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Full Length Research Paper

An assessment of spatial analysis of erosion risk in Shafe watershed, Western Hills of Lake Abaya, South Western Ethiopia

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The study area is among the most affected parts of Ethiopian highlands that suffered from soil degradation of varying degrees, over grazing and siltation resulting from inappropriate land use practices, and historic settlement. This paper tried to predict rate of soil loss and regionalized erosion risk areas in intensive farming mountainous environment of Shafe watershed. Universal Soil Loss Equation (USLM) and Geographic Information Techniques (GIS) were used to map and estimate mean annual soil loss in the area. Laboratory analysis of soil revealed, except in the homestead plots, that total nitrogen and organic matter content of the soil was low and progressively decreasing from the homestead. Mean annual soil loss in the study area ranged between 0.04 t and 70 t ha^{-1} y^{-1}. Low to moderate erosion hazardous areas were found in south and central part, while high to severe erosion risk areas were concentrated in the intensively cultivated hilly northern localities. More than a third of the study watershed (32.8%) was categorized under high to severe erosion risk area with soil loss rate ranging between 30 t and 70 t ha^{-1} y^{-1}.

Key words: Watershed, soil erosion, universal soil, loss equation, geographic information system.

INTRODUCTION

Soil plays an important role in the ecosystems to provide diverse services necessary for human wellbeing. However, there has been a continuous deterioration of soil and depletion of land resources due to human beings’ mismanagement and misuse. Soil erosion here refers to detachment and transport of soil and soil material by water, wind, ice or gravity, where water and wind being the major factors. No substantial erosion is possible unless both detachment and transport processes are operative. In soil erosion by water, these processes are largely the result of raindrop splash, turbulence of moving water caused by raindrops and flowing water. Thus, soils that are most readily detached by raindrop splash erosion are fine sands and silt. Due to its greater weight and volume, coarser soil particles are less susceptible to erosion. As mentioned by Haile and Fetene (2012), fine textured soils such as clays and clay-loams are highly susceptible to detachment by erosive act of rainwater because of the strong forces of cohesion that keeps them aggregate.

The underlying cause for the excessive rate of soil loss in Ethiopia is over exploitation of land resource (forest cutting, overgrazing, expansion of cultivation into hilly and fragile environment, unwise land use practices, etc.) and this has become the main cause for low agricultural production which in turn resulted in structural food insecurity problem (Bewket, 2002; Amsalu et al., 2007). According to Bedadi (2004), in Ethiopia out of 60 million hectares of agriculturally productive lands, 45% are significantly eroded, 23.2% are seriously eroded and 3.3% have reached the point of no return, with an estimated soil loss of 2 billion m^2 top soil per annum. The same source further stated the average soil loss in the Ethiopian highlands as being 70 ha^{-1} y^{-1}. But the experiments conducted by Soil Conservation and Research Project in six fields in different agro-ecologies of Ethiopia (namely: Maybar, Hunde lafto, Andit Tid, Anjeleni and Dezi) reported the average annual soil loss

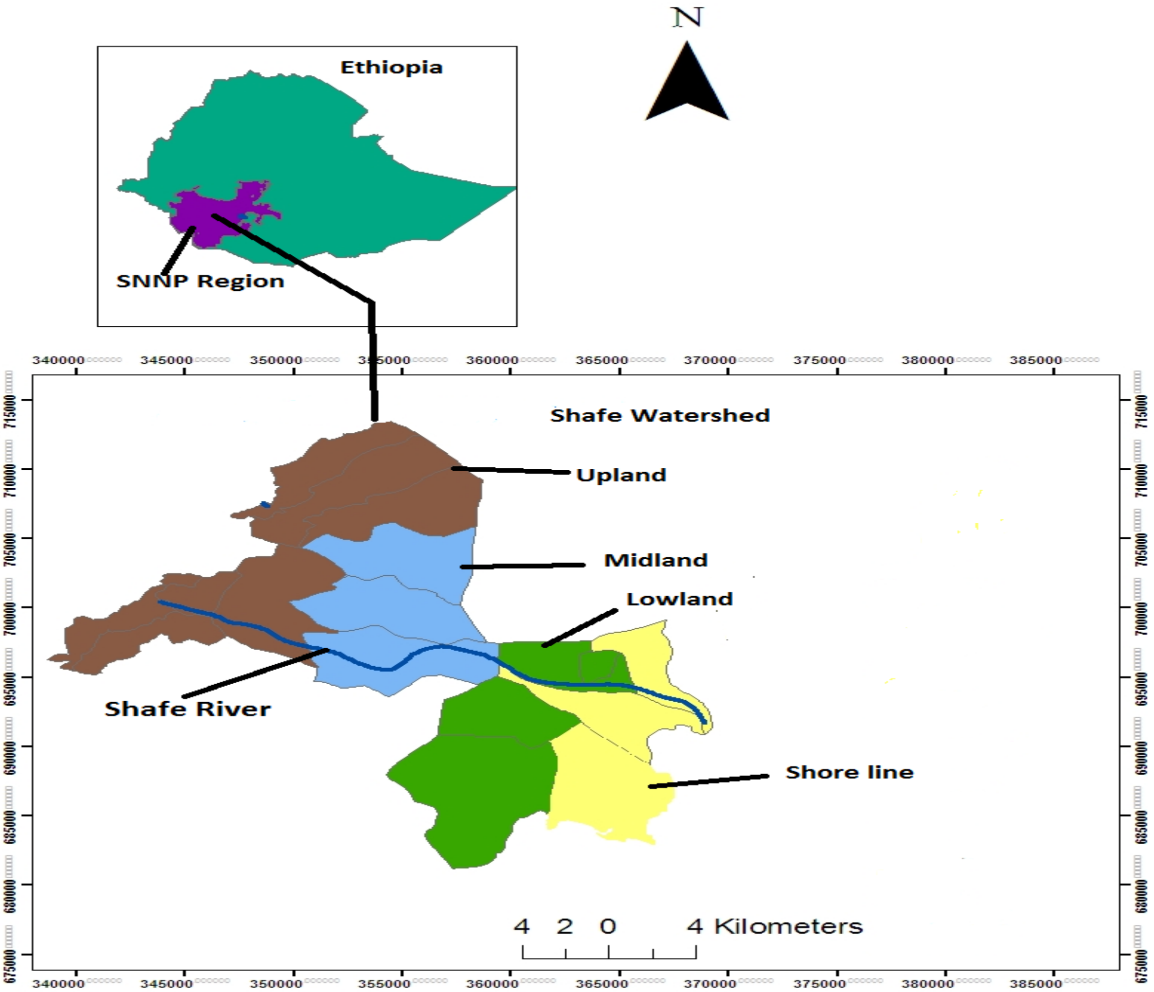

Figure 1. Location of Shafe watershed.

of 42 t ha^{-1} y^{-1} from cultivated land (Hurni, 1990). It is observed that 42 tons of annual soil loss from cultivated farmland is in excess of 11 tons ha^{-1} y^{-1}, from the permissible rate of annual soil loss (Montgomery, 2007). In the same scenario, empirical studies conducted by Belay (2002) in the neighboring locality of the study area (Gununo area) revealed the rate of soil loss from cultivated land as 64 t ha^{-1} y^{-1}.

Literature show that topographic characteristics of a given area such as slope, gradient length, and aspects determine the amount of run-off, its potential to cause erosion and loss of nutrients in the soil (Lal, 1994). A climatic factor such as rainfall amount is also an important factor that affects rainfall erosivity. Soil factors such as texture, structure, organic matter content, and permeability and land-use management systems are also important in deciding soil erodibility (Wischmeier and Smith, 1978). In addition, cover and management factors are also vital to estimate soil loss rate and regionalize erosion risk areas in a given watershed. To undertake effective soil and water conservation schemes in severely degraded and hilly terrain like the study area, the availability of spatial erosion risk map is highly beneficial. However, such types of spatial data are unavailable for the study area. Hence, this situation has initiated the researcher to undertake the study. The objective of the research is to examine spatial variation in erosion intensity and map various categories of vulnerable areas in Shafe watershed.

METHODOLOGY

Description of the study area

The study was conducted at Shafe watershed, Eastern Gamo highland, south western Ethiopia. It lies between 6° 15”N to 6° 20’ 00”N latitude and 37° 39’E to 370 50’ E longitude (Figure 1). It is dominated by rugged terrain (in the upstream) and volcanic Graben (in the downstream). Mean annual rainfall varies significantly throughout the

Table 1. Laboratory result of soil sample, Shafe watershed.

Basin	**Upland**			**Midland**			**Rift valley**		
Soil property	A	B	C	A	B	C	D	E	C
pH (H_2O)	4.87	5.74	5.36	6.92	6.38	6.9	7.47	7.78	10.08
Texture class	Clay	Clay	Clay	Clay loam	Clay loam	Sandy loam	Silt loam	Silt loam	Silt loam
OM	2.26	3.17	0.78	0.94	3.84	1.16	1.05	2.19	1.1
Total N (%)	0.07	0.10	0.05	0.06	0.10	0.09	0.06	0.07	0.06
Av. K	48.08	110.9	161.7	235.4	425.5	144.4	227.36	190.82	443.6
Av. P	27.22	47.84	40.7	52.3	235.6	41.8	46.8	65.23	94.16
CEC	42	46.99	44	38.61	38.15	38.15	34.57	37.22	38.89

Note: Code of the land use types: A = Barley; B = Enset (*Ensete ventricosum*); C = Grazing; D = Maize; and E = Banana.

watershed (840 mm to 1320 mm); similarly mean annual temperature also shows a great variation (between 14.6°C and 24.6°C). Remnant trees such as Arundinaria Alpina, Eucalyptus Globulus and Juniperus Procera in upland; Carissa Spinarum, Hagenia Abyssinica, and Syzygium Guineense in the midlands; and Carissa Spinarum, Dodonaea Viscosa, Entada Abyssinica, Acacia Albida, Albizia Malocophylla and Aloe Vera along the shores of Lake Abaya are the dominant tree species grown.

Cambisols and Nitosols in the upstream, and Fluvisols in the downstream are the principal soil types. Laboratory soil analysis revealed that there was a significant variation in pH reaction (4.87 and 10.08 in upland and lowland respectively) throughout the watershed. Similarly, due to soil clay nature and high organic matter content of soil, the cation exchange capacity (CEC) in the soil was found to be high in all land use types, which ranged between 34.57 meq/100 g and 46.99 meq/100 g (Table 1). According to Kjeldah method (used for nitrogen determination in soil), rating of the total nitrogen content in the study area was classified as low. But organic matter content in Enset and Banana fields was found to be high as compared to other land use types. The analysis showed that the available phosphorus in barley and enset fields was 27.22 and 235.6 ppm respectively. A study by Morgan (2005) suggested that when available phosphorus in the soil is less than 7 ppm, it should be supplemented with phosphorus fertilizer. Based on Morgans' findings, all land use types have sufficient amount of available phosphorus in the soil.

The population of Shafe watershed was about 52,441; with 2.7% current growth rate, it is expected to double by 2048. Per capita landholding in the upstream was less than 0.25 ha, without alternative source of income one can imagine the impact of growing population on fragile land resource after 36 years. In the study area, the livelihood of the people is basically agricultural (farming mixed with livestock rearing), but off farm activities are also carried out during the off farming seasons. In the watershed, perennial trees cover a significant portion (23.7%) of cultivated land. Thus, of perennial crops, Ensete Ventricosum in the upland, and Musa Mesta and Mangifera Indica in the lowland are an important source of food and cash income. But due to climatic variability, farmland exhaustion, and absence of supplementary means of income (35.3%) of the total population are food insecure.

Data sources and methods of acquisition

In the study, both primary and secondary data were utilized. The primary data were generated through four main tools such as satellite imageries and topographic maps, soil samples, and focus group discussion. In addition, secondary sources such as climatic and demographic data were also used. Data on slope angle, and length were derived from topographic map (1:50,000) and contour lines of various heights were digitized and computerized in GIS environment for preparing terrain elevation model (TEM), which was used to determine slope length (L) and slope steepness (S) factors, while satellite imagery (Landsat ETMA acquired in February 2006 with path 168 and row 054) was used to develop land use/cover map and to determine crop management (C factor), and conservation practices (P factor). In addition, field visit was undertaken to identify the obscured features, crop management practices and final output verification of the land use. Composite soil samples were collected from varying land use/cover types of three agro-ecologies. Sample soils were collected from 30 cm depth of each auger points by using auger and Geographic Position System (GPS). In this case, 120 samples were collected and dried, and ground for laboratory analysis for its physical and chemical properties (Tables 1 and 3). Rainfall data (1998-2012) of two stations (Chencha and Mirab Abaya) were collected from the respective meteorological station for computation of rainfall erosivity (R factor) in the USLE.

Method

To assess annual mean soil loss and delineate erosion hazardous areas in Shafe watershed, Universal Soil Loss

Table 2. Mean annual rainfall and rainfall erosivity factor.

Name of the station	Mean annual rainfall (mm)	R-factor
Chencha	110.6	54.04
Mirab Abaya	66.6	29.31

Table 3. Soil properties and their respective mean erodibility factor values.

Soil characteristics	Upland (summit)	Midland	Lowland
Silt (%)	26.4	43.7	64.9
Very fine sand (%)	12.5	26	21.2
Clay (%)	61.2	30.3	13.8
Organic matter	2.1	0.94	1.1
Structure	4	4	3
Permeability	5	4	2
K value	0.145	0.126	0.081

Equation (USLE) together with Remote Sensing and Geographic Information System (GIS) were used. Literature has confirmed the importance of USLE to estimate mean annual soil loss rate in original or modified form (Wischmeier and Smith, 1978). The use of GIS has further enabled its application to predict soil loss rate for large areas satisfactorily and to map erosion risk areas in the watershed (Mellerowcz et al., 1994; Bewket and Tereri, 2009). USLE model was computed using the formula:

$A = R*K*L*S*C*P$ (tons per hectare per year)

where, A is calculated annual soil loss (tonne/ha/year), R is rainfall erosivity, K is soil erodibility factor, S is slope steepness factor, L is slope length factor, C is cropping and management factor, and P is conservation practice factor.

Factors used in USLE prediction

Rainfall erosivity (R) factor

Rainfall Erosivity (R) is defined as detachment and transportation of soil due to raindrop impact and runoff, primarily depends on the intensity and the amount of rainfall. The term 'rain erosivity index' was used in the universal soil loss equation to describe the influence of rainfall in rain erosion. In order to calculate R-value, the researcher used the modified formula and adapted to the Ethiopian conditions (Hurni, 1985a). Accordingly, $R= -8.12+ (0.562 * P)$ where; R is rainfall erosivity factor and P is mean annual precipitation (mm). Thus, the estimated value of erosivity for the upland and low land was 54.04 and 29.31, respectively (Table 2). Then these data were converted to a surface grid of 30 m cell size using ArcGIS, taking R-factor as the value for cell as presented in Figure 2.

Soil erodibility (K) factor

Soil erodibility factor, K is a quantitative description of the inherent resistance to particle detachment (degradation) and transport by rainfall and runoff (erosion). Erodibility strongly depended on the structural stability of the soil and its ability to absorb rainfall. Thus, it is largely dependent upon texture, structure, and organic matter, permeability and land-use management systems, and erodibility ranged between 0.02 and 0.69 (Goldman et al., 1986). Soil erodibility factor for different mapping units was calculated using the formula by Wischmeier and Smith (1978) and fed into Arc GIS for regionalizing it on the map. Accordingly, K factor = $(27.66/ m^{1.14} * 10\text{-}8 (12\text{-}a)) + (0.0043 * (b\text{-}2)) + (0.0033 * (c\text{-}3))$, in which K = soil erodibility factor ($t\_ha^{-1}\_MJ^{-1}\_mm^{-1}$); m = (silt (%) + very fine sand (%)) (100-clay (%)); a = organic matter (%); b = structure code: (1) very structured or particulate, (2) fairly structured, (3) slightly structured and (4) solid (Adapted from c = profile permeability code: (1) rapid, (2) moderate to rapid, (3) moderate, (4) moderate to slow, (5) slow and (6) very slow. The mean K factor value in the study area was 0.118. It is high in the north and central parts as compared to the southern margin of the study area (Table 3). Thus, according to Wismeir and Smith's factor class in the study area, it is considered to be at a very high erodibility index, which is greater than 0.066 t*ha/MJ*mm. After assigning K factors for different mapping units in the watershed, the constructed map was converted to a grid map of 30 m cell size taking K factors as values for the cells (Figure 3).

Topographic factor (LS)

Within the USLE, the LS factor reflects the effect of

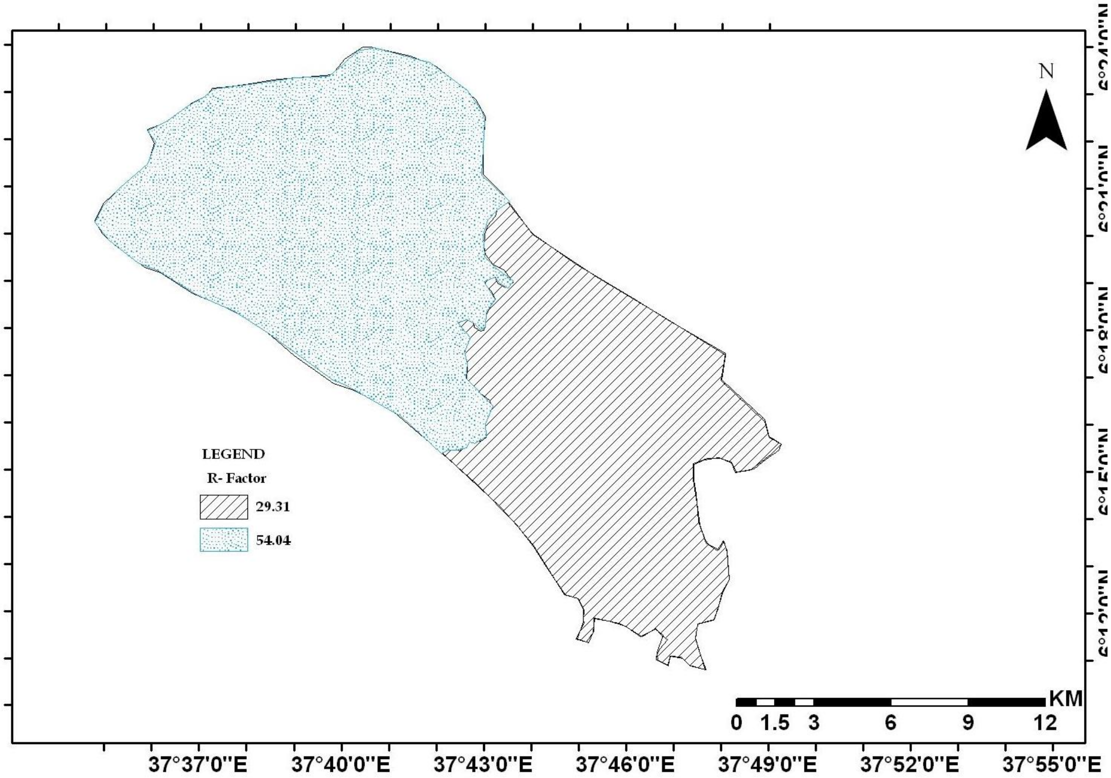

Figure 2. R-factor map of Shafe watershed.

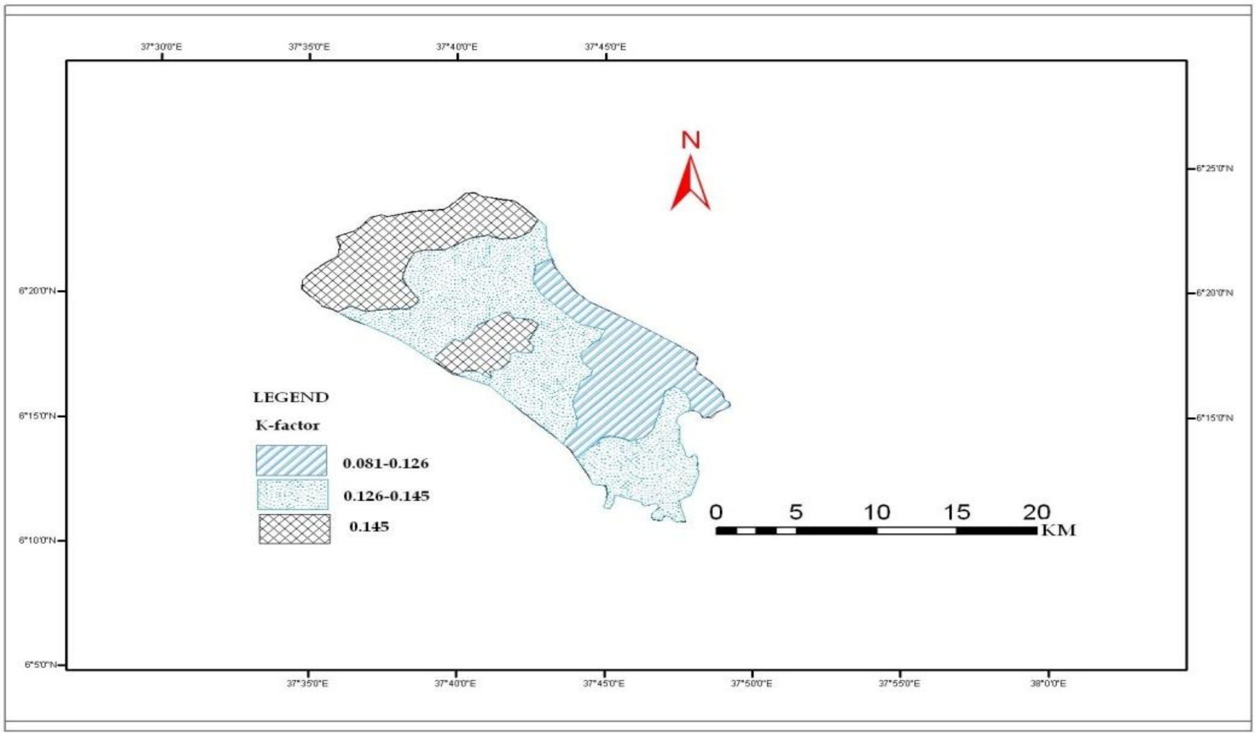

Figure 3. K-factor map of Shafe watershed.

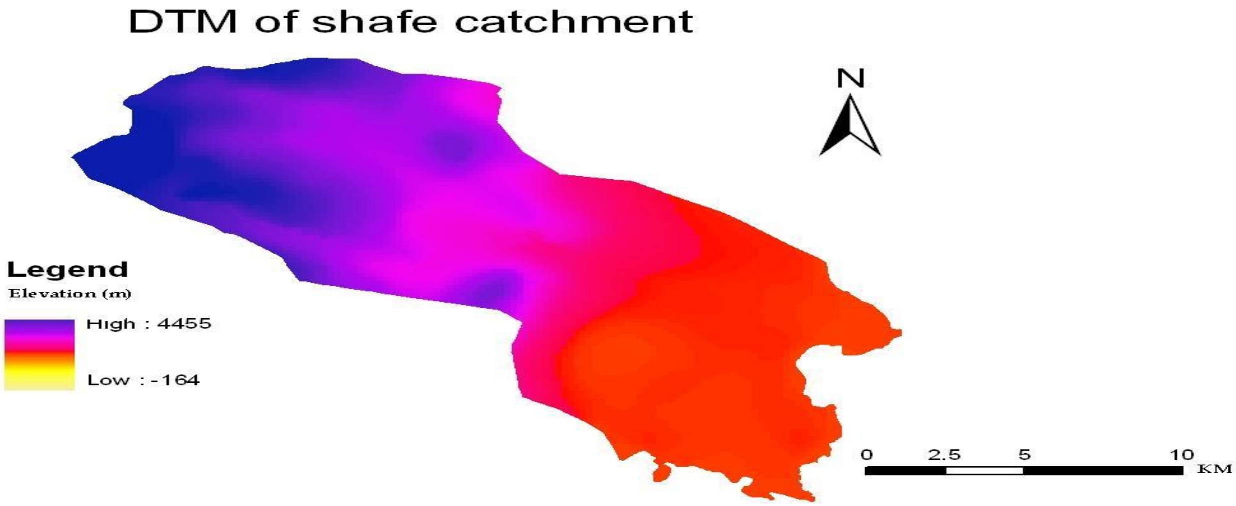

Figure 4. Digital terrain model of Shafe watershed.

topography on erosion, the slope length factor (L) represents the effect of slope length on erosion, and the slope steepness factor (S) reflects the influence of slope gradient on erosion (Lu et al., 2004). L and S factors were generated from Digital Terrain Model (Figure 4) developed from topo sheets of the study area. Topo sheets with the scale 1:50,000 were digitized to develop elevation information drainage network and boundary of the study watershed. In determining slope length (L) factor, the researcher used the formula after Moore and Wilson (1992):

$L = (\lambda/22.13)^m$

where λ is the projected horizontal distance in meters between the onset of runoff and the point where the runoff enters the channel larger than a rill or deposition occurring, and m is an exponent that depends on slope steepness. The exponent is 0.5 for slope greater than 5%, 0.4 for slopes ranging from 3-5%, 0.3 for slopes ranging from 1-3% and 0.2 for slopes less than 1%. Then slope length (L- factor) was obtained from digital terrain model using ArcGIS as presented in Figure 5.

It can be ascertained that 41.7% of the study area is under steep gradient. On the steep terrain, due to the effect of gravity, water moves more rapidly with little time to infiltrate and got much more force to erode the soil particles. In computing the S-factor, the researcher used the formula by Moore and Wilson (1992):

$S = (0.065 + 0.045 + 0.0065x^2)$

Where S is the steepness factor and x represents the slope in percent.

In Arc GIS system, slope gradient map of 30 m grid cell size was developed from DTM of the study area. Then S-factor values after Wischmeier and Smith (1978) that was modified to the Ethiopian situation were assigned to each slope gradient classes (Table 4) and S-factor map prepared as presented in Figure 6.

Land cover (C) factor

In presentation of land-use and land-cover map, Remote Sensing and Geographic Information Systems have been efficient and powerful tools in providing reliable information on natural resource classification and mapping of land-cover changes over space and time. Using Arc GIS software, different land-use/cover classes of the study area were identified based on image characteristics like tone, texture, size, shape, pattern and location. In addition, field check was conducted with the help of Topo sheet and GPS to identify the ground truth. Then image elements were corrected based on the ground checks. Accordingly, the identified land use/cover classes were: Bush land, Enset land (Ensete ventricosum) and Banana land (Musa Mesta), degraded grass, open woodland, cereal fields, dense settlement and bare land. These land use/ cover classes were assigned with its corresponding C-factor value (Hurni, 1985a) to develop C-factor map as shown in Table 5 and Figure 7.

Conservation practice (P) factor

In the study area, people use conservation measures for two main reasons: first, to control soil erosion and second, to maintain soil fertility. The improvement measures of soil erosion have strongly been taken up and widely spread over the densely populated upstream areas, while in the downstream areas, the practices are comparatively less pronounced as the people have

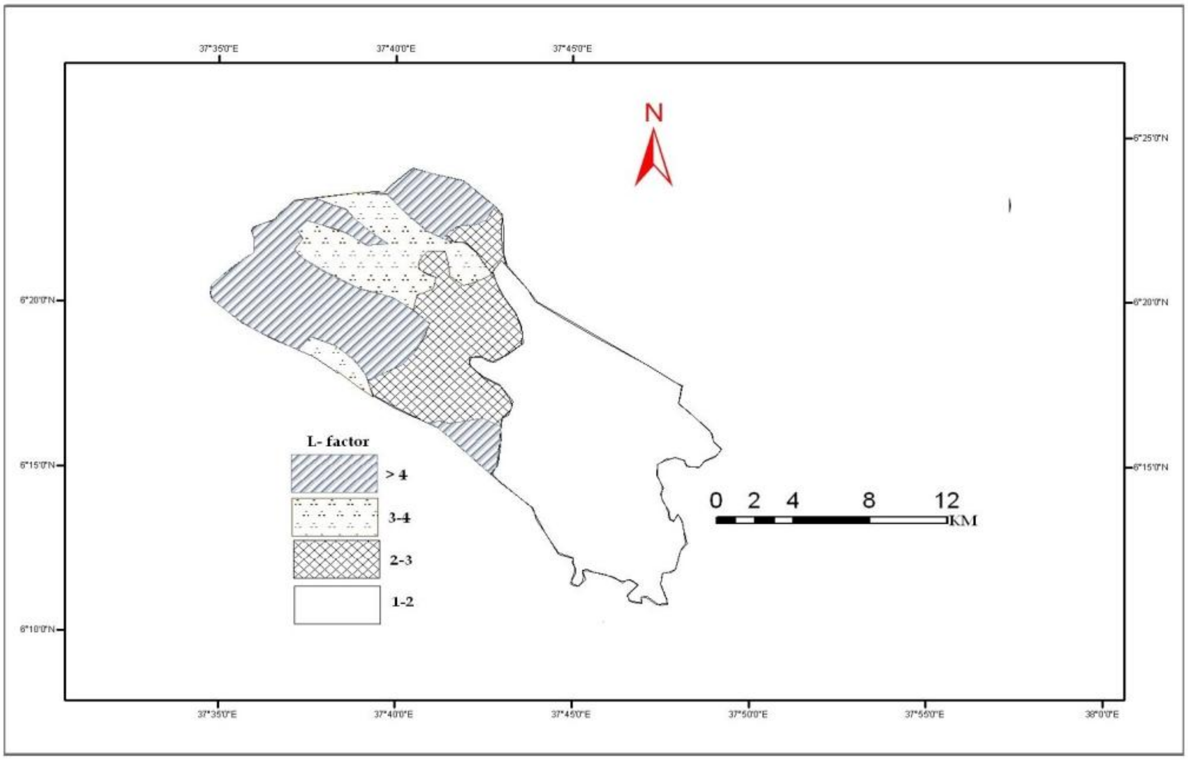

Figure 5. Slope length (L) factor map of Shafe watershed.

Table 4. Slope gradient of Shafe watershed.

Slope class	Slope (in percent)	S-factor
1	5	0.4
2	10	1.0
3	15	1.6
4	20	2.2
5	> 30	3.0 and above

access to potentially productive agricultural land.

The techniques that were practiced to control soil erosion in the study area among others included contour ridging, check dams, earth terraces, and agro forestry. In determining P-factor, two land use classes namely agricultural and others and their slopes were used (Wischmeier and Smith, 1978). Based on slope gradients of land use types, P-factor map was prepared (Table 6 and Figure 8).

In regionalizing soil erosion risk map of Shafe watershed, each layers of USLE parameter were converted into a 30 × 30 m grid cell size. Then annual soil loss rate was computed by multiplying values of USLE variables (soil erosivity, erodibility, slope length and gradients, land use and management practices) in GIS system on a pixel by pixel basis using USLE equation.

RESULTS AND DISCUSSION

Regionalization of erosion hazards area

In the study area, mean annual soil loss rate ranged between 0.04 t and 70 t ha^{-1} y^{-1} (Table 7 and Figure 9). The finding is incomparable with the study conducted in the immediate localities of Shafe watershed (Belay, 2002). Belay in Gununo locality identified annual mean soil loss rate between 48 t and 80 t ha^{-1} y^{-1}.

Spatially, almost a quarter (26.2%) of the study watershed was exposed to minimum erosion risk with an annual mean soil loss ranging from 0.04 - 10 t ha^{-1} y^{-1}. Soil loss estimate was in line with Morgan's (2005) findings. Morgan regarded annual soil loss of less than 11 t ha^{-1} y^{-1} as tolerable for tropical soils; however

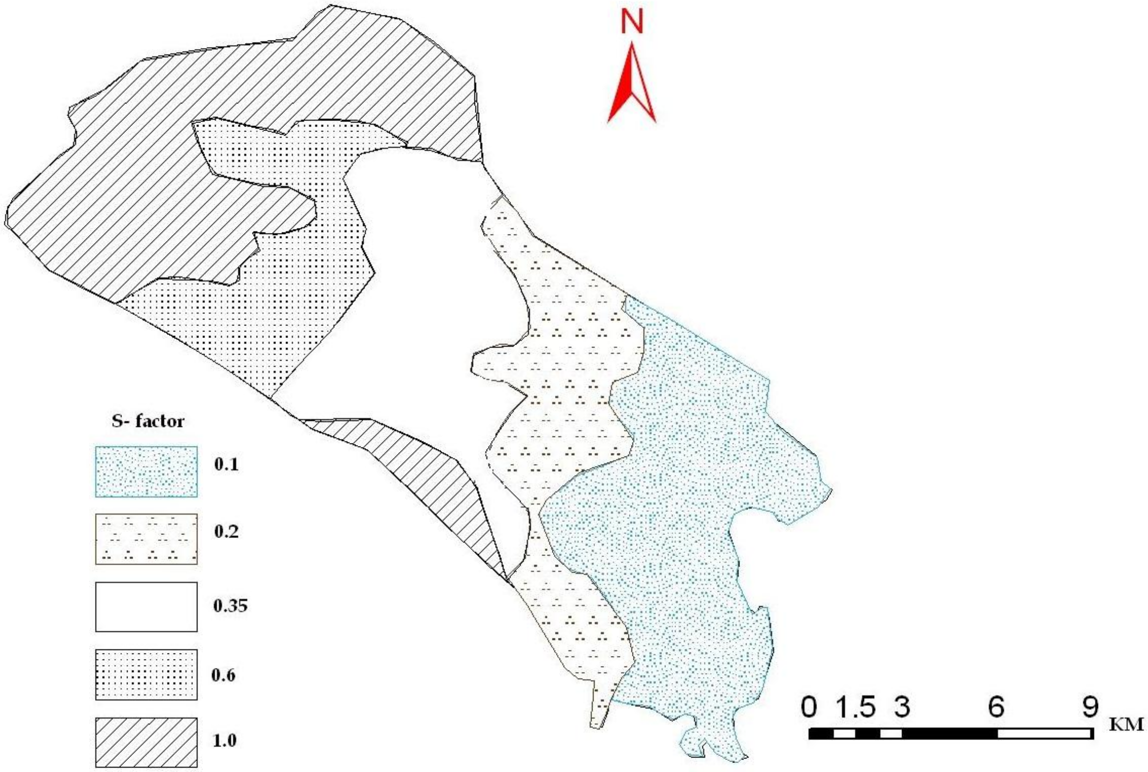

Figure 6. Slope gradient (S) factor map of Shafe.

Table 5. C-factor for varying land use/cover classes.

Land use/cover	C-factor value
Enset/Banana land	0.01
Bush/Shrub land	0.01
Degraded land	0.05
Open woodland	0.06
Maize land	0.10
Cereals	0.15
Dense settlement	0.15
Bare land	0.6

according to Hudson (1981), it may be as low as 2 t ha^{-1} y^{-1} in sensitive areas. Due to fruit cultivation and vegetation cover, the southern part of the study area was classified under minimum erosion risk category. But in some localities, a significant portion of Banana farms (more than 150 ha) were inundated by gravels and sediments brought by River Shafe (Figure 10). Thus, upstream degradation due to improper farming practices and riverine deforestation exacerbated siltation, increased turbidity of water and disturbed shore ecology by affecting aquatic life at the shore of Lake Abaya.

Hence, to rehabilitate the degraded environment, soil and water conservation measures such as gully treatment and reforestation programs in the upstream, and flood control measures like construction of stone dykes and limiting shoreline farming practices are recommended interventions. In central and north-western part of the study area, mean annual soil loss was estimated to be moderate, that is, between 20 and 30 t ha^{-1} y^{-1}.

On the other hand, as seen in Table 7, high to severe erosion risk (30-70 t ha^{-1} y^{-1}) was found in the upstream areas. This part shared a significant portion (94.4%) of the total soil loss. This may be related to the hilly nature and erodible volcanic soil of the area. High to severe erosion risk area which was found in northern and central part covered a significant part of the study area (42.2%) but it contributed less than 2% of the total soil loss in the watershed.

As revealed in Table 8, the estimated mean annual soil loss for each of the four land-use/covers at 30° slopes ranged between 0.04 and 52.9 t ha^{-1} y^{-1} (on enset and barley fields respectively). The result compares well with the studies of Hurni (1985b), who in the northern highlands of Ethiopia estimated an annual soil loss rate of 1 and 42 t ha^{-1} y^{-1} on perennial and cereal fields, respectively.

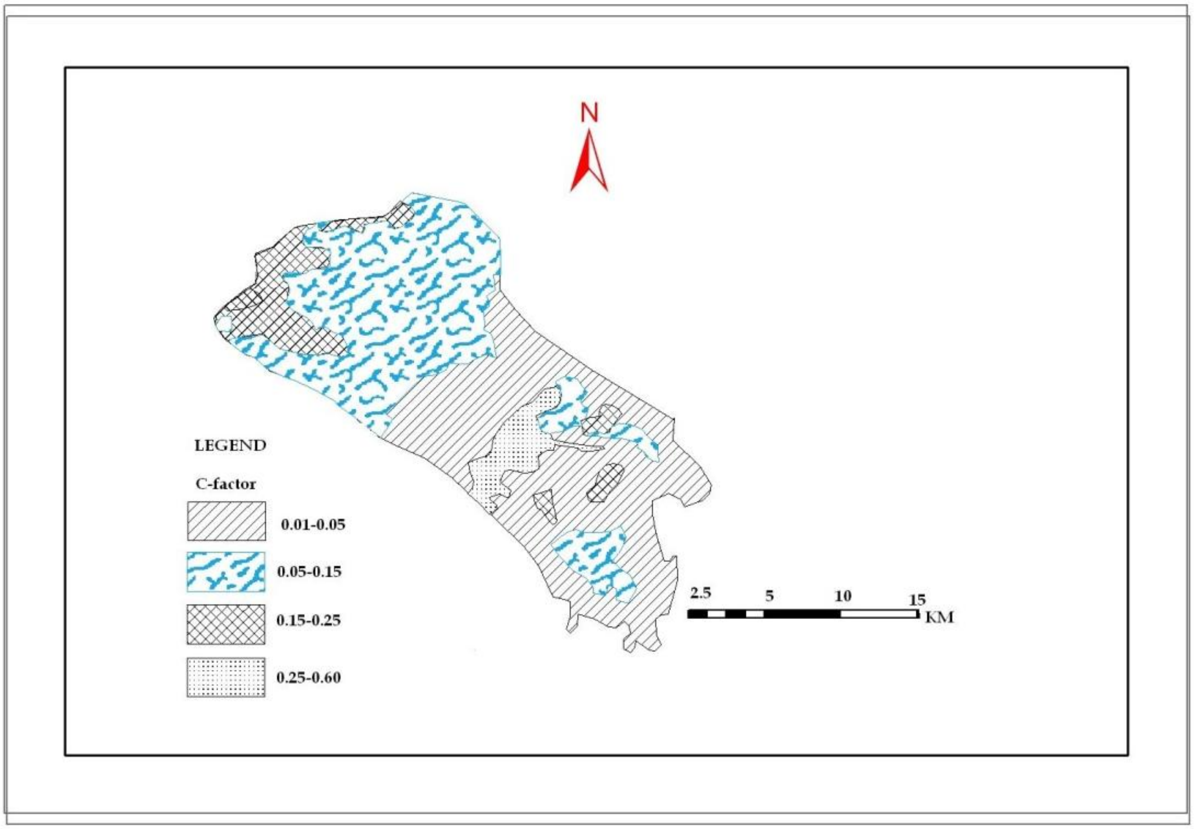

Figure 7. Cover (C) factor map of Shafe watershed.

Table 6. Conservation practice (P) factor.

Land use type	Slope (%)	P- factor
Cultivated land	0 – 5	0.1
	5 – 10	0.12
	10 – 20	0.14
	20 – 30	0.19
	30 – 50	0.25
	50 – 100	0.33
Other land covers	All	1.00

The plot level data in Enset and Banana plots showed minimum rate (0.04 and 0.06 t ha-1 y-1 respectively) compared to Hurni's estimate. On cereal farm, the model estimated high level of soil loss rate than the mean soil generation rate (6 t ha $^{-1}$ y^{-1}) as estimated by Hurni (1983) for the Ethiopian highland. Further analysis of soil data at varying slopes (53 and 30% gradients) of barley fields revealed variable soil loss rate, which is 52.9 t and 26.6 t ha^{-1} y^{-1}, respectively.

According to Tolcha (1999), an area with soil loss rate more than 30 t ha^{-1} y^{-1} needs conservation measure; in this regard, barley field and grazing land with slope gradient exceeding 30°C requires further management practices.

Conclusion

Inappropriate farming practice, over grazing and soil erosion in the upstream, and siltation in the downstream put the potentials of fertile soil of the study area at risk. Though, some inaccuracies are expected in the quantitative predictions of USLE model and GIS techniques, the model was helpful in assessing erosion hazardous areas in the study area which was useful for

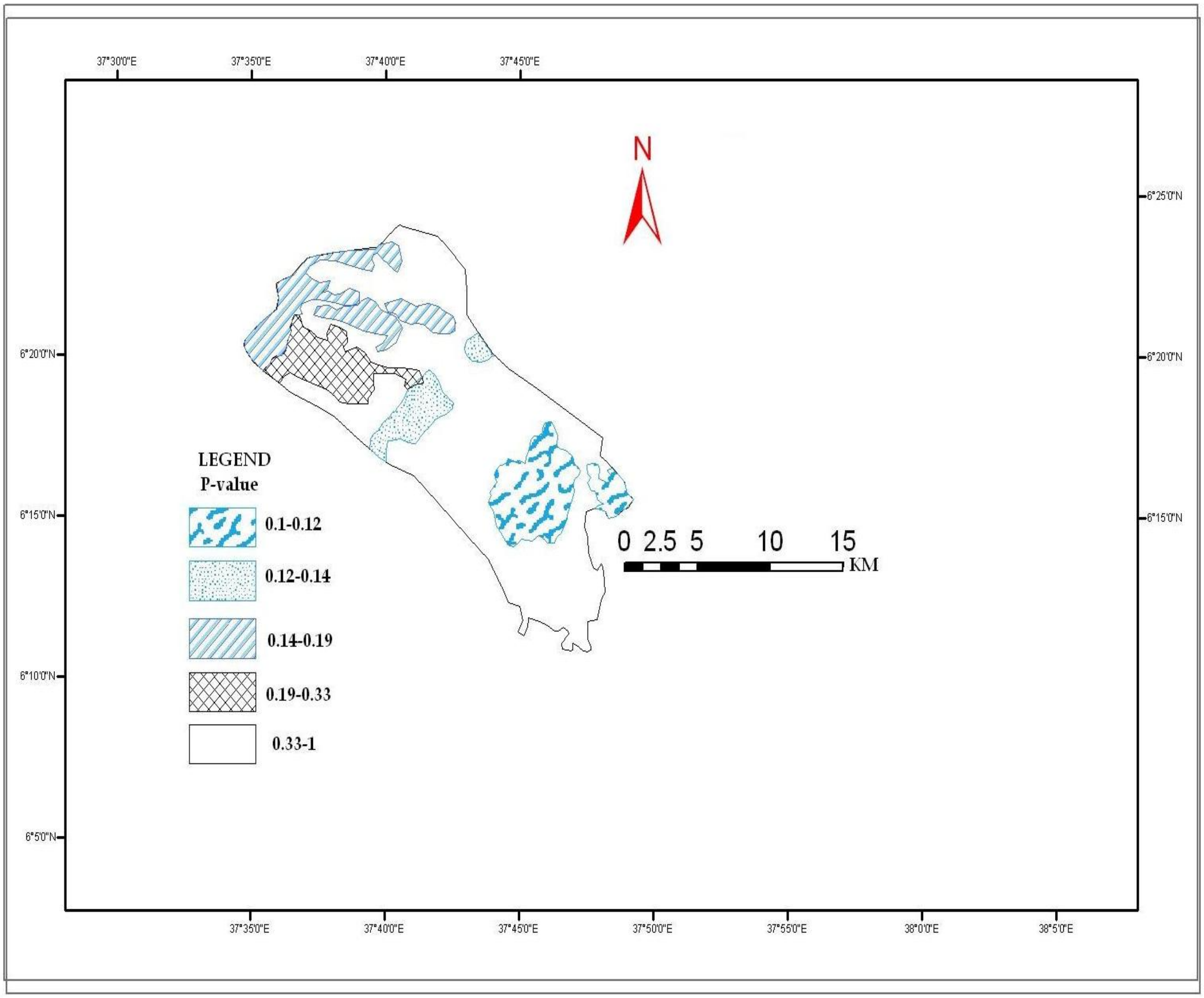

Figure 8. Conservation (P) factor map of Shafe watershed.

Table 7. Soil erosion in erosion categories of Shafe watershed.

Erosion category	Numeric range ($t/h^{-1}/y^{-1}$)	Area (ha)	Area (%)	Loss rate (x 10^4 t/y^{-1})	Soil loss (%)
Minimal	0 - 5	7213	26.2	1.8	0.4
Low	5 – 20	4434	16.0	5.9	1.3
Moderate	20 – 30	6875	25.0	17.2	3.9
High	30 – 50	2913	10.6	51.6	11.7
Extreme	> 50	6107	22.2	366	82.7
Total		27,542	100	442.5	100

providing evidence for rehabilitation planning and sustainable land management interventions. Thus, in further studies, attention should be given to plot level sediment load measurement to reach into more

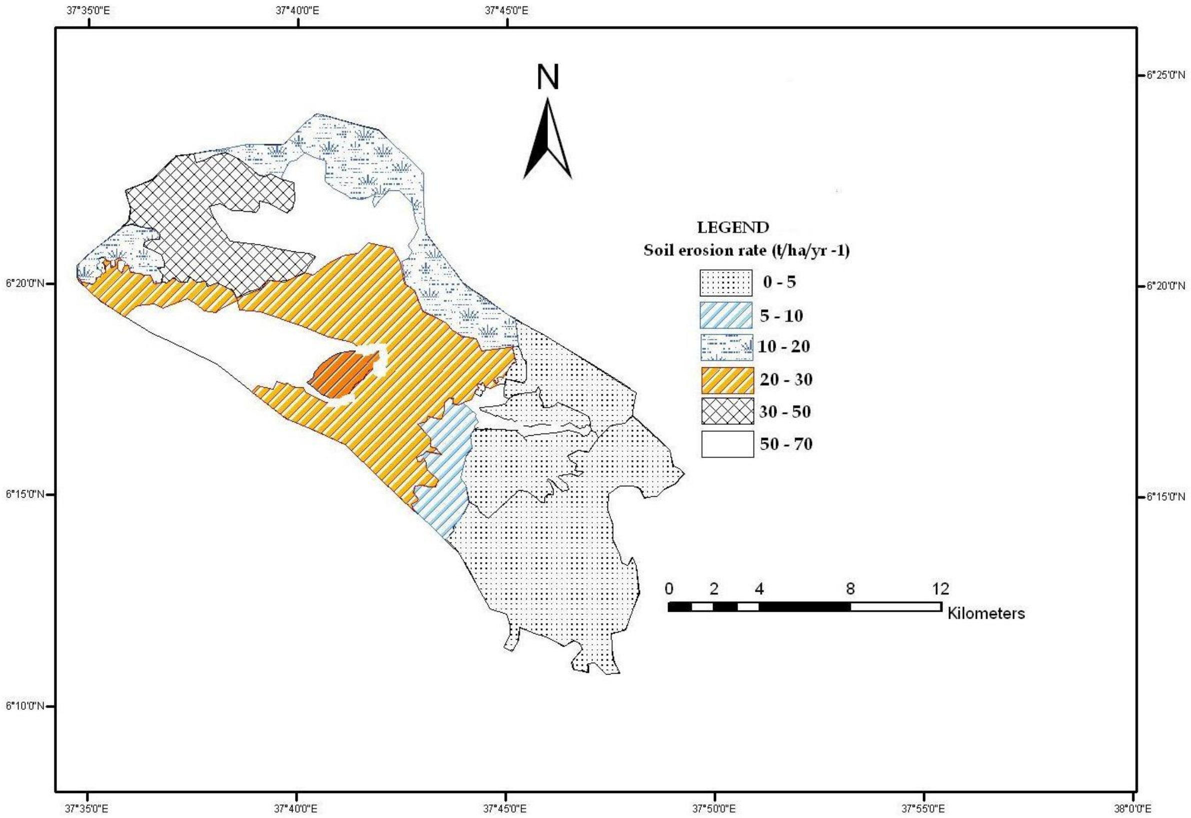

Figure 9. Mean annual soil loss rate, Shafe watershed.

Figure 10. Inundation of sediments on Banana farm, Ankober PA, Shafe watershed.

Table 8. Rate of soil loss in varying land use/covers.

Land use/cover type	Slope gradient in percent	Erosion rate (tone/ha/y)
Enset field	30	0.04
Barley field	53	52.9
Barley field	30	26.6
Grazing land	50	49.5
Banana field	6.7	0.06
Bush/ticket land	8.3	2.4
Maize field	25	7.0

meaningful soil loss prediction. In general, gully treatment and reforestation schemes in the upland and flood control measures in the down streams needs immediate intervention.

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