

# Mapping of potential soil loss due to erosion in Oke-Oyi dam agricultural watershed, Ilorin, Nigeria

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## ABSTRACT

The increasing rate of urbanization in Nigeria has led to serious disruption in the landscape which has made some areas (on-site and off-site) susceptible to various forms of erosion. Due to scarce resources, erosion goes on continually without notice. Erosion most times is only observed when gullies are beginning to form, at this stage much damage would have been inflicted on the soil and the recovery process will be more expensive compared to what it would have been if pre-emptive measures were taken. In this regard, therefore, there is need for an inquisition to determine the current state of soils in the watersheds of Nigeria by estimating and mapping soil loss. To achieve this, a study was conducted in the Oke-Oyi dam watershed in Ilorin, Nigeria to estimate annual soil loss using the Revised Universal Soil Loss Equation (RUSLE) with the aid of Remote Sensing and GIS techniques. Thirty-eight (38) samples of surface (0–15 cm depth) soil were collected from the watershed area with respect to the topography and land use/cover type. Secondary data included 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 30 m spatial resolution was used to derive the topographical map of the area. Monthly precipitation data for the last 25 years which have been recorded and available in the nearby Ilorin International Airport Meteorological Station was used to derive the erosivity of the area. Results indicated that rainfall erosivity of the study area was  $83.48 \text{ MJ mm ha}^{-1} \text{ y}^{-1}$  and was projected to reach  $94.17 \text{ MJ mm ha}^{-1} \text{ y}^{-1}$  in the next decade. Erodibility of the soil was high whereas the annual soil loss ranged from 0 to  $1,272 \text{ t ha}^{-1} \text{ y}^{-1}$ . Soil loss in 22% (164 ha) of the study area was severe. The soil loss in the watershed fell far above the maximum tolerable limit of  $12 \text{ t ha}^{-1} \text{ y}^{-1}$  set by the FAO for sustainable land use. The total annual soil loss for the whole watershed is about  $327,709.58 \text{ t ha}^{-1} \text{ y}^{-1}$  with a mean soil loss of about  $1,310.84 \text{ t ha}^{-1} \text{ y}^{-1}$ , this figure is expected to continue to rise if adequate soil management measures are not expediently instituted. In the long term, if the present erosion control practices of contouring are substituted with strip-cropping or terracing, soil loss will be reduced from  $630.73 \text{ t ha}^{-1} \text{ y}^{-1}$  to  $315.40 \text{ t ha}^{-1} \text{ y}^{-1}$  (50%) and  $126.15 \text{ t ha}^{-1} \text{ y}^{-1}$  (80%), respectively.

**Keywords:** Oke-Oyi dam, watershed, soil loss, USLE, ArcGIS, erosion hotspot

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## INTRODUCTION

Soil erosion is described as an accelerated process under which soil is bodily displaced and transported away faster than it can be formed; the agents of soil erosion are principally flowing water, glaciers, waves, and wind (Efe *et al.*, 2008). Soil erosion by water is a serious environmental problem in many parts of the world (Efe *et al.*, 2008). Furthermore, it is a common cause of soil deterioration around the world and has been accelerated by improper land use practices over the last several decades (Trimble and Crosson, 2000; Vanni re *et al.*, 2003; Piccarreta *et al.*, 2006; Szilassi *et al.*, 2006). It is estimated that 85% of global land degradation is associated with soil erosion (Piccarreta *et al.*, 2006). Therefore, it is important to estimate soil loss due to erosion.

Universal Soil Loss Equation (USLE) of Wischmeier and Smith (1978) is widely used for the study of soil erosion by water because of its simplicity, despite some inconveniences due to its extensive requirement for input data (Tiwari *et al.*, 2000; Lufafa *et al.*, 2003; Parveen and Kumar, 2012). Roose (1977) also reported that the USLE is well adapted for the majority of cultivated soils, especially the Ultisols and Alfisols, which is common in West Africa. Successive studies lead to the Revised Universal Soil Loss Equation (RUSLE) model (Renard *et al.*, 1997) to broaden the applicability of the model to incorporate soil loss estimation for rangeland, forestland, disturbed sites, and steep slopes. The RUSLE could be combined with Remote Sensing (RS) and ArcGIS techniques to make soil erosion estimation and its spatial distribution feasible with reasonable costs, time, and better accuracy in large areas. The increasing rate of urbanization in Nigeria has led to serious disruption in the landscape which

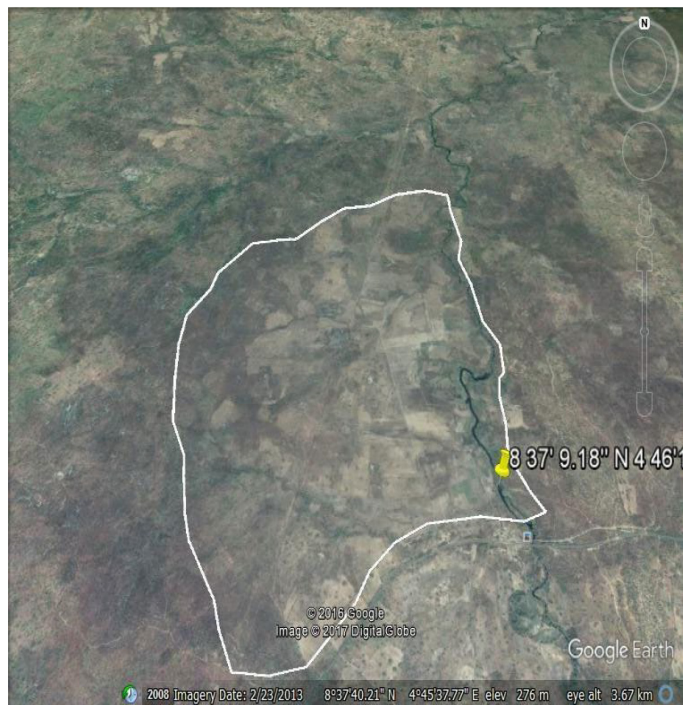
made some areas susceptible to various forms of erosion thereby reducing and intensifying agricultural activities on cultivable lands, hence there is need for the inquisition to determine the current state of soils in the watersheds of Nigeria by estimating and mapping its soil loss.

The objectives of this study were to: (1) determine the soil loss with reference to the tolerable limit of soil loss set by the Food and Agriculture Organization of the United Nations (FAO, 1984), (2) map the factors responsible for soil loss in the area, (3) derive soil erosion hazard map for the area, (4) locate the erosion hotspots for conservation prioritization and (5) suggest the best management practices that can reduce soil loss in the area. The result of this study will help farmers plan sustainable land use for improved agricultural productivity and assist environmental protection agencies and river basin development authorities with information on soil loss in this area for use in soil conservation and land use programmes.

## MATERIALS AND METHODS

### Study Area

The study site was located in Oke-Oyi dam agricultural watershed pinned on a google earth map (Figure 1). Oke-Oyi is the headquarter of Ilorin East Local Government Area of Kwara State. It is about 25 km away from Ilorin main town on Ilorin-Share Road. It lies between latitudes 8°36'36.09"N and 8°38'04.71"N and longitudes 4°45'27.10"E and 4°45'55.86"E of the Greenwich meridian. Oke-Oyi has an area of about 486 km<sup>2</sup> land coverage with the watershed area constituting about 250 ha, which falls in the western upland physiographic region of the state with an average height of about 360 m above sea level and a slope of 10 degrees.

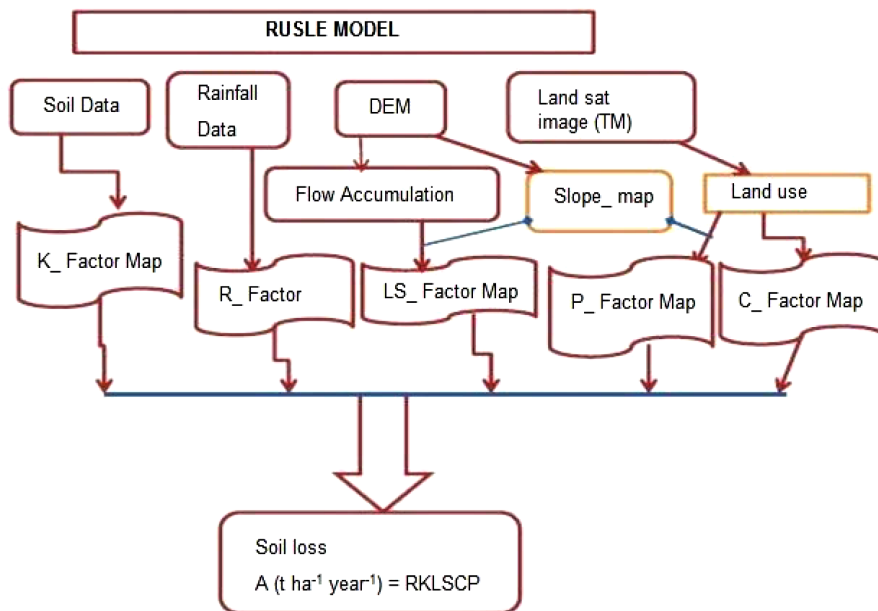


**Figure 1** Google earth image of the Oke-Oyi dam watershed

The terrain slopes in the northwest and southwest direction and then drains into River Oshin which forms the eastern boundary (Gbadegesin and Oriola, 2004). It has a total population of 204,310 going by the 2006 census (Ogunleye and Yekinni, 2012). The watershed location is characterized by dry and wet seasons. The wet season usually commences in March and ends in October while the dry season spans between November and February. Relative humidity varies around 70% in the dry months, and approximately 80% in the wet months. The natural vegetation of this location consists of forest and wooded savannah and the area is predominantly cultivated to groundnut with contouring as the erosion control practice. Annual rainfall ranges from 1,000–1,500 mm while the maximum average temperature ranged between 30 and 35°C (Ogunleye and Yekinni, 2012).

### Data Sources and Collection

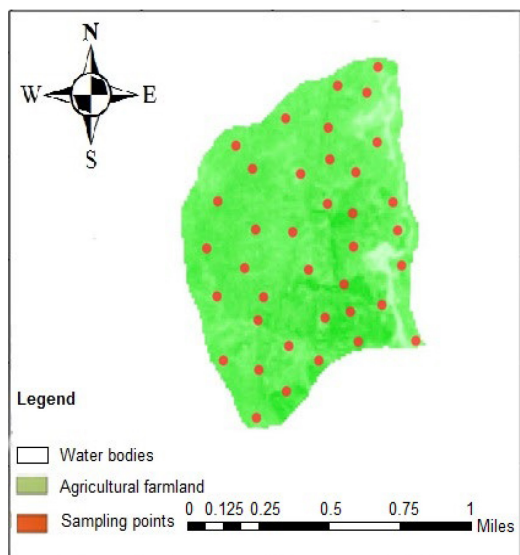
Primary and secondary data sources were used for this study. Primary data were collected in the field randomly with the locations marked with the aid of the Global Positioning System (GPS) device. Field observation using GPS to mark the various land use and land cover types (LULC) of the watershed was carried out to generate the land use and land cover map of the area (Gelagay and Minale, 2016) as shown in the flow chart (Figure 2). In this study, thirty-eight (38) surface (0–15 cm depth) soil samples were collected from the watershed area for the topography and land use/cover type as shown in the soil sampling map (Figure 3).



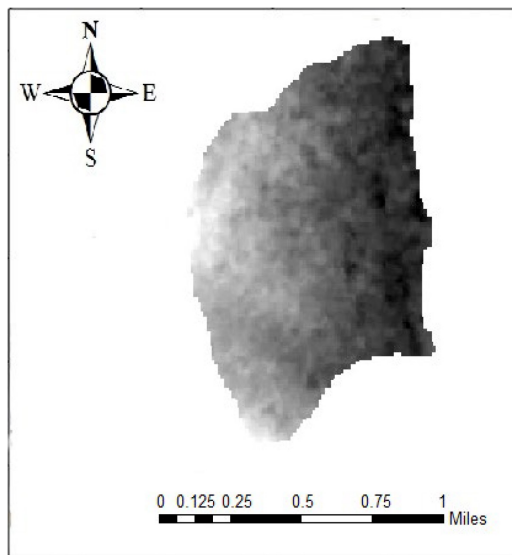
**Figure 2** Flow chart of the study modified from Gelagay and Minale (2016)

The geographical locations of the soils sampled were recorded using a GPS (Yildirim and Erkal, 2013). Secondary data included a multispectral satellite image of Landsat 8 Operational Land Imager (OLI), with a spatial resolution of 30 m for land use and cover mapping of the area. A Shuttle Radar Topological Mission (SRTM) Digital Elevation

Model (DEM) of 30 m spatial resolution to derive the topographical map of the area was as shown in Figure 4. Monthly precipitation data for the last 25 years (Table 1) which have been recorded and available in the nearby Ilorin International Airport Meteorological Station (29.2 km from the study site) was used to derive the erosivity of the area.



**Figure 3** Oke-Oyi dam watershed soil sampling map



**Figure 4** Digital Elevation Map (DEM) of the Oke-Oyi dam watershed

**Table 1** Rainfall data (mm y<sup>-1</sup>) of the study area

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total	Mean	Erosivity
1992	0	0	2.0	46.7	166.6	90.1	134.7	75.9	129.4	193.2	0	0	838.6	69.9	69.9
1993	0	102.5	79.0	35.2	176.1	220.6	100.4	333.6	362.8	84.9	0	0	1,495.0	124.6	124.6
1994	70.1	0	7.9	161.0	168.0	168.1	283.1	83.4	201.0	317.9	289.9	0	1,750.4	145.9	145.9
1995	0	0	79.0	79.0	234.0	186.5	140.5	245.1	272.5	133.0	11.5	12.0	1,393.1	116.1	116.1
1996	0	0	56.5	67.1	165.3	154.2	96.4	154.6	199.8	96.3	0	0	990.2	82.5	82.5
1997	0	0	93.1	206.4	207.4	375.2	158.8	107.6	224.4	115.3	15.0	0	1,503.2	125.3	125.3
1998	0	0.8	17.1	73.9	159.6	132.3	58.5	170.9	224.8	140.0	0	0	977.9	81.5	81.5
1999	0	32.5	54.9	67.1	143.3	244.9	195.6	85.7	265.6	182.5	22.8	0	1,294.9	107.9	107.9
2000	0	2.2	2.4	22.8	68.2	262.2	93.4	163.9	268.0	9.0	0	0	892.1	74.3	74.3
2001	0	0	18.0	45.0	139.0	121.8	138.7	44.5	176.4	60.8	0	0	744.2	62.0	62.0
2002	0	0	59.4	163.2	57.2	97.8	180.8	182.7	144.5	176.7	6.5	0	1,068.8	89.1	89.1
2003	0	14.0	12.4	93.9	124.5	360.7	123.2	130.9	176.2	133.4	46.7	0	1,215.9	101.3	101.3
2004	18.2	33.1	4.0	67.0	260.5	159.2	211.4	145.4	243.5	98.1	31.6	0	1,272.0	106.0	106.0
2005	0	5.5	25.5	75.7	187.6	171.0	130.2	93.6	282.6	109.8	10.5	0	1,092.0	91.0	91.0
2006	1.2	16.1	27.5	106.6	163.7	259.6	224.1	88.2	276.2	190.0	0	0	1,353.2	112.8	112.8
2007	0	7.0	22.0	115.0	306.2	227.7	205.3	189.9	236.2	162.5	0	2.5	1,474.3	122.9	122.9
2008	0	0	9.5	123.5	35.2	184.1	394.1	329.5	343.6	88.6	3.4	5.2	1,516.7	126.4	126.4
2009	6	0.5	19.6	219.2	112.1	170.6	249.5	226.0	231.0	112.0	47.4	0	1,393.9	116.2	116.2
2010	0	6.5	60.9	58.2	112.2	45.1	139.1	123.7	228.3	226.4	2	0	1,002.4	83.5	83.5
2011	0	19.1	4.8	13.5	169.1	231.8	220.2	294.5	334.6	163.2	0	0	1,450.8	120.9	120.9
2012	26.0	0	0.6	173.3	205.7	162.8	202.6	168.1	200.8	84.4	0	7.2	1,231.5	102.6	102.6
2013	0.5	39.0	39.8	181.8	81.8	132.9	107.3	17.7	202.5	154.3	0	11.4	969.0	80.8	80.8
2014	6.3	34.2	71.0	321.4	163.8	154.7	82.1	94.9	391.6	259.4	0	0	1,579.4	131.6	131.6
2015	0	38.5	0	3.6	206.7	206.1	153.5	342.0	583.9	127.8	0	0	1,662.1	138.5	138.5
2016	0	0	137.6	22.3	618.0	242.8	317.7	185.5	529.2	139.4	24.8	31.6	2,248.9	187.4	187.4
2017	0	0	40.3	63.6	244.2	337.6	53.2	403.1	357.8	7.8	5.3	49.3	1,562.2	130.2	130.2

Soil samples collected from the field survey were analyzed in the laboratory to determine properties such as soil texture, soil structure, soil organic matter content, and permeability (Yildirim and Erkal, 2013). Soil texture was determined by the hydrometer method according to Gee and Bauder (1986) whereas organic matter (OM) was determined according to Walkley and Black (1934) method. All the data collected were used to generate soil loss factor layers and projected using the Projection Coordination System (World Geodetic System, 1984) at 30 m pixel size for the estimation of soil loss.

### Soil Loss Estimation

The Revised Universal Soil Loss Equation (RUSLE) was used to estimate the mean annual soil loss occurring in the watershed. The RUSLE (Renard *et al.*, 1997) is empirically expressed as:

$$A = R \times K \times LS \times C \times P \quad \text{----- (1)}$$

where A is the mean annual soil loss ( $t \text{ ha}^{-1} \text{ y}^{-1}$ ), R is the rainfall erosivity factor ( $\text{MJ mm ha}^{-1} \text{ y}^{-1}$ ), K is the soil erodibility factor ( $t \text{ ha}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$ ), LS is the topographic factor represents slope length and steepness (dimensionless), C is the cover management factor (dimensionless; ranges from 0 to 1) and P is the erosion support practice or land management factor (dimensionless; ranges 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 and Erkal, 2013; Tiruneh and Ayalew, 2015). The resulting layer which is the soil loss rate in the watershed was grouped based on five main class systems (FAO, 1984) to show the severity of erosion in relation to the spatial distribution.

#### Rainfall erosivity (R) factor

Erosivity was computed using the following equation by Lee and Lee (2006):

$$R = 38.5 + 0.35 \times P \quad \text{----- (2)}$$

where R is the rainfall erosivity factor and P is the annual average rainfall ( $\text{mm y}^{-1}$ ). Monthly rainfall data for 25 years was used for this purpose as shown in Table 1. 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 published by Wischmeier *et al.* (1971) was used in form of the modified equation 1 below:

$$K = [2.73 \times 10^{-6} M^{1.14} (12 - \text{OM})] + [3.2 \times 10^{-2} (S - 2)] + [2.5^{-2} (P - 3)] \quad \text{----- (3)}$$

where K is the soil erodibility factor ( $t \text{ ha hr MJ}^{-1} \text{ ha}^{-1} \text{ mm}^{-1}$ ) and M is the texture which was calculated using equation 4 below based on soil primary particles percentage, OM is the organic matter content (in percent) that would be determined in the laboratory, S is the soil structure code and P is the soil permeability class and both were obtained from USDA published documents based on soil texture (Wischmeier *et al.*, 1971).

Texture (M) was calculated thus:

$$M = [(100 - \text{Ac}) (L + \text{Arm}f)] \quad \text{----- (4)}$$

where Ac is the percentage (%) of clay content ( $< 0.002 \text{ mm}$ ), L is the percentage (%) of silt content ( $0.002\text{--}0.05 \text{ mm}$ ) and Armf is the percentage (%) of very fine sand content ( $0.05\text{--}0.10 \text{ mm}$ ; Pérez-Rodríguez *et al.*, 2007).

Then, each 30 m cell of the grid surface of the study area was assigned a K value using a Kriging interpolation tool in the ArcGIS environment, in order to generate a K factor map of the area (Vaezi *et al.*, 2010; Yildirim and Erkal, 2013). Soil erodibility classes are shown in Table 2.

**Table 2** Soil erodibility classification

Class	Range (t ha <sup>-1</sup> MJ <sup>-1</sup> mm <sup>-1</sup> )
Low	0.10–0.20
Medium	0.24–0.32
High	0.37–0.49
Very high	0.49–0.64

**Source:** United States Department of Agricult (Wischmeier *et al.*, 1971)

*Slope gradient and length (LS) factor*

The LS factor is expressed as:

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

where  $\lambda$  is the slope length in meters,  $\theta$  is the slope in degrees, and  $m$  is a constant dependent on the value of the slope gradient: 0.5 if the percent slope is greater than or equal to 5%, 0.4 on slopes between 3.5% and 4.5%, 0.3 for slopes between 1% and 3%, and 0.2 for uniform gradients with slopes less than 1% (Wischmeier and Smith, 1978; Lu *et al.*, 2004).

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

$$LS = [\text{Flow accumulation} \times (\text{Cell size} / 22.13)]^{0.4} \times (\text{Sin slope} / 0.0896)^{1.3} \quad \text{----- (6)}$$

where LS is the combined slope length and slope steepness factor, the flow accumulation denotes the accumulated upslope contribution for a given cell, the cell size is the size of the grid cell (for this study 30 m) and the sin slope is a slope map whose degree values are in sine (Simms *et al.*, 2003). The values of S were directly derived from the 30 m resolution Digital Elevation Map (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*

The C factor is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow (Wischmeier and 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 values were inversed. An NDVI value is expressed using equation 7 below (Van der Knijff *et al.*, 2000):

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

where rNIR is the reflectance value in near infrared whereas rRed is the reflectance value of visible red band. After calculating NDVI, the C factor was estimated by applying equation 8 below (Zhou *et al.*, 2008; Kouli *et al.*, 2009):

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

where C is the calculated C factor, NDVI is the vegetation index, and  $\alpha$  and  $\beta$  are two scaling factors. Van der Knijff *et al.* (2000) suggest that by applying this relationship, better results than using a linear relationship can be obtained. The authors suggested values for the two scaling factors  $\alpha$  and  $\beta$  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 multispectral Landsat images covering the watershed area in the ArcGIS environment. The maximum likelihood classifier tool (MLC) algorithm of ArcGIS based on all the Land Sat bands was used to map the major land cover classes (Anejionu *et al.*, 2013). The C factor values of the watershed generated in the ArcGIS environment were used to determine the land use type as classified Landsat image. The C factor value generated from the multispectral Landsat images is assigned a land use term.

#### *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 upslope and down slope cultivation (Wischmeier and Smith, 1978). The values shown in Table 3 were used to reclassify the slope dataset to obtain the P factor for the study area. The predominant practice for the study area was known through the ground truth assessment and the values under this column were used for the reclassification (Anejionu *et al.*, 2013). To estimate the efficiency of contouring, stripping, and terracing management practice in reducing soil loss according to the Korea Institute of Construction Technology (1992) soil loss was calculated using

the RUSLE equation with the value of P for each practice (Table 3).

$$A = R \times K \times LS \times C \times P \text{ (contouring)} \quad \text{----- (9)}$$

$$A = R \times K \times LS \times C \times P \text{ (stripping)} \quad \text{----- (10)}$$

$$A = R \times K \times LS \times C \times P \text{ (terracing)} \quad \text{----- (11)}$$

where P is the management practice factor whose value is determined by the slope gradient and management practice established in the area to estimate soil loss. The efficiency of the management factor was derived by comparing the soil loss using contouring as against when management practices 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 in tons per hectare per year (A) in the watershed was estimated through the multiplication of all the corresponding USLE factors of the soil loss equation, by overlaying each factor data set in map algebra raster calculator tool in ArcGIS environment. The results were used to produce a map of potential soil erosion hazards of the watershed according to Anejionu *et al.* (2013). Using the reclassify tool in ArcGIS, the resulting map was reproduced into various risk classes (FAO, 1984) as shown in Table 4.

**Table 3** Support practice (P) factor depending on cultivation types and slope

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:** Korea Institute of Construction Technology (1992)

**Table 4** Categorization of soil loss risk

Erosion risk	Soil loss (t ha <sup>-1</sup> y <sup>-1</sup> )
Very low	≤ 2
Low	2–10
Moderate	10–50
High	50–100
Very high	> 100

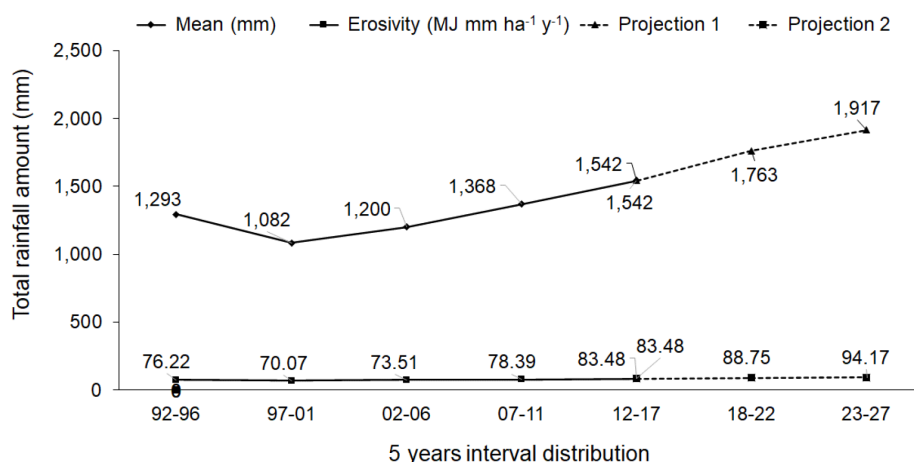
**Source:** Food and Agriculture Organization of the United Nations (1984)

## RESULTS AND DISCUSSION

### Rainfall Erosivity (R) Factor

The mean total rainfall amount and erosivity pattern of the Oke-Oyi dam watershed (1992–2017) are shown at 5-year intervals (Figure 5) as derived from Table 1. The result indicates about 50% rise in mean total rainfall amount from the periods 1997–2001 to 2012–2017 whereas erosivity of rainfall increased by 19% over the same periods. These increments observed in these rainfall parameters are evidence of climate change as a result of green-house gases emission from industries and other carbon emission sources (Al-Ansari, 2013). Erosivity values observed in the Oke-Oyi dam watershed were observed to be low when compared to the erosivity map scale (Panagos *et al.*, 2015). Therefore, the rate of soil loss is expected to be low when other factors contributing to soil loss (soil erodibility, slope-length and steepness factor,

cover factor, and support practice factor) are held constant. The sharp decrease (1992–2001) and increase (1997–2017) observed in the mean total rainfall of the study area did not similarly reflect the erosivity pattern for the period under consideration. This is thought to be due to the contribution of rainfall parameters other than amount, like drop size, intensity, and return period (de Carvalho *et al.*, 2005; Machado *et al.*, 2008) in the determination of erosivity. According to Hudson (1981), high rainfall may have high erosive power but the total erosivity is not directly proportional to the total amount of rainfall. Based on the rainfall pattern of the study area in the last two decades, mean total rainfall is projected to increase by 24% whereas erosivity will increase by 12% in the next decade (2018–2027) which will consequently increase soil loss if the present erosion control practice (contouring) is not substituted with a more responsive practice.

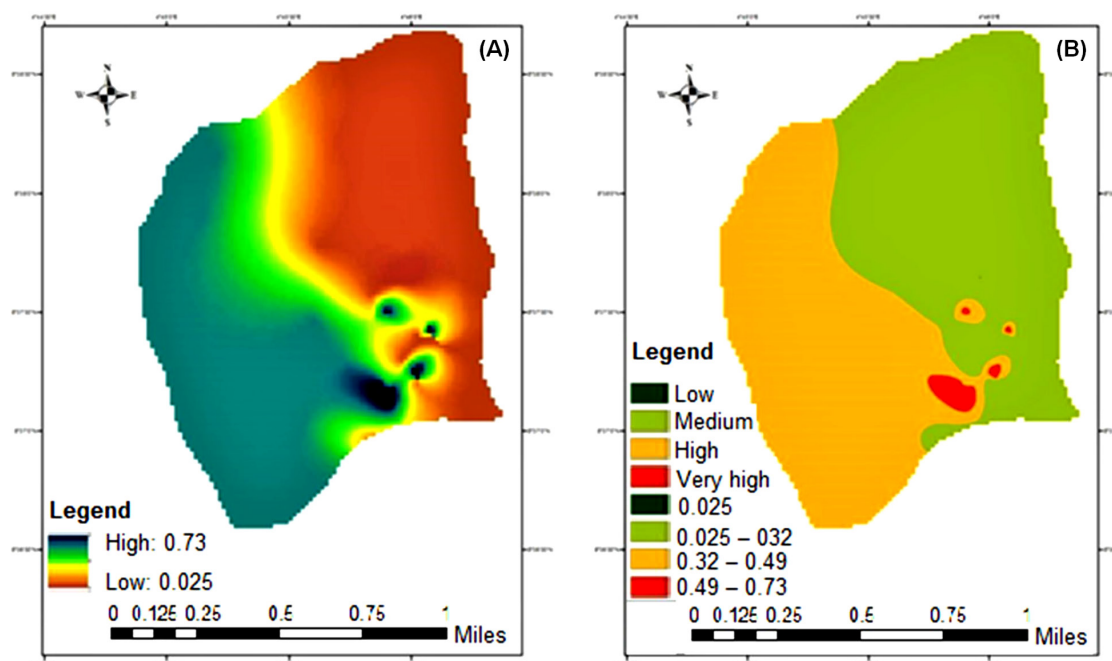


**Figure 5** Mean total rainfall amount and erosivity of the Oke-Oyi dam watershed

### Soil Erodibility (K) Factor

Soil erodibility rate in the Oke-Oyi dam watershed ranged from 0.025–0.73 t ha<sup>-1</sup>y<sup>-1</sup> (Figure 6A). These values ranged from low (0.061 ha and 0.008%), high (345.74 ha and 46.94%) to very high class (8.17 ha and 1.11%) as classified in Figure 6B according United States Department of Agriculture (Table 2), which implies that the ability of the soils in this area to withstand detachment varies because K is strongly related to the physical properties of the soil and plays an important role in soil conservation strategies (Shabani *et al.*, 2014) and also reflects the rate of soil loss per rainfall

erosivity index (Parveen and Kumar, 2012). Low erodibility means that the soil has high resistance to erosion whereas very high erodibility means the soil resistance to erosive agents is low. Particle size and organic matter are properties that majorly determine the erodibility of soil. Larger portions of the Oke-Oyi dam watershed fall in the medium and high erodibility class (due to inherently low organic matter content) which make the area prone to erosion. Organic matter content contributes to the resistance of soils to erosion as it helps in improving soil structure and hence reduces the erodibility of soil.



**Figure 6** Soil erodibility map (A) and classified soil erodibility map (B) of the Oke-Oyi dam watershed

### Slope Length and Steepness (LS) Factor

A slope map of the watershed is shown in Figure 7. The slope map indicated that the slope gradient in the Oke-Oyi dam watershed (Figure 8A) was comprised of seven (7) different classes. They were 0–0.5% (level), 0.5–2% (nearly level), 2–5% (very gentle slope), 5–9% (gentle slope), 9–15% (moderate slope), 15–30% (strong slope),

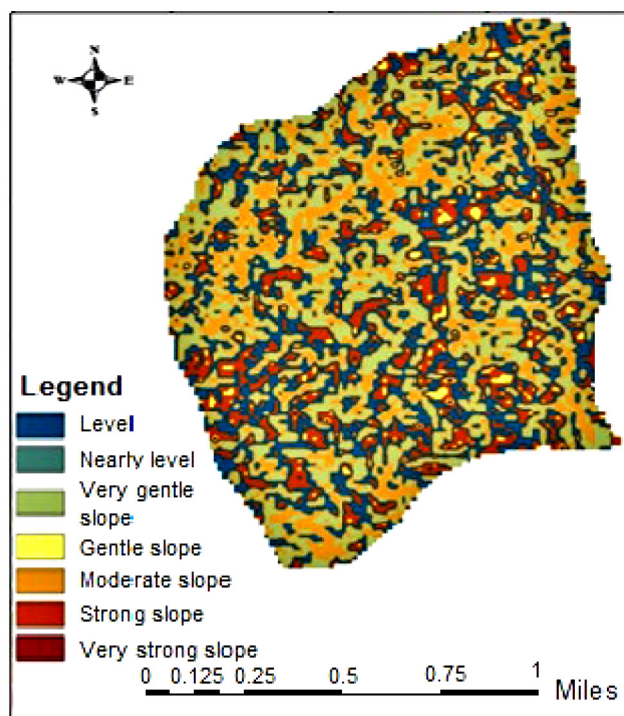
and 30–45% (very strong slope). A large portion of the watershed fell under the gentle and moderate slope class which occupied 32.44% (240.24 ha) and 31.23% (231.28 ha) respectively, whereas level, strong and very strong slopes occupied the smallest areas of 0.10% (0.75 ha), 13.47% (99.78 ha) and 0.11% (0.84 ha) of the watershed, respectively (Table 5).

**Table 5** Slope steepness and slope length data of the Oke-Oyi dam watershed

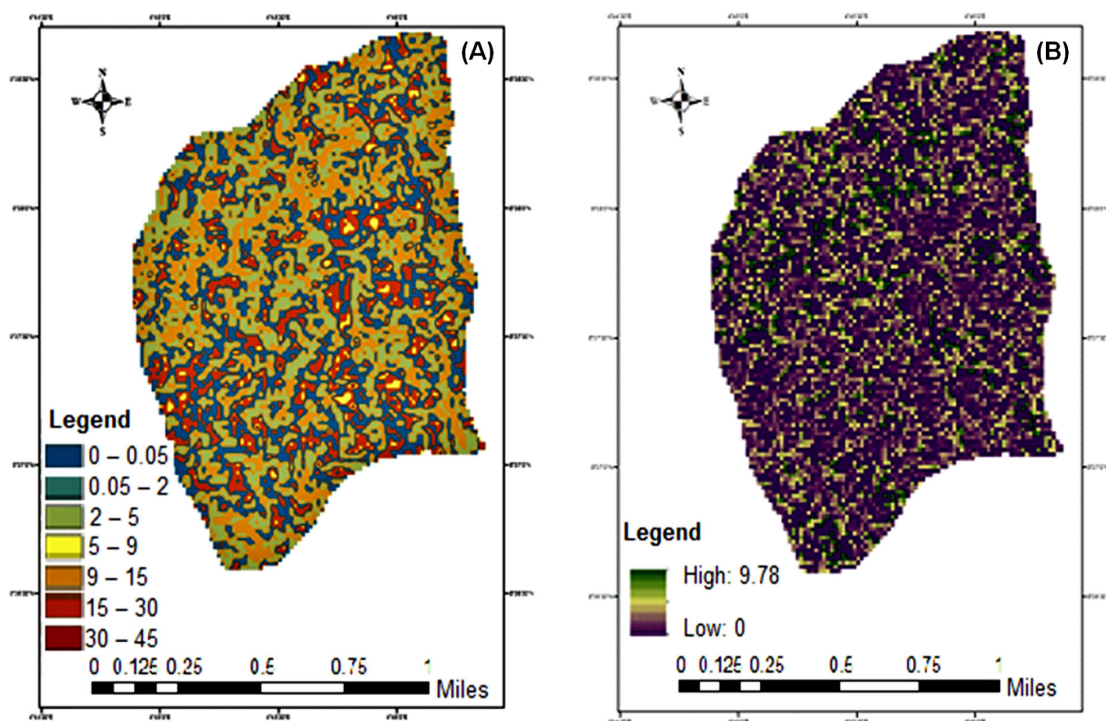
Slope class	Area (ha)	Coverage (%)
Level	0.75	0.10
Nearly level	29.91	4.04
Very gentle slope	137.69	18.59
Gentle slope	240.24	32.44
Moderate slope	231.28	31.23
Strong slope	99.78	13.47
Very strong slope	0.84	0.11

The slope length (LS) factor (Figure 8B) of the Oke-Oyi dam watershed ranged from 0–9.78 with a mean of 4.31. The LS factor is one of the factors that have the greatest impact on modeling soil loss (Ritchie and McHenry, 1990). Slope intervenes in erosion in terms of its form, gradient, length, and position. Steeper slope gradients will usually

correspond with higher soil loss due to water erosion. Therefore, the erosion hotspot of the Oke-Oyi dam watershed is expected to fall in the strong and very strong slope classes with less variation in other factors contributory to soil loss. Such areas will need urgent and improved management practices.



**Figure 7** Slope map of the Oke-Oyi dam watershed

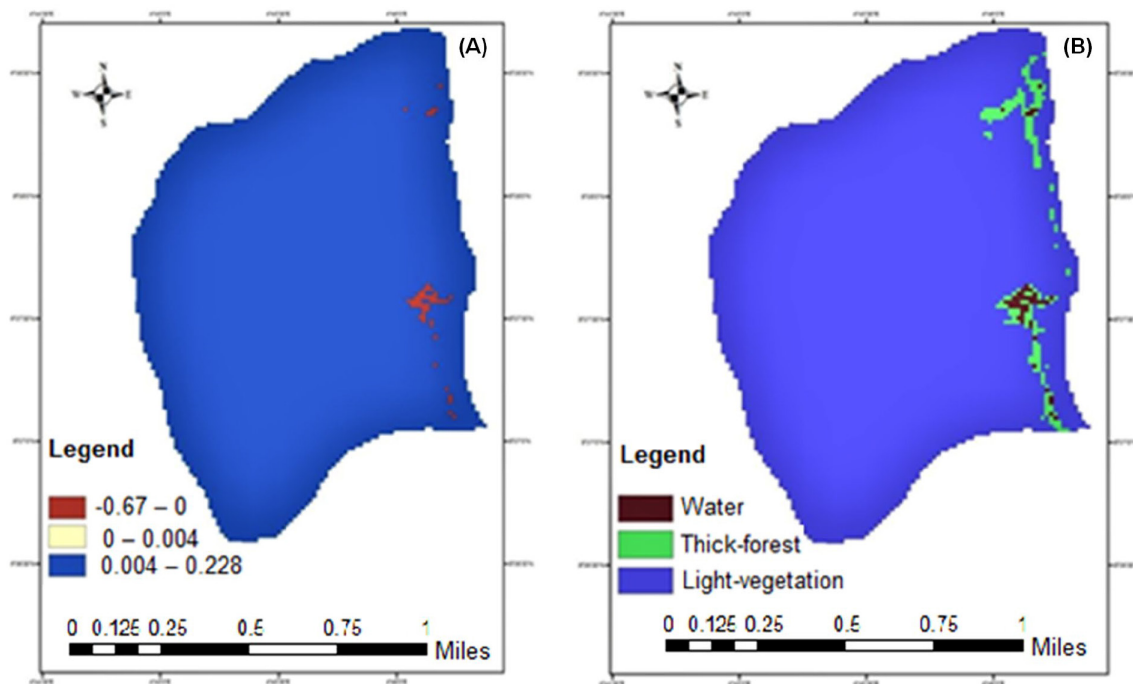


**Figure 8** Slope gradient map (A) and slope length and steepness factor map (B) of the Oke-Oyi dam watershed

**Cover Management (C) Factor**

Cover management factor values varied from -0.67 to 0.23 (Figure 9A) based on the classification of Lee and Lee (2006). The major land use and cover types (Figure 9B) of the watershed identified by supervised image classification of the ArcGIS software were water (-0.67 to 0) which covers 4.50 ha (0.62%) coverage, thick forest (0–0.004) covers 16.43 ha (2.27%), and light vegetation (0.004–0.23) 702.41 ha (97.11%), as shown in

Table 6. The C factor value of 0 indicates sufficient cover for the soil against erosion, and the protection reduces as the value increases to 1. This result implies that soils in this area are prone to the agent of erosions due to a larger portion of the area being light vegetation (0.004–0.23) 702.41 ha at 97.11% and consequently unable to provide enough cover over the soils of the watershed against agents of erosion such as raindrop.



**Figure 9** Cover factor map (A) and land use and land-cover map (B) of the Oke-Oyi dam watershed

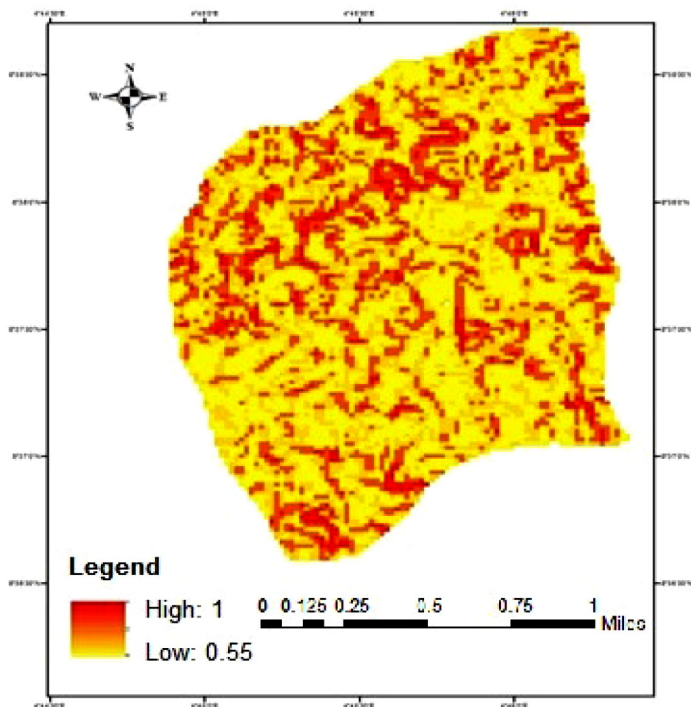
**Table 6** Cover factor, land use, and land cover data of the Oke-Oyi dam watershed

Class	Area (ha)	Coverage (%)
Thick forest	16.43	2.27
Water	4.50	0.62
Light vegetation	702.41	97.11

**Management Practice (P) Factor**

The P factor values of the Oke-Oyi dam watershed ranged from 0.55 to 1.00 (Figure 10). Values varied following slope classes occurring in the area. Areas with low P factor values as modified by slope gradient are expected to produce erosion hotspots, this is due to P factor modification of potential soil erosion by water runoff through the effects of contouring, strip cropping, and terraced contour farming (Wischmeier and Smith, 1978;

Kim and Julien, 2006; Kuok *et al.*, 2013). Contouring was observed to be the major erosion management technique used in the study area and this is likely to increase the chance of soil loss occurrence in the study area due to its comparatively higher score as shown in Table 3. This might be abated if terracing or strip-cropping management techniques with lower scores as shown in Table 3 are substituted for contouring.



**Figure 10** Support practice factor map of the Oke-Oyi dam watershed

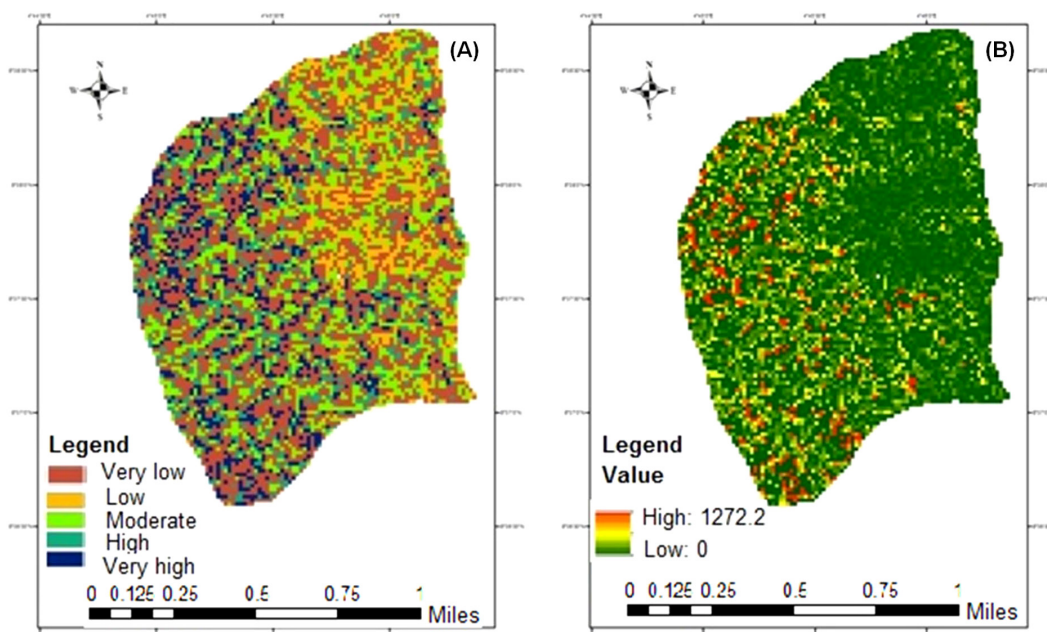
### Soil Loss

The potential annual soil loss of the Oke-Oyi dam watershed (Figures 11A–11B) was produced by overlaying the various maps computed for the five erosion parameters (R, K, LS, C, and P) using equation 1. The annual soil loss of the study area ranged from  $0 \text{ t ha}^{-1} \text{ y}^{-1}$  (areas under water) to  $1,272.2 \text{ t ha}^{-1} \text{ y}^{-1}$  (erosion hot spots). The rate of soil loss was classified following Table 4 with 46.85% (345.07 ha) of the area falling within the very low class, 7.48% (55.09 ha) in the low class, 23.23% (171.11 ha) in the moderate class, 11.20% (82.46 ha) in the high class and 11.24% (82.77 ha) in the

very high class (FAO, 1984) as shown in Table 7. About 78% of this watershed fell within the moderate to very low soil loss class (Table 7) due to adequate soil cover with less bare soil as observed in the high C factor values (Figure 9A). This condition of the surface protects the soil against impacting raindrops and subsequent transportation of detached soil particles. The dominance of moderate and gentle slopes in this area also contributed to the moderate to very low soil loss. Soil loss in about 23% of the watershed fell within the high to very high soil loss class due to the interaction of strong to very strong slope (Table 5) and high erodibility.

**Table 7** Soil loss of the Oke-Oyi dam water watershed

Class	Area (ha)	Coverage (%)
Very low	345.07	46.85
Low	55.09	7.48
Moderate	171.11	23.23
High	82.46	11.20
Very high	82.77	11.24



**Figure 11** Classified soil loss map (A) and soil loss map (B) of Oke-Oyi dam watershed

However, the total annual soil loss for the whole watershed is about 327,709.58 t ha<sup>-1</sup> y<sup>-1</sup> with a mean annual soil loss of about 1,310.84 t ha<sup>-1</sup> y<sup>-1</sup>. The mean annual soil loss observed in this watershed exceeds the maximum tolerable annual soil loss for a watershed set by FAO (1984) at 12 t ha<sup>-1</sup> y<sup>-1</sup> and the average annual soil loss set by Wischmeier and Smith (1978) at 112 t ha<sup>-1</sup> y<sup>-1</sup>. The mean annual soil loss estimate of this watershed (1,310.84 t ha<sup>-1</sup> y<sup>-1</sup>) was also found to be higher than 50–300 t ha<sup>-1</sup> y<sup>-1</sup> estimated by Mbagwu and Salako (1985) in South-Eastern Nigeria, 243 t ha<sup>-1</sup> y<sup>-1</sup> by Zeleke (2000) in North-Western

Ethiopia highlands and a weighted mean of 84 t ha<sup>-1</sup> y<sup>-1</sup> estimated by Selassie and Belay (2013) in North-Western Ethiopia highlands. Europe's environment assessment (European Environment Agency, 1998) considered that tolerable soil loss varies between different soil depths, types, and agro-climatic conditions. Though the study area has a comparatively lower rainfall than that of the South-Eastern part of Nigeria where Mbagwu and Salako (1985) obtained lower soil loss and poorer soil organic matter as a result of constant bush fire and dominance of low activity clays in the soils of the Southern Guinea Savannah (Ano and Agwu,

2005; Eifediyi *et al.*, 2017) is thought to have played a major role in the comparatively very high soil loss recorded in this study. Farmer's agricultural production is at risk if sustainable land use techniques are not urgently adopted. The idea of bush burning for vegetation regeneration for grazing animals and as part of land preparation should be discarded. Soil losses estimated by multiplying the factors of the RUSLE generated in one of the erosion hotspots of the Oke-Oyi dam watershed indicated

that contouring which is the dominant management practice in the study area was estimated to lose 630.73 t ha<sup>-1</sup> y<sup>-1</sup> (applying equation 9 as shown in equation 14) of soil whereas practices such as terracing and stripping were estimated to reduce soil loss in the erosion hotspot by 80% (126.15 t ha<sup>-1</sup> y<sup>-1</sup>) and 50% (315.40 t ha<sup>-1</sup> y<sup>-1</sup>) for terracing (applying equation 11 as shown in equation 12) and stripping (applying equation 10 as shown in equation 13) respectively.

$$A (\text{terracing}) = 83.48 \times 0.73 \times 45 \times 0.23 \times 0.2 = 126.15 \text{ t ha}^{-1} \text{ y}^{-1} \quad \text{----- (12)}$$

$$A (\text{stripping}) = 83.48 \times 0.73 \times 45 \times 0.23 \times 0.5 = 315.40 \text{ t ha}^{-1} \text{ y}^{-1} \quad \text{----- (13)}$$

$$A (\text{contouring}) = 83.48 \times 0.73 \times 45 \times 0.23 \times 1 = 630.73 \text{ t ha}^{-1} \text{ y}^{-1} \quad \text{----- (14)}$$

These results show that terracing is the best management practice that should be adopted in the study area to curb the menace of soil loss, especially against the backdrop of increasing total rainfall and erosivity projected for the next decade (Figure 5). However, an economic analysis of the two promising management practices revealed in this study (terracing and stripping) is necessary to recommend and influence farmer adoption, since most of the farmers are resource-poor.

## CONCLUSIONS

The potential soil loss rate per unit area of land annually in the Oke-Oyi dam watershed ranged between 0 and 1,272.2 t ha<sup>-1</sup> y<sup>-1</sup> whereas the total annual soil loss was estimated to be 327,709.58 t ha<sup>-1</sup> y<sup>-1</sup>. About 23% of the watershed

is experiencing high to very high soil loss and this falls above the tolerable limit of soil loss set by the FAO. The situation is expected to worsen in the next decade against the backdrop of increasing total annual rainfall and erosivity with attendant consequences on water supply and agricultural productivity for the immediate environment.

In areas where very high soil loss occurred, it was due to the interaction between slope and erodibility, however, conservation methods such as terracing and strip-cropping were found to reduce the impact of the slope thereby retarding transportation of soil particles. Therefore, economic analysis of the management practices coupled with strong advocacy to farmers and other stakeholders is needed for sustainable use of this watershed for crop production.

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