elevation of 465.003 m close to the town of Ila Oragun and flows in an approximately northeast direction for about 80 km before joining the Asa River (Mustafa, Yusuf, 2012). The climate of Kwara State is of the wet and dry tropical type, with mean annual rainfall of about 1 318 mm, monthly rainfall 50.8–241.3 mm, and the mean monthly temperature of 32 °C, with the highest temperatures observed in March. The land is majorly used for agriculture with a little fishing activity at the peak of the rainfall.

Methodology

Primary data was collected via a field survey and using the Global Positioning System (GPS) device. The field survey was conducted to identify different land use and land cover types of the watershed. Its results were used to generate the land use and land cover types maps of the study area (Fig. 2) following Gelagay, Minale (2016). In this study, thirty samples of soil from the depth of 0–15 cm were randomly collected from different land cover types and topography in the watershed of the study area. The geographical locations of the soils sampled were recorded by means of the GPS (Yildirim, Erkal, 2013). Secondary data include: a multispectral satellite image of Landsat 8 Operational Land Imager (OLI), with a spatial resolution of 30 m for the purpose of land use and cover mapping of the area. A Shuttle Radar Topological Mission (SRTM) digital elevation model (DEM) of a 30 m spatial resolution was used to derive the topographical map of the area. Monthly precipitation data for the last 25 years were provided by the meteorological station closest to the study area and were used to calculate the present erosivity. Finally, soil samples collected from the field survey were analysed in the laboratory to determine the following soil properties: soil texture, soil organic matter content and exchangeable bases. All the data collected were used to generate soil loss factor layers and were projected using the Projection Coordination System (World Mecartor, 1984) at 30 m pixel size to estimate soil loss.

The Revised Universal Soil Loss Equation (RUSLE) was used to estimate the mean annual soil loss occurring in the watershed. The RUSLE is empirically expressed as:

$$A = (R * K * LS * C * P) \quad (1)$$

where:

A = mean annual soil loss (t ha^{-1} year^{-1})
R = rainfall erosivity factor (MJ mm h^{-1} ha^{-1} year^{-1})
K = soil erodibility factor (t ha^{-1} MJ^{-1} mm^{-1})
LS = topographic factor (slope length and steepness; dimensionless)
C = cover management factor (dimensionless, ranging from 0 to 1)
P = erosion support practice or land management factor (dimensionless, ranging from 0 to 1)

The prepared map data layers were overlaid in addition to the derived R factor value, and the soil loss rate was calculated by the application of RUSLE in a GIS environment using the ArcGIS map algebra–raster calculator tool (Yildirim, Erkal, 2013; Tiruneh, Ayalew, 2015). The resulting layer, which is the soil loss rate in the watershed area, was grouped based on five main class systems (FAO, 1978) to show the severity of erosion in relation to the spatial distribution (Fig. 2).

Rainfall erosivity (*R*) factor. Erosivity can be predicted by a suitable regression equation in a case of insufficient rainfall records (FES, 2009). This

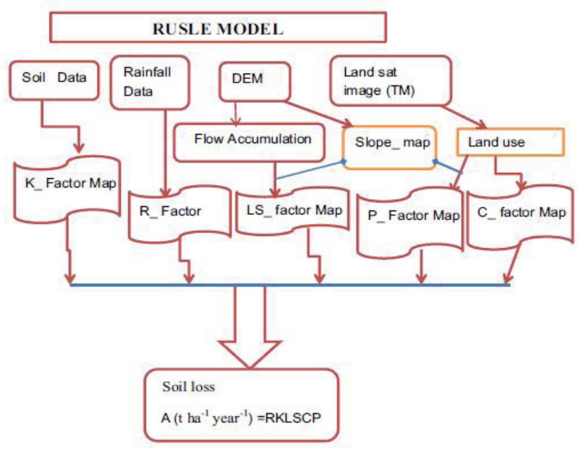


Fig. 2. Flow chart of the study (Gelagay, Minale, 2016)
A = (R * K * LS * C * P)
A = mean annual soil loss (t ha^{-1} year^{-1}), R = rainfall erosivity factor (MJ mm ha^{-1} year^{-1}), K = soil erodibility factor (t ha^{-1} MJ^{-1} mm^{-1}), LS = topographic factor (slope length and steepness, dimensionless), C = cover management factor (0–1, dimensionless), P = erosion support practice or land management factor (0–1, dimensionless), DEM = digital elevation model

Table 1. Soil erodibility classification (Wischmeier et al., 1971)

Class	Range (t ha^{-1} MJ^{-1} mm^{-1})
Low	0.10–0.20
Medium	0.24–0.32
High	0.37–0.49
Very high	0.49–0.64

was computed using the following equation (Lee, Lee, 2006):

$R = 38.5 + 0.35\ P$ (2)

where:

R = rainfall erosivity factor (MJ mm h^{-1} ha^{-1} year^{-1})

P = annual average rainfall (mm year^{-1})

Monthly rainfall data for 25 years were used for this purpose. Mean total rainfall and estimated erosivity of a 5-year interval were used to plot the erosivity factor graph.

Soil erodibility (*K*) factor. To estimate the soil erodibility factor, the USLE nomograph (Wischmeier et al., 1971) was used in form of the modified equation 3:

$K = 2.73 \times 10 - 6M\ 1.14(12 - OM) + 3.2 \times 10 - 2(S - 2) + 2.5 - 2(P - 3)$ (3)

where:

K = soil erodibility factor (t·ha^{-1}·MJ^{-1}·mm^{-1})

M = texture calculated using equation (4) based on soil primary particles percentage

OM = organic matter content (in %) determined in a laboratory

S = soil structure code

P= soil permeability class

(S and P values were obtained from USDA documents based on soil texture; Wischmeier et al., 1971)

Texture (M) was calculated according to Perez-Rodriguez et al (2007) as follows:

$M = [(100 - Ac)\ (L + Armf)]$ (4)

where:

Ac = clay content (< 0.002 mm) (in %)

L = silt content (0.002–0.05 mm) (in %)

$Armf$ = very fine sand content (0.05–0.1 mm) (in %)

Then, each 30-metre cell of the grid surface of the study area was assigned a K value by means of a Kriging interpolation tool in the ArcGIS environment, in order to generate a K factor map of the area (Vaezi et al., 2010; Yildirim, Erkal, 2013) (Table 1).

Slope length and steepness (*LS*) factor. The LS factor is expressed as:

$LS = (\lambda/22.13)\text{m} \times (65.41 \sin 2\ \theta + 4.6 \sin \theta + 0.0065)$ (5)

where:

λ = slope length (in m)

θ = slope steepness (in degrees)

m = a constant dependent on the value of the slope gradient (0.5 for slopes ≥ 5 %, 0.4 for slopes 3.5–4.5 %, 0.3 for slopes 1–3 %, and 0.2 for uniform gradients with slopes < 1 % (Wischmeier, Smith, 1978; Lu et al., 2004).

The modified equation 5, as shown below in equation 6, was put in the map algebra raster calculator tool of ArcGIS to calculate the LS factor (Simms et al., 2003).

$LS = (Flow\ accumulation \times Cell\ size/22.13)^{0.4} \times (sine\ slope/0.0896)^{1.3}$ (6)

$LS = (Flow\ accumulation * Cell\ size/22.1)\ m\ (0.065 + 0.045\ S + 0.0065\ S2)$

where:

Flow accumulation = accumulated upslope contribution for a given cell

LS = combined slope length and slope steepness factor

Cell size = size of a grid cell (30 m for this study)

sine slope = slope map with degree values given in the sine

m = a constant dependent on the value of the slope gradient

The values of *S& S2* were directly derived from 30 m resolution DEM. Similarly, flow accumulation was derived from the DEM after conducting fill and flow direction processes in ArcGIS 10.5 using the ArcHydro tool. Thereafter an LS factor map of the area was generated.

Cover management (*C*) factor. Cover management factor is the ratio of soil loss from an area with specified cover and management to that from an identical area in a tilled continuous fallow (Wischmeier, Smith, 1978). It is used to express the combined effects of plants and soil cover as well as those of all other interrelated cover and management variables (Karaburun, 2010). The C factor values were calculated from the Landsat 8 OLI multispectral satellite image through the Normalized Difference Vegetation Index (NDVI) tab of the image analysis window in ArcGIS 5.1.0. Since the C factor ranges from 0 (full cover) to 1 (bare land) and the NDVI values range from 1 (full cover) to 0 (bare land), the calculated NDVI value was inversed and expressed using equation 7 (Van der Knijff et al., 2000):

$\text{NDVI} = \text{rNIR} - \text{rRED}/\text{rNIR} + \text{rRED}$ (7)

NDVI = Float (band 5 – band 4)/Float (band 5 + band 4) in raster calculator

where:

NDVI = Normalized Difference Vegetation Index

rNIR = reflectance value in near-infrared

rRed = reflectance value of visible red band

After calculating NDVI, the C factor can be estimated by applying equation 8 (Zhou et al., 2008; Kouli et al., 2009):

$C = \exp(-\alpha \times \text{NDVI}/\beta - \text{NDVI})$ (8)

C = exp(–2 * ‘Extract_rast3’/(1 – ‘Extract_rast3’)

where:

C = cover management factor

NDVI = Normalized Difference Vegetation Index

α, β = scaling factors

Van der Knijff et al. (2000) suggest that by applying this relationship, better results than using

Table 2. Categorization of the cover management (C) factor values (L e e, L e e, 2006)

Code	Land use	C
1	water	0.0
2	barren	0.5
3	developed	0.003
4	light vegetation	0.05
5	agriculture	0.3
6	thick forest	0.004
7	swamp	0.002

Table 3. The management practice (P) factor depending on support practice and slope gradient

Slope (%)	Contouring	Stripping	Terracing
0.00–7.00	0.55	0.27	0.10
7.00–11.30	0.60	0.30	0.12
11.30–17.60	0.80	0.40	0.16
17.60–26.80	0.90	0.45	0.18
26.80 >	1.00	0.50	0.20

Source: K I C T, 1992

a linear relationship can be obtained. The suggested values for the two scaling factors α and β are 2 and 1, respectively. To obtain the land use cover map, supervised classification was carried out on the already calculated C factor values of the Landsat 8 OLI multispectral satellite images covering the watershed area in the ArcGIS environment. The maximum likelihood classifier tool (MLC) algorithm of ArcGIS based on all the Landsat bands was used to map the major land cover classes (A n e j i o n u et al., 2013). The C factor values of the watershed area generated in the ArcGIS environment were used to determine the land use type as a classified Landsat image. The C factor value generated from the multispectral Landsat images is assigned a land use term (Table 2).

Management practice (*P*) factor. The erosion control practice factor (P factor) is the ratio of soil loss with a specific support practice to the corresponding loss with up-slope and down-slope cultivation (W i s c h m e i e r, S m i t h, 1978). The values shown in Table 1 were used to reclassify the slope dataset to obtain the P factor for the study area. The predominant practice for the study area was determined through the ground truth assessment and the values under the pertinent column of Table 1 used for the reclassification (A n e j i o n u et al., 2013). To estimate the efficiency of contouring, stripping and terracing management practices in reducing soil loss, soil loss was calculated according to Korea Institute of Construction Technology (1992) using RUSLE equation with the value of P for each practice as stated in Table 3.

$$A = R * K * LS * C * contouring\ (P) \quad (9)$$

$$A = R * K * LS * C * stripping\ (P) \quad (10)$$

$$A = R * K * LS * C * terracing\ (P) \quad (11)$$

where:

P = management practice factor the value of which is determined by the slope gradient and management practice established in the area in order to estimate soil loss (Table 3)

The efficiency of the management practice factor was derived by comparing the soil loss using contouring as against when management practice such as terracing and stripping are introduced in the study area.

Potential soil loss (*A*). After computing the various USLE factors, the average soil loss (A; in t ha^{-1} per year) in the watershed was estimated through the multiplication of all the corresponding USLE factors, by overlaying each factor data set in map algebra raster calculator tool in ArcGIS environment. The result was used to produce a map of potential soil erosion hazards of the watershed (O b i n n a et al., 2013). Using the reclassify tool in ArcGIS, the resulting map was reproduced into various risk classes (Y i l d i r i m, E r k a l, 2013) (Table 4).

RESULTS

Rainfall erosivity (*R*) factor

The mean total rainfall and erosivity data on the Oyun River watershed (1992–2017) presented in 5-year intervals are shown in Fig. 3. The result shows an increase in mean total rainfall and erosivity from 1 082.46 mm and 70.07 MJ mm ha^{-1} per year in the period 1997–2001 to 1 542.18 mm and 83.48 MJ mm ha^{-1} per year in the period 2012–2017 representing increases of ca. 50 % and 19 %, respectively. The mean total rainfall is projected to almost double, reaching 1 916.93 mm (broken trend line) from the period 1997–2001 to the period 2023–2027, whereas erosivity will increase by a third, peaking at 94.17 MJ mm ha^{-1} per year over the same periods. The results indicate a more rapid increase in the mean total rainfall amount disproportionate to erosivity (Fig. 3).

Table 4. Categorization of soil loss risk

Erosion risk	Threshold (t ha^{-1} per year)
Very low	soil loss ≤ 2
Low	2 < soil loss ≤ 10
Moderate	10 < soil loss ≤ 50
High	50 < soil loss ≤ 100
Very high	soil loss ≥ 100

Source: F A O (1984)

Soil erodibility (*K*) factor

The soil erodibility factor *K* of the Oyun River watershed in Ijagbo, Kwara State, Nigeria was found to range from 0.10 to 0.11 t ha^{-1} MJ^{-1} cm (Fig. 4). The *K* values obtained were low according to Wischmeier et al. (1971) (Table 1). The watershed soils showed comparatively high organic matter content (Table 5). The soils of the study area were classed as sandy loam (SL) (Table 5).

Slope length and steepness (*LS*) factor

Fig. 5a, b shows seven classes of percentage slope steepness identified in the Oyun River watershed. The slope gradients are as follows: 0–0.5 % (flat plane, 0.5–2 % (nearly flat plane), 2–5 % (very gentle slope), 5–9 % (gentle slope), 9–15 % (moderate slope), 15–30 % (steep slope), and 30–45 % (very steep slope) (Fig. 4, Table 5).

About 79 % of the watershed occupies level to moderate slope classes whereas steep to very steep slopes occupy 21 % of the watershed (Table 6). As shown in Fig. 5c, the *LS* factor of the study area ranges from 0 to 11.25. The slopes in the Oyun River watershed in Ijagbo were mostly classed as gentle and moderate (Table 6, Fig. 5a–c).

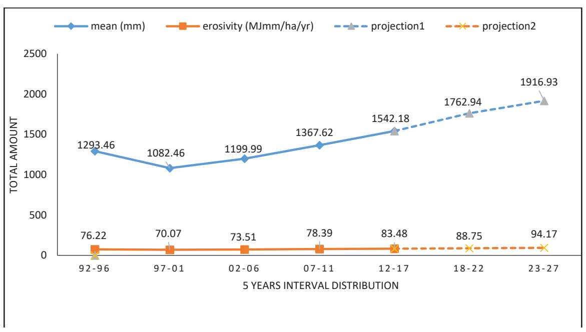


Fig. 3. Mean total rainfall and erosivity of the Oyun River watershed, Ijagbo, Nigeria

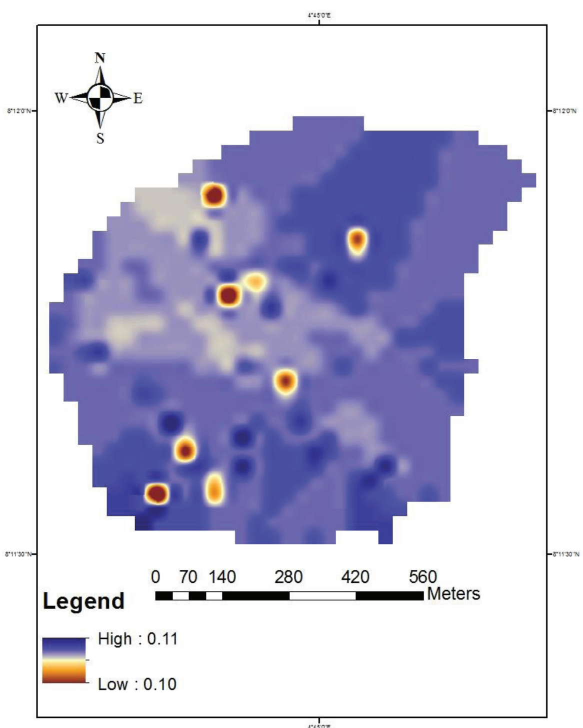


Fig. 4. Soil erodibility distribution map of the Oyun River watershed in Ijagbo, Nigeria

Table 5. Textural class and organic matter content of soils in the Oyun River watershed, Ijagbo, Nigeria

S/N	Sand (%)	Silt (%)	Clay (%)	Textural class	OM (%)
1	81.5	12.0	6.5	SL	1.7
2	79.5	12.0	8.5	SL	1.9
3	81.5	11.0	7.5	SL	2.0
4	83.5	10.0	6.5	SL	1.9
5	83.5	10.0	6.5	SL	2.0
6	83.5	10.0	6.5	SL	1.5
7	81.5	9.0	9.5	SL	0.9
8	81.5	12.0	6.5	SL	1.8
9	83.5	10.0	6.5	SL	1.2
10	83.5	10.0	6.5	SL	1.7
11	79.5	14.0	6.5	SL	1.2
12	81.5	10.0	8.5	SL	2.0
13	82.5	11.0	6.5	SL	0.9
14	81.5	12.0	6.5	SL	2.0
15	83.5	10.0	6.5	SL	0.8
16	83.5	10.0	6.5	SL	2.1
17	81.5	11.0	6.5	SL	2.4
18	81.5	12.0	6.5	SL	1.8
19	81.5	10.0	8.5	SL	1.9
20	79.5	12.0	8.5	SL	2.0
21	79.5	14.0	6.5	SL	2.6
22	81.5	12.0	6.5	SL	1.9
23	81.5	12.0	6.5	SL	1.06
24	83.5	10.0	6.5	SL	0.03
25	83.5	10.0	6.5	SL	1.8
26	83.5	10.0	6.5	SL	0.03
27	83.5	10.0	6.5	SL	0.03
28	81.5	10.0	8.5	SL	0.03
29	83.5	10.0	6.5	SL	0.7
30	81.5	12.0	6.5	SL	2.2

S = serial, N = number, OM = organic matter, SL = sandy loam

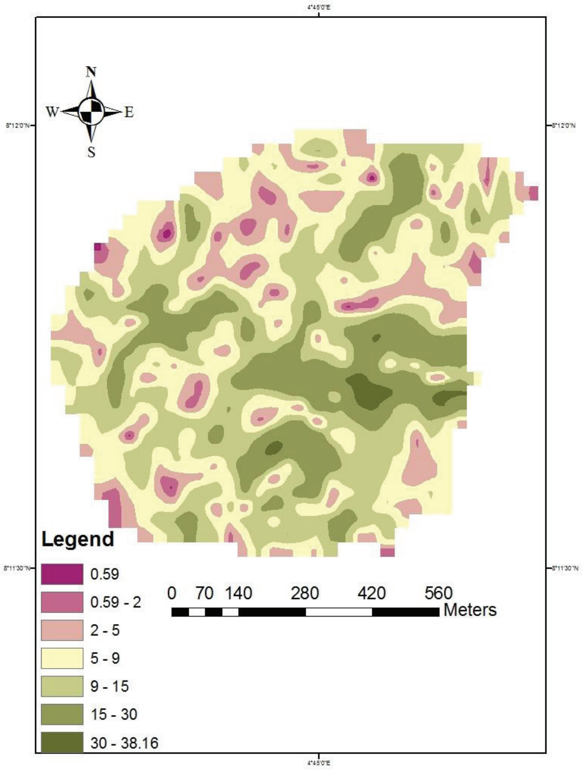


Fig. 5a. Slope steepness factor map of the Oyun River watershed, Ijagbo, Nigeria

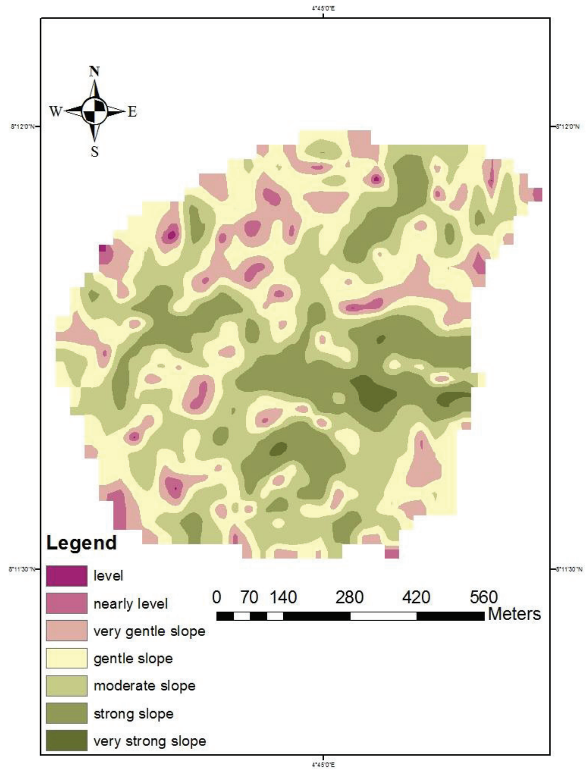


Fig. 5b. Slope steepness classification map of the Oyun River watershed, Ijagbo, Nigeria

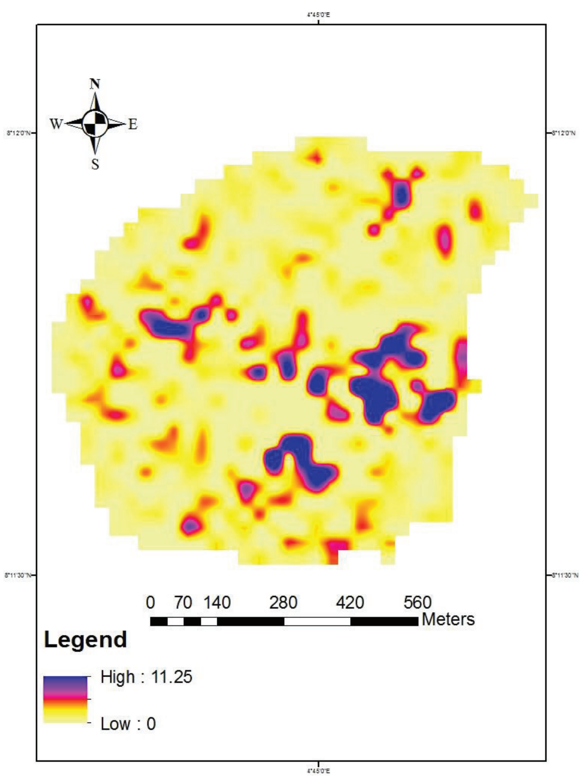


Fig. 5c. Slope length and steepness map of the Oyun River watershed, Ijagbo, Nigeria

Cover management (*C*) factor

The *C* factor values are in the range from 0 to 0.16 (Fig. 6a) based on the classification by Lee, Lee (2006) (Table 2). Three land cover/land use types were identified in the Oyun River watershed by a supervised image classification of the ArcGIS software. The *C* factor value 0 indicates a sufficient cover for the soil against erosion, and the protection reduces as the values increase to 1. The variation in the *C* factor values is due to the different land cover and land use types in the study area. Fig. 6b shows the three land use/land cover types of the watershed: water (0) covering 15.86 % (10.46 ha), light vegetation (0–0.05) covering 3.28 % (2.16 ha) and agriculture (0.05–0.16) which occupies 78.26 % (51.66 ha). The *C* factor values of the Oyun River watershed as generated by the ArcGIS environment range 0–0.16, representing a good cover type/land use. Most of the land is under agriculture, light vegetation and water body which give cover to soil, limit the impact of rain drops and hence reduce detachment and transport of soil particles.

Management practice (*P*) factor

The management practice (*P*) factor values as shown in Fig. 7 range from 0.55 to 1.0. Higher values of the *P* factor would lead to increased soil loss; this how-

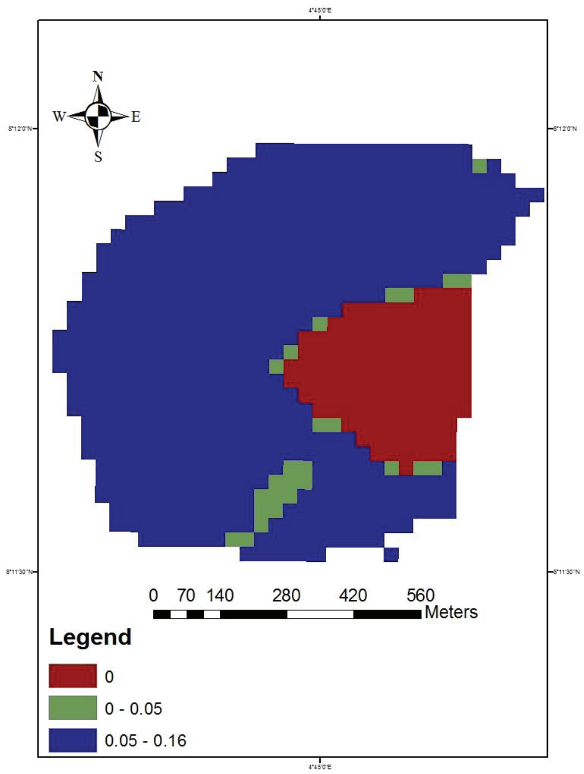


Fig. 6a. Land cover factor map of the Oyun River watershed, Ijagbo, Nigeria

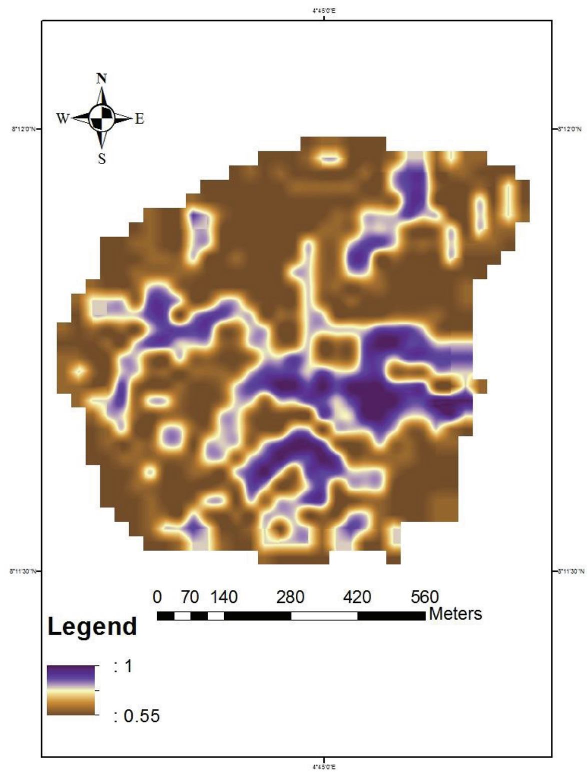


Fig. 7. Management practice factor map of the Oyun River watershed, Ijagbo, Nigeria

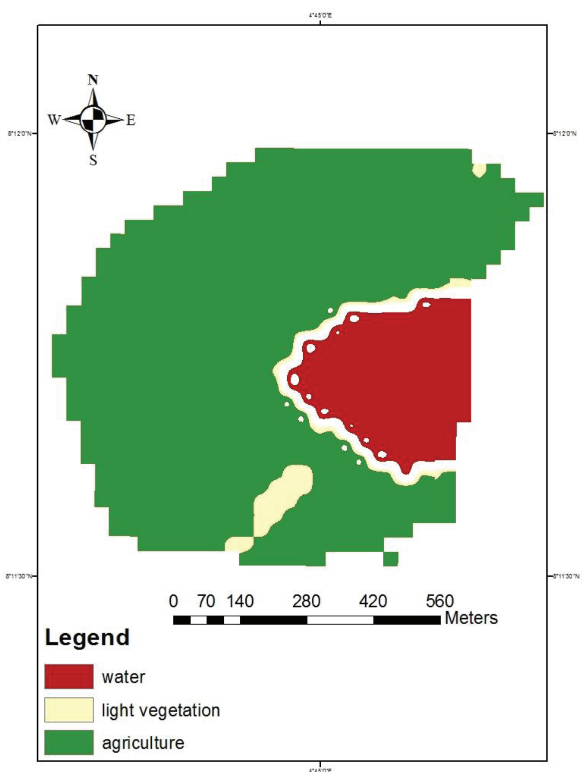


Fig. 6b. Land cover classification map of the Oyun River watershed, Ijagbo, Nigeria

ever depends on the slope gradient classes occurring in the studied area. The erosion hotspots with high *P* factor values and strong to very strong slope gradient are expected to lose more soil. High soil loss due to the effect of contouring (sole management practice in the area) in this watershed is however expected to be moderated by the level terrain to moderate slope classes dominating in this landscape (Fig. 6a, b, Fig. 7).

Soil loss

Fig, 8a, b presents the soil loss distribution map of the Oyun River watershed. The annual soil loss of the study area ranges from 0 to 35.02 t ha^{-1}. The soil loss in in the Oyun River watershed was classified according to F A O (1978) standard. Three soil loss classes have been observed, namely: very low (≤ 2 t ha^{-1} per year) covering 9.62 % (6.35 ha) of the area, low (2 <…. ≤ 10 t ha^{-1} per year) covering 75.33 % (49.7 ha) of the area, and moderate (10 <….≤ 50 t ha^{-1} per year) soil loss class covering 11.62 % (7.68 ha) of the study area, respectively, as shown in Table 7. The annual total soil loss for the whole watershed is 254.25 t per year with a mean soil loss value of 3.39 t ha^{-1}. The mean soil loss of the study area falls within the maximum tolerable limit for crop production (12 t ha^{-1} per year) set by FAO.

Table 6. Slope gradient data of the Oyun River watershed, Ijagbo, Nigeria

Slope gradient (%)	Slope class	Area (ha)	Coverage (%)
0–0.5	level	0.54	0.82
> 0.5–2	nearly level	1.99	3.02
> 2–5	very gentle	10.82	16.39
> 5–9	gentle	20.27	30.71
> 9–15	moderate	18.75	28.42
> 15–30	strong	13.05	19.77
> 30–45	very strong	0.71	1.08

Table 7. Soil loss of the Oyun River watershed, Ijagbo, Nigeria

Soil loss ($t\ ha^{-1}$ per year)	Rate	Coverage (%)	Area (ha)
0–2	very low	9.62	6.35
2–10	low	75.33	49.70
10–35.02	moderate	11.62	7.68

Large part of the area was observed to be under the low soil loss class covering more than 75 % of the study area and soil loss in most areas was generally found to be within the maximum tolerable limit set by FAO with the exception of the erosion hotspots. Soil loss of 35.02 $t\ ha^{-1}$ per year was the maximum observed in 11.62 % (7.68 ha) of the watershed under investigation as against the maximum tolerable limit set by FAO. This area suggests the erosion hotspots. The erosion hazard map (Fig. 8a, b) of this area shows several erosion hotspots falling in the moderate soil loss class, with soil loss exceeding the maximum tolerable limits set by FAO. The results indicate (by using equation 11 as computed in equation 13) that through the adoption of terracing as against contouring, which is the prevailing erosion control practice in the study area, soil loss in the erosion hotspots could be reduced to 12.02 $t\ ha^{-1}$ per year, whereas stripping could reduce soil loss to 30.05 $t\ ha^{-1}$ per year as shown in equation 14.

$$A = 83.48 \times 0.1 \times 45 \times 0.16 \times 0.2 = 12.02\ t\ ha^{-1}\ year^{-1} \quad (13)$$

$$A = 83.48 \times 0.1 \times 45 \times 0.16 \times 0.5 = 30.05\ t\ ha^{-1}\ year^{-1} \quad (14)$$

DISCUSSION

The low total rainfall observed in the study area is characteristic of tropical savannah climate whereas the increase in mean total rainfall and erosivity in the past two decades could be attributed to changing climatic conditions caused by deforestation, emission of green-house gases from industrial and agricultural sources. The disproportionality between the increase in the amount of mean total rainfall and erosivity indicates that erosivity, besides the rainfall amount, is determined also by other rainfall characteristics, such as intensity, drop diameter, terminal velocity and kinetic energy (Carvalho et al., 2005; Machado et al., 2008). A slow increase in these rainfall characteristics (intensity, drop diameter, terminal velocity and kinetic energy) will likely impart a non-rapid increase on rainfall erosivity as observed. The erosivity of the study area was observed to be very low in compare with its extent presented on the global erosivity map scale by Panos et al. (2015); therefore it is not expected to exacerbate soil loss presently in the studied watershed.

The low erodibility of the watershed soils indicates a high resistance of their particles to forces of detachment and transport provided by water and wind (erosion). Particle size and organic matter content are properties that majorly determine erodibility of a soil. Erodibility is generally less for both coarse and very fine (clay) textured fractions. Fine sands and silts are very unstable and are in the category of easily erodible soils. The high organic matter content of soils of the watershed is rather unusual of the southern Guinea savannah soils due to inherently low soil fertility and constant bush burning (Eifediyi et al., 2017). This relatively high organic matter content may result from local practices that improve soil organic matter and this, therefore, will contribute to the resistance of the soil aggregates to erosion. Organic matter leads to improved soil structure and hence reduces soil erodibility.

The slope classes observed are also contributors to soil loss in the study area. The slope length and steepness (*LS*) factor is one of the factors that have the greatest impact on soil loss modelling (Ritchie, McHenry, 1990). Slope intervenes in erosion in terms of its form, gradient, length and position. Consequently, erosion hotspots of the study area are expected to fall in the strong and very strong slope land classes. Steeper slopes naturally lead to higher soil loss due to erosion. Therefore, the erosion hotspots will require improved slope management practices to forestall soil degeneration.

Contouring as a slope management practice adopted in this watershed is not the best among available options due to its higher *P* factor values compared to terracing and stripping according to KICT (1992) (Table 3). Therefore, the *P* factor is expected to be a major determinant of soil loss in this watershed considering that erodibility of the soil is low and with large parts under a good cover and terrain.

Large part of the watershed is classed as of a low soil loss. This is conditioned by low rainfall characteristic of the Guinea savannah zone of Nigeria, low erodibility conferred by the soil organic matter content, flat land to mostly moderate (79 % in total) slopes, and a good cover type/land use which protect the soil from the shattering impacts of raindrops and subsequent transport of soil particles.

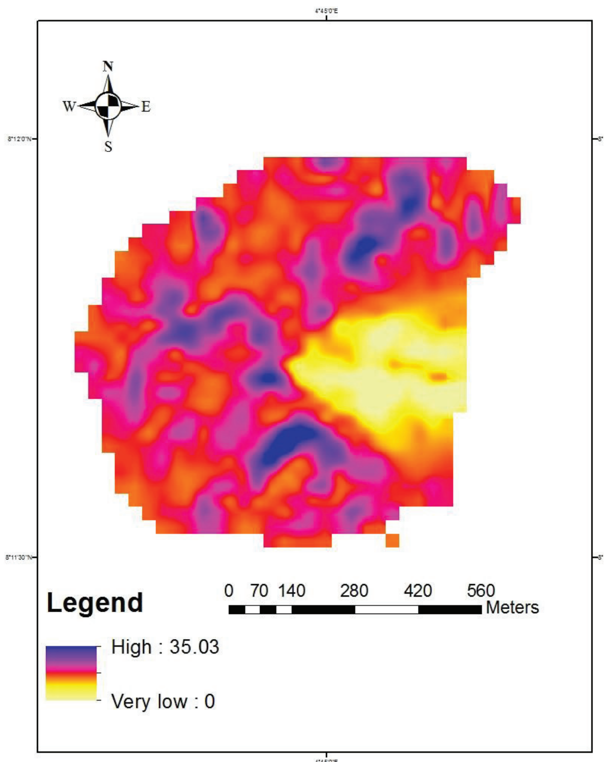


Fig. 8a. Soil loss hazard map of the Oyun River watershed, Ijagbo, Nigeria

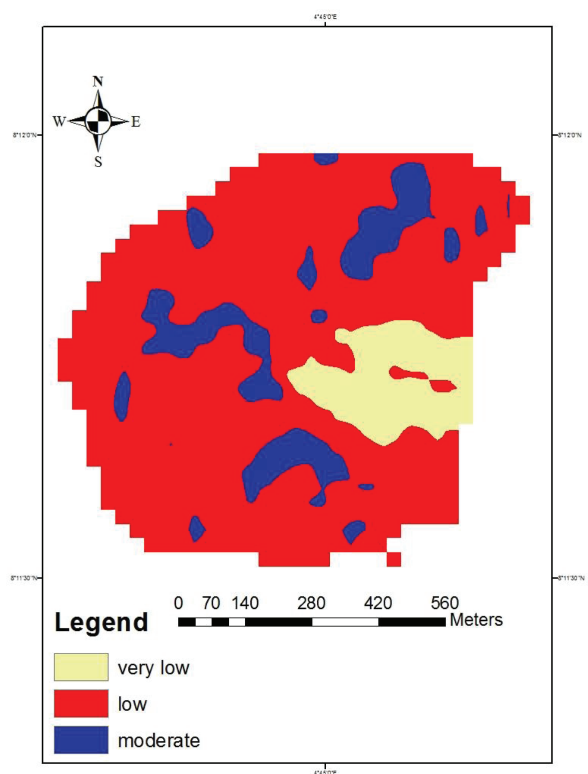


Fig. 8b. Soil loss classification map of the Oyun River watershed, Ijagbo, Nigeria

Due to the above given facts the watershed has currently been at minimum risk and not at risk if sustainable land use, proper crop growing and management techniques are instituted. The mean soil loss of 3.39 t ha^{-1} per year estimated for this study location was therefore, found to be lower compared to 50–300 t ha^{-1} per year obtained in Ultisols of south-eastern Nigeria by Mbagwu, Salako (1985) and 131–171 t ha^{-1} per year estimated by the Anjeni Research Unit of the Soil Conservation *Research* Program (Kefeni, 1995) in the north-western Ethiopian highlands. This suggests that the Alfisols of Nigeria are more stable to erosion (Ahamefule et al., 2019) compared to the Ultisols. The Ultisol of south-eastern Nigeria has been reported to be most prone to erosion due its structural fragility (Oguike, Mbagwu, 2009). Idowu, Oluwatosin (2008) reported that the Ultisols of south-eastern Nigeria have high erodibility and therefore have been classed as structurally unstable. However, the erosion hotspots identified in this study will require special conservational attention to avoid both localized degeneration and spread to other areas hitherto under low soil loss. This special attention should be such that will ensure sustainable crop production in the watershed and by extension food security for the local population. Zuazo et al. (2006) observed the terracing technique was more effective to improve the exploitation of steep slope and to increase its agricultural potential. Therefore, adopting terracing in this watershed will greatly reduce soil loss and conserve the land for agricultural activities, especially with increasing total rainfall and erosivity as projected in Fig. 3. The result of this study also shows that for any future development of erosion/soil loss prediction model for Ijagbo (a typical derived savannah zone of Nigeria), the parameters of interest should be the topographic and management practice factors. This is because model development usually entails the consideration of only those factors which significantly contribute to the prediction abilities of the model.

CONCLUSION

Remotely sensed data and a GIS-based approach were effective techniques to estimate watershed based soil loss. After estimating the annual soil loss of the Ijagbo watershed in Kwara State, Nigeria, it was observed that the potential soil loss rate per unit area of land ranges from 0 to 35.02 t ha^{-1} per year, with a mean soil loss of 3.39 t ha^{-1} per year. This falls within the tolerable limit of soil loss set by the FAO. Therefore, crop productivity and associated food production will still be sustained and the reservoir can supply good quality water to the immediate environment. The erosion hotspots were found to be located on steep slopes where soil loss fell into the moderate class, however it exceeded the FAO maximum tolerable limits of 12 t ha^{-1} per year. Thus, more efficient soil management practices like terracing and stripping must be introduced. This can be used to reduce the runoff impact on soil particles transport and also to reduce the soil loss rate in the watershed.

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