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Comparison of Measured and Derived Topographic Factor Values for Soil Loss Estimation

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Abstract
One of the inputs for the Revised Universal Soil Loss Equation (RUSLE) is the topographic factors specifically slope gradient and length derived from Digital Elevation Model (DEM). However, the accuracy of the derived data was not estimated. Therefore, this study was conducted in Quashay watershed, Northwestern Ethiopia to compare the topographic factor of slope length and gradient derived from Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) DEM with measured value for soil loss estimation. DEM data were downloaded from reliable sources and other slope length and gradient data were measured from the field. Statistical Product and Services Solutions version 20 was used to analyze measured and derived values. The result shows no significant difference between measured and derived slope length and gradient ($p>0.05$).Therefore, I conclude that the topographic data derived from ASTER DEM can be used as an input for soil loss estimation.
Keywords: ASTERDEM, Slope length and gradient, soil loss, RUSLE, Ethiopia.

1. Introduction
We all know that soil is a key element of agriculture. Without it we wouldn´t be able to grow plants, which are used as food for both humans and animals. Contemporary soil erosion is a natural geological phenomenon resulting from the removal of soil particles by water or wind (Gitas *et al.* 2009). This natural process can be accelerated by human activities creating soil loss that exceeds the soil formation rate in a given area. Human activities that change land use from a comparatively higher form of permanent vegetation cover to a state of lesser vegetation cover, have increased soil erosion (Cebecauer and Hofierka 2008).

Due to this reason soil erosion is a problem in many parts of the world (DeGraaff *et al.* 2008). Soil erosion due to water remains a problem in Europe (Wauters *et al.* 2010), the Mid west of America (Zhou *et al.* 2009), Latin America (Kessler 2006; Posthumous and Stoosijder 2010), in Africa (Tenge *et al.* 2005), and China (Heerink*et al.* 2009). Worldwide, soil erosion losses are highest in Asia, Africa, and South America, averaging 30 to 40 t/ha/yr (GirmaTaddesse 2001). Worldwide, 80% of agricultural land suffers from moderate (10 to 20 t/ha/yr) to severe soil loss greater than 20 t/ha/yr (Pimentel 2006). The soil erosion hazard was much higher for annual cropland compared to other land use types (World Bank, 2006). Thus, soil erosion clearly threatens agricultural sustainability as it harms the structure and nutrient content of soils (Posthumus and Stroosnijder 2010).

Once occurred, soil erosion affects the physical environment particularly soil fertility and productivity and reducing the cropland available for food production. Soil erosion might adversely affect land productivity (Pimentel 2006), and disturb soil and water resources and ecosystem services (Bayramin *et al.* 2002). It is a major threat to biodiversity, ecological sustainability, and ecosystem stability (Pendleton 2007) and it interrupts the regulating and provisioning services of ecosystems, such as nutrient cycling,the global carbon cycle and the hydrological cycle (MulatieMekonen *et al.* 2015).

In developing countries, soil erosion is a serious problem on small farms particularly on marginal lands where the soil quality is poor and the topography is steep (Pimentel 2006). Soil erosion has become the main environmental problems all over the world particularly in the third world countries including Africa (World Bank 2006), due to inappropriate land use practices and deforestation (Bayramin *et al.* 2002).

Estimating soil loss rate plays a great role in the decision making and to recommend soil and water conservation measures for hot spot area. To predict and evaluate soil erosion problem models which are the simplification of reality have effectively been developed and employed. Many erosion models such as

Universal Soil Loss Equation, Areal Nonpoint Source Watershed Environment Response Simulator (Beasley *et al.* 1980), Water Erosion Prediction project (Flanagan and Nearing 1995), Kinematic Runoff and Erosion Model(Woolhiser *et al.*1990), Revised Morgan Morgan Finny (Pohlman,1993),Soil and Water Assessment (Arnold *et al.*1998), European Soil Erosion Model (Morgan *et al.*1998), Chemical And Erosion from Agricultural Management Systems, Soil Loss Estimator for Southern Africa, Griffith University Erosion Sedimentation System, the Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE)were developed and used over the years to estimate annual soil loss and to develop optimal soil erosion management plans.

Among these models, Universal Soil Loss Equation model and its derivative, the RUSLE are commonly used throughout the world to estimate average annual soil loss per unit land area resulting from rill and sheet (interrill) erosion, to assess soil erosion risk, and to guide development and conservation plans in order to control erosion under different land-cover conditions, such as croplands, rangelands, and disturbed forest lands (Lu *et al.* 2004; Prasannakumar *et al.* 2012; Ganasri and Ramesh 2015).

When using the USLE or RUSLE, five component factors rainfall erosivity (R), soil Erodiability (K), slope factors (LS), land cover factors(C) and management practices (P) that are multiplied together are required to calculate the average annual soil loss per unit area. Topographic factors refer to the slope length and slope steepness factors which expresses the ratio of soil loss from field slope length and the field slope gradient (Robert and Hilborn 2000). The local slope gradient (S) influences flow velocity and thus the rate of soil erosion while slope length (L) describes the distance between the origin and termination of inter-rill processes that deposition starts (Renard *et al,* 1997). Increasing in slope steepness and slope length can accelerate erosion rate as a result of respective increases in velocity and volume of surface runoff (Doere 2005).

The data used for estimating soil loss using RUSLE can be measured or estimated from sample plot data, which may affect the result because the limited plots may not provide reliable data for covering large areas. Currently the combination of GIS and remote sensing enables for the interpolation and estimation of the factors used in RUSLE on a cell by cell basis, which can be defined by the spatial resolution of the image or by the researcher, covering large areas with reliable data and with reasonable cost (Lu *et al.* 2004). This makes soil erosion estimation on a cell-by-cell basis and on each land cover/use and allows researcher to map the spatial distribution of soil erosion risk and to identify the spatial patterns of soil loss present within a large region, which is the interest of land managers and policy makers. The combination of GIS and RUSLE can then be used to isolate the exact locations where high amount of soil loss occurs and also the factor contributing to estimated soil loss.

Conventional methods can be used to measure topographic factors (LS); however, it is expensive and time consuming. Currently, the RUSLE integrated with GIS and remote sensing is widely used to predict slope length and slope steepness and also it spatial extent because of its speed and accuracy (Bayramin *et al.*. 2002). In the study area slope length and slope steepness was not studied not only conventional but also using GIS and remote sensing techniques.

Therefore, this study aimed to compare topographic factors using measured and derived values from digital elevation model combined with Geographic Information System (GIS) and remote sensing techniques.

2. Materials and method

2.1. Description of the study area

The study was conducted in Quashay micro-watershed Burie District, West *Gojjam* Zone of Amhara National Regional State, Northwest Ethiopia. The study area covers 327 hectare, lies between 10°45'0" to 10°46'0" N and 37°3'0" to 37°4'0"E.

2.2. Required Data Inputs

(a) Measured slope length and slope steepness

From the four land use/cover types, a total of 94 randomly distributed points (30, 18, 28 and 18 points from grazing, settlement; cultivated and forest land use/cover, respectively) were selected. The methodologies were designing by a field plot of 6 treatments with 5 replicate, 3 treatments with 6 replicate, 7 treatments with 4 replicate, 6 treatments with 3 replicate from grazing, settlement, cultivated and forest land use/cover, respectively.

Slope length and steepness data were collected from the field as follows: after classifying the study area into homogeneous land unit. The slope length were measured as follows: first, the study area was divided into 16 land unit classes (Figure. 2); second, in each land unit the land use types were identified; third, 16 land units (6 grazing land, 3 settlement area, 4 cultivated land and 3 forest land) were randomly selected; fourth, from the selected land unit ground distance was measured horizontally from origin of runoff point to deposition point; and fifth, from the selected land unit slope were measured over 10meter distance in the direction of perceived maximum slope with 1.5meter width of field plot. After collecting slope length data during field measurement the slope length of the study area were interpolated using tabulated values of slope length with its (L) factor values (Wischmeier and Smith 1978) and adopted for Ethiopian conditions (Hurni 1985).

(b) Derived slope length and slope

A digital elevation model (DEM) with 30-meter resolution developed by NASA was implemented for analyzing the slope length and slope gradient of the study area. The LS factor can be generated from DEM. Therefore the LS factor for the study area is the ratio of soil loss per unit area from a field slopes to that from a 22.13m length of uniform 9 percent slope under otherwise identical conditions (Wischmeier and Smith 1978). Deriving slope by geographic information system (GIS) benefit a wide range of environmental models because slope attributes are frequently needed as input for landslides, land planning and construction, and others (Dunn and Hickey

1998). The shortcomings of slope length calculation can be solved by using the cumulative uphill length from each cell which accounts for convergent flow paths and depositional areas during the use of the Universal Soil Loss Equation (Hickey 2000). Similarly, LS factor in the RUSLE are measures of the sediment transport capacity of the flow (Moore and Wilson 1992).

In USLE and RUSLE, the method of slope length calculation was with the notion of the longer the slope the higher the soil loss without considering the three dimensional complex nature of terrain (Robert and Hilborn 2000).

Slope length and steepness were determined using ASTER DEM 30m resolution. ASTER DEM was used because it is provided for free (http://earthexploler.gov).Slope steepness can be estimated using neighbourhood, quadratic surface, maximum slope, and maximum downhill slope techniques (Dunn and Hickey 1998). For small watershed, the slope length and gradient factor can be measured from the field, which is labour intensive and thus not feasible for estimating LS factor at large size watershed. To solve this problem, a computer program that could generate a grid LS factor from DEM was developed (Wischmeier and Smith 1978).

Slope length and slope steepness factor of the study area was computed using equation (1 and 3) in spatial analyst tool by raster calculator in map algebra.

$$L = 0.799 + (0.0101 * \text{Flow accumulation}) \quad (1)$$

The slope gradient factor of the watershed was computed in spatial analyst tool using raster calculator in map algebra

$$S = 0.344 + (0.0798 * \text{Slope}) \quad (2)$$

Where; L and S for slope length and slope gradient factor

To create (LS) raster as one layer for RUSLE, the researcher compute (LS) factor as one factor using equation (3) in spatial analyst tool using raster calculator in map algebra. LS-factor was computed in Arc GIS raster calculator using the map algebra expression in equation (3) suggested by (Mitasova and Mitas 1999; and Simms *et al.*2003).

$$LS = \text{Power} [(\text{Flow Accumulation}) * \text{cell size} / 22.13]^{0.6} * \text{power} [(\sin (\text{slope} * 0.01745) / 0.09)]^{1.3} \quad (3)$$

Where: 0.01745 is $\pi/180$ and these were used to convert slope in degrees to radians,
0.09 is the slope gradient constant,
n is 1.3, which is an adjustable value depending on the slope,
m is 0.6, which is an adjustable value depending on the slope effect to erosion, for slope more than 5%, m is 0.6, which is the ratio of soil loss from rill to inter-rill
22.13 is the unit plot length, Flow accumulation is the number of cells contributing to flow in to a given cell and derived from the DEM after conducting fill from flow direction processes in ArcGIS,
Cell size is the size of the cells being used in the grid based representation of the landscape; it is spatial resolution of DEM. i.e.30m*30m resolution in ASTER DEM and
Slope is the gradient of the study area in degree.

This study was therefore used the above modified approach of determining slope length and gradient (LS) factor. The values of S were directly derived from 30-meter resolution DEM. Similarly, flow accumulation was derived from the DEM after conducting Fill and Flow Direction processes in ArcGIS 10.2 in line with Arc Hydro tool. Flow accumulation grid represents number of grid cells that are contributing for down ward flow and cell size represents 30m*30m contributing area.

2.3. Statistical analysis

Chi-square test and Paired samples (T-test) method were used for comparison of measured L, S with derived LS value from RUSLE model in SPSS version20. RUSLE model analysis was used for generating topographic factor (LS) using Arc GIS10.2.

3. Results and discussions

To evaluate the measured and derived slope length and gradient, the paired T-test, a parametric procedure which is useful for testing whether the means of two groups (predicted aligned with measured LS) values are different where the samples were drawn in pairs. The measured and derived LS value was used for paired sample analysis.

3.1. Derived slope length (L) value

As slope length and gradient increases total soil eroded and soil loss per unit area may increase due to the progressive accumulation of runoff in the down slope direction.The minimum and the maximum slope length (L) value of the study area was 0.8 and 23m (Figure.3) using equation2.

3.2. Derived topographic factor (LS) value
The slope class of the study area was six classes (1: 0-2%, 2-8%, 8-15%, 15-30%, 30-50%, and 50-63%) with area coverage of 2%, 20%34%, 38%, 5% and 1%, respectively. In RUSLE slope length and slope gradient factors are considered as a single index value and it was used as an input layer for soil loss estimation. The topographic component of RUSLE was computed using equation (4) suggested by (Moore and Bruch 1985; Mitasova and Mitas 1999; and Simms *et al.*2003). Slope length was substituted by upslope contributing area so as to take in to account the flow convergence, and divergence in a three dimensional complex terrain condition. Thus, the upstream contributing factor and slope angle were considered in the aforementioned method of slope length and gradient factor estimation. Therefore, in this study it was generated once within a short time by using equation (3). As shown in Figure.4 the LS factor ranged from 0 to 4. The higer th LS value the more vulnerable to soil erosion. The river bank of the watershed recorded as high LS value.As a result , the LS factor of RUSLE extends from 0 in the lower part of the watershed to 4 in the steepest slope upper part of the watershed. This implies that, the influence of the combined slope length steepness (LS) for soil loss is significant in the upper part of the watershed. On the oterhand, the topographic (slope length gradient) factor contribute less impact for soil erosion in the lower and middle part of the watershed (Figure.4).

3.3. Measured slope length (L) and gradient (S) value
Four land use/cover type within 16 land unit were identified in the field observation. Slope length (L), which is the distance between the start of runoff to a position where deposition happen, was taken from field measurements among the land cover types. Representative slope lengths from each land cover types and in various topographical terrains were measured and recorded during field work. The slope length of grazing land was between (14.68m to 21.23m), Settlement (16.63m to 21.54m), cultivated land (14.23m to 19.57m). Based on the analysis the minimum and maximum slope and slope gradient and S factor in the study area based on land use unit was 4.35%, 56.5% and 0.35, 4.68, respectively. As shown in Table 1 there is a significant variation of slope gradient within grazing and settlements land unit while no significant variation of slope gradient within forest and cultivated land unit.

In four landuse/cover type, we found an overall trend of significantly difference slope gradient among land use ($p < 0.05$). As shown in Table 4 there is no significant variation between measured from the field and derived slope length and slope gradient from Ethiopian DEM of the watershed. This result indicates derived LS from modeling of slope and flow accumulation is the best and precise method by using Arc GIS 10.2 and remote sensing technique within a short time and less cost than measuring topographic factor and assigning based on Ethiopian condition.

4. Conclusions
This study shows that there is no significant variation between measured and derived slope length and slope gradient from ASTER DEM. Labor-intensive field measurements are obviously not feasible for modeling soil erosion on a regional scale. Therefore, ASTER DEM can be used as a reliable data source for slope gradient and slope length factor generation for topographic factor derivation where the study area has a slope class of between 0 to 63%.

Based on the result areas characterized by maximum slope class should be given special priority to reduce or control the rate of soil erosion by means of conservation planning. On the other hand, the management of moderate slope class should be to protect them from further erosion, vegetation degradation and removal should be stabilizing through plantations and soil management practices. The study demonstrates DEM together with GIS and RS provides great advantage to derive LS factor over areas. The parameter values of the topographic factors are site specific and need to be standardized for the specific area to enable reasonable prediction of the of topographic factors (LS). Similar researches needed to be implemented to identify the accuracy of measured and derived topographic factors value in different part of the country based on land unit.

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Author's biography

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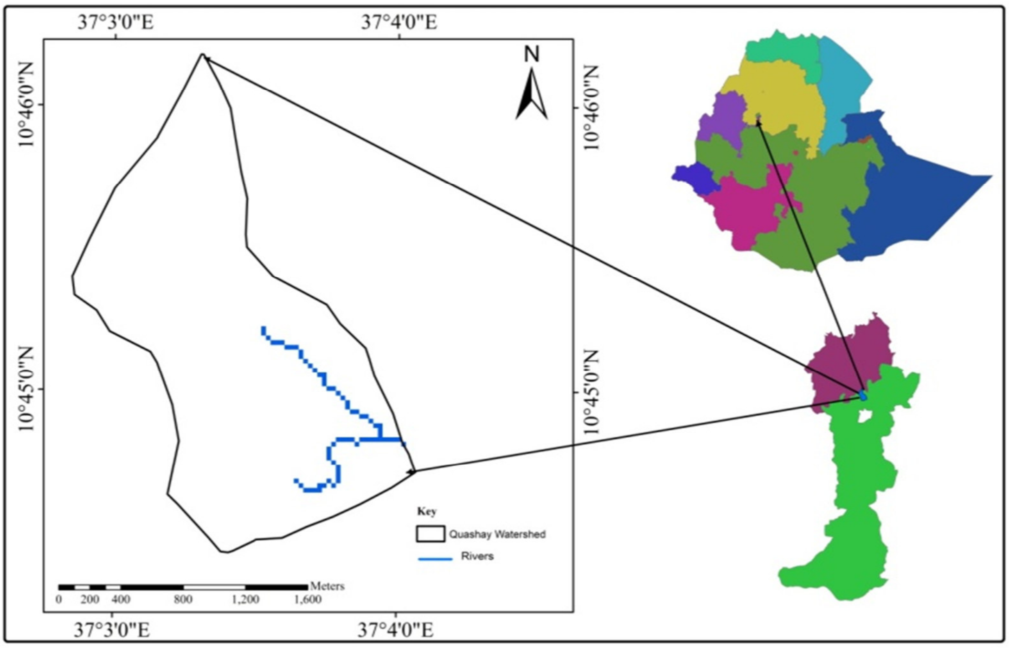

Figure 1. Location map of the study area

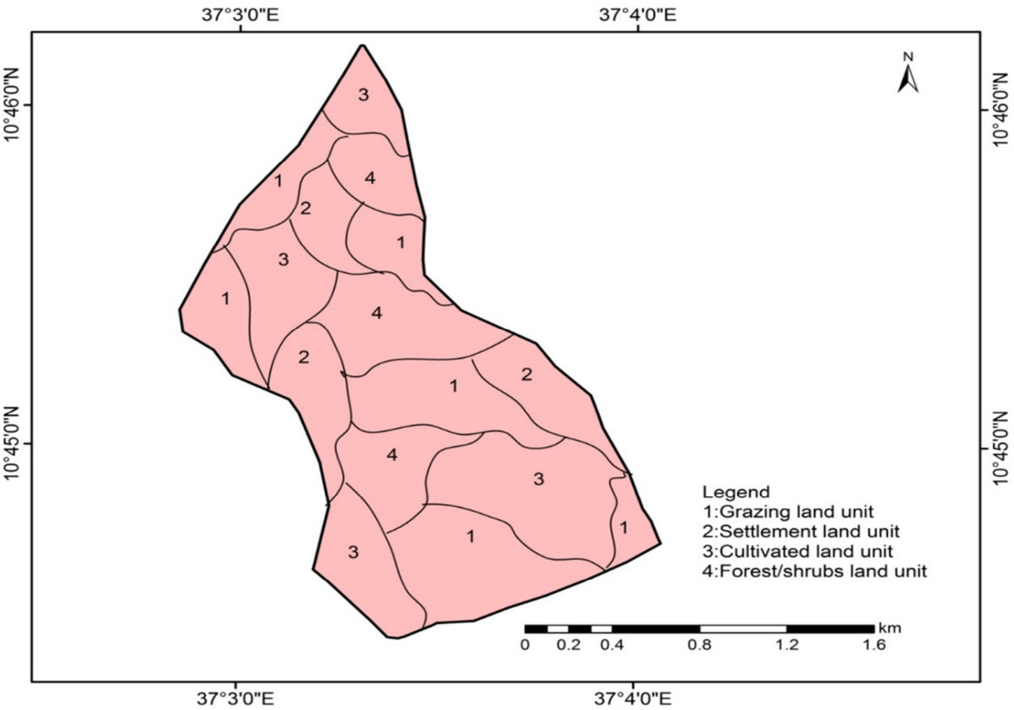

Figure 2. Classified land unit type of the study area

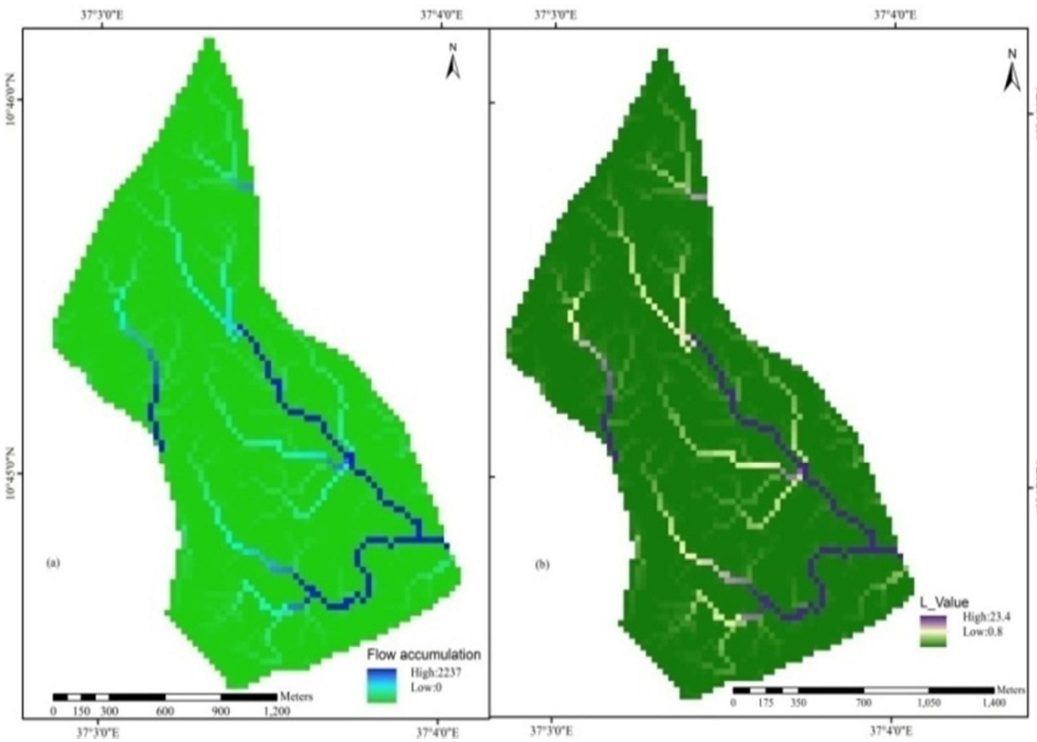

Figure 3. Derived slope length from flow accumulation

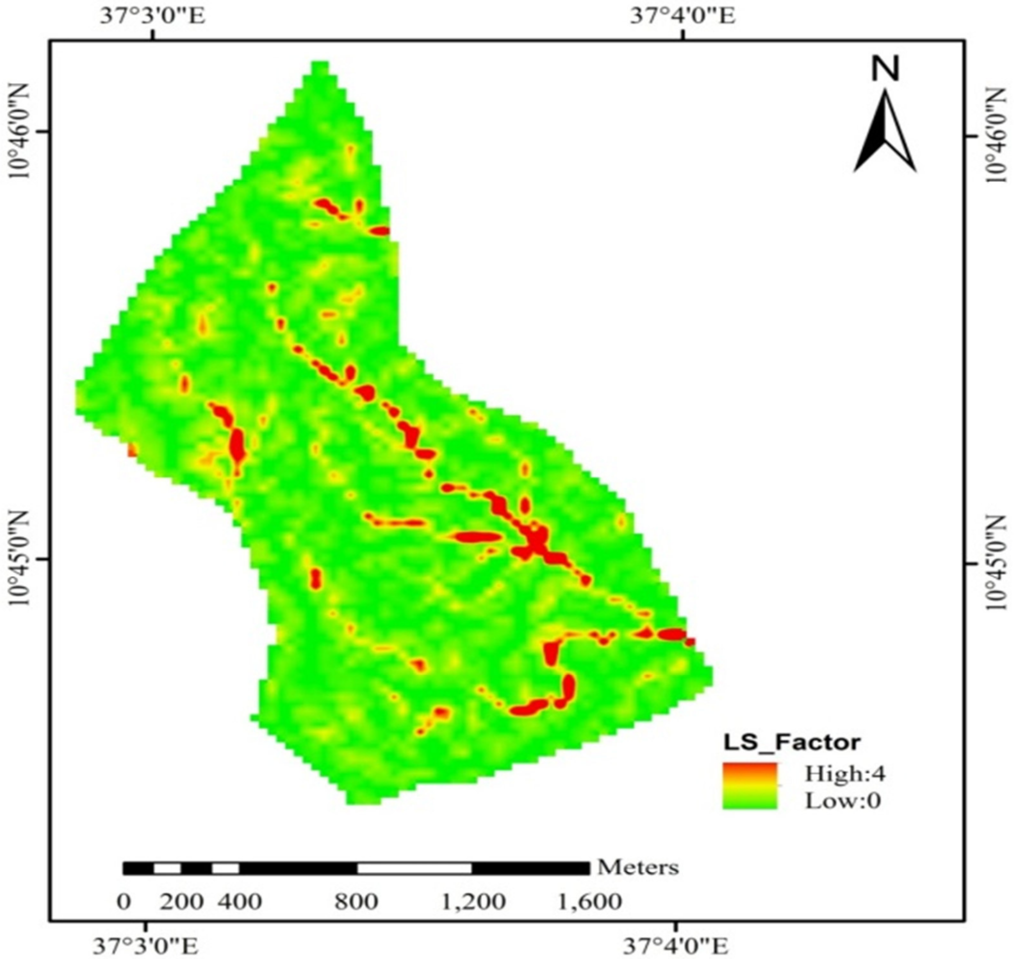

Figure 4. LS raster layer of the study area

Table 1. Slope measured in the study area for each land use unit

Land use/cover type	Mean slope (%)	Standard deviation	Standard Error	Sign.
Grazing land	14.32	15.17	1.55	0.015*
Settlement	12.37	6.74	1.58	0.025*
Cultivated land	16.92	18.22	3.44	0.099
Forest land	22.75	21.80	5.13	0.099

** = significant variation*

Table 2. Measured slope of the study area

Land use type	Measured values in (LUU)	Measurement value of study area (LULC)		
	M±SD	M±SD	CV	Sign.
Grazing land	14.32±15.17	16.34±16.61	0.08	0.003**
Settlement	12.37±6.74			
Cultivated	16.92±6.74			
Forest land	22.75±21.80			

*M=mean, SD=standard deviation, CV=coefficient of variation, ** = significant, LUU = land use unit, and LULC=land use/cover*

Table 3. Measured and derived LS values of the study area used for T-test

	Minimum Slope length (L) in m	Maximum Slope length (L) in m	Minimum Slope gradient (S) in %	Maximum Slope gradient (S) in %
Measured	8.64	21.23	4.35	56.50
Derived	0.8	23.15	0.18	62.72

Table 4. Paired sample T-test of measured and derived LS

Paired Differences								
	Mean	SD	SEM	95% confidence interval Difference		T	df	Sig.(2-tailed)
				Lower	Upper			
MS vs DS	-1.02	7.35	5.2	-67.05	65.01	-0.197	1	0.876
ML vs DL	2.96	6.90	4.88	-59.05	64.97	0.607	1	0.653

ML and DL were measured and derived slope length, MS and DS were measured and derived slope gradient, SEM= Std. Error Mean and SD=Std. Deviation N.B: all are not significant at 95% confidence interval.