International Annals of Science
ISSN: 2456-7132
Volume 8, Issue 1, pp. 120-129, 2020
DOI: https://doi.org/10.21467/ias.8.1.120-129

RESEARCH ARTICLE

Soil Erosion Impact Assessment using USLE/GIS Approaches to Identify High Erosion Risk Areas in the Lowland Agricultural Watershed of Blue Nile Basin, Ethiopia

Kidist Tsegaye [a], Hailu Kendie Addis[b*], Ebrahim Esa Hassen[c]

[a] Department of Natural Resources Management, College of Agriculture and Rural Transformation, University of Gondar, Gondar, Ethiopia

[b]Soil and Water Management Directorate, Amhara Regional Agricultural Research Institute, Bahir Dar, Ethiopia

[c] Department of Geography and Environmental Studies, University of Gondar, Gondar, Ethiopia

* Corresponding author email: hailukendie@gmail.com

Received: 22 August 2019 / Revised: 04 October 2019 / Accepted: 01 November 2019 / Published: 03 November 2019

ABSTRACT

Erosion map of a watershed offers a wealth of knowledge and can be crucial for implementing site-specific management interventions. Thus, watershed-based soil erosion assessment was conducted to recognize erosion hotspot areas, while aiming to roughly calculate the average annual soil loss in Genda-wuha watershed, with a total area of 154,548.5 ha located in the northwest lowland of Blue Nile basin Ethiopia using USLE/GIS approach. Sixteen years of rainfall data, 53 soil sample data, a 30m by 30m digital elevation model (DEM), a land-use/land-cover map, and support practice factor were used to determine high erosion risk areas. The USLE parameters were integrated and analyzed using a raster calculator in the ArcGIS platform to predict and map the mean annual soil loss of Genda-wuha watershed. The result showed that the annual soil loss of the watershed extends from none in the lower and middle part of the watershed to 75.36 Megagram (Mg) $ha^{-1}yr^{-1}$ in the steeper parts of the watershed with a mean annual soil loss of 7.9 Mg $ha^{-1}yr^{-1}$. Most of the soil erosion affected areas are spatially situated in the upper steep slope parts of Genda-wuha watershed, which could be as a result of an increased slope gradient and length in the specified location. However, the majority of the watershed (82.62%) was estimated to be low erosion rates varying from 0 to 5 Mg ha^{-1} yr^{-1} and these areas correspond primarily to nearly flat landscapes of the watershed.

Keywords: Cover factor; digital elevation model; Genda-wuha watershed; soil erodibility; soil erosion.

1 Introduction

The soil is an essential natural resource although it is being degraded at an extraordinary level, both in rate and geographical extent. Soil degradation ranges from soil loss through erosion, chemical depletion, to solute accumulation like salinization [1]. Soil erosion is one of the most significant environmental problems in the world, causing great economic losses every year and threatening natural resources, agriculture and sustainable development [2]. Accelerated soil erosion has occurred on most of the world, particularly in developing countries, caused by limited resources, different socio-economic and demographic factors [3]. Soil erosion not only hampers sustainable land management but also offsite environmental problems such as siltation of lakes and reservoirs [4] and increased dust in the air over long distances [5, 6]. In developing countries like Ethiopia soil degradation resulting from rainfall-driven soil erosion is an extensively recognized problem [7]. The direct reliance of population in the highlands of Ethiopia on intensified use of already stressed resources and expansion of production to marginal and fragile lands is a major reason behind the severity of land degradation also clearing of vegetation, cultivation of steep slopes, and overgrazing are some of the key factors that accelerate erosion in the highlands of Ethiopia [8]. Such exploitative and unsustainable landuse practices as a result of increasing demand for fiber, food, and fodder by the growing human and livestock populations are responsible for severe erosion [9].

Environmental degradation, particularly rainfall driven soil erosion, has severely affected the highlands of Ethiopia for more than 2000 years and annually more land had to be cultivated than ever in search of feeding more people [10]. However, erosion is severe in the highlands of Ethiopia, the problem is significantly observed also in the Northwestern lowlands of the country which is characterized by a semi-arid ecological zone. Because of the scarcity of information about soil loss measurements of soil conservation are not also considered in this area. Soils of arid and semi-arid zones are very susceptible to erosion [11] mostly due to the scares vegetation coverage, low organic matter amount, low resistance to the erosion forces. Arid and semi-arid areas considered as a fragile environment where vegetation cover is sparse and erosion processes occur very rapidly and severely after rainfall. Moreover, semi-arid areas are characterized by extreme events, such as severe floods, storms, and droughts [12]. Typically, precipitation in these areas is categorized as torrential events, occurring in short time period with high rainfall intensities [12, 13]. There is a need for soil conservation to overturn the process of land abandonment and improvement in agricultural production to ensure food security and sustainability. Effective watershed management plans for sustainable development need consistent long-term soil loss information to investigate controlling factors, and identify hotspot areas for targeted management intervention [14, 15]. Soil erosion evaluation and mapping of soil loss susceptible areas provide knowledge regarding soil conservation and ecosystem management mechanisms [16].

Therefore, appropriate hydrological models such as empirical, semi-empirical and physical based models are developed and being utilized for many decades in order to assess and predict mean annual soil loss of a specific area [17, 18]. Universal Soil Loss Equation (USLE) [19] and Revised Universal Soil Loss Equation (RUSLE) [20] are the most known, accepted and frequently used empirical models. These empirical models are relatively simple, cost and time-saving tools under a condition of scarcity in field data than other types of models [21, 22]. A number of scholars had been studied soil erosion in the northwest highlands of Ethiopia [8, 16, 23-27] but no or little had been done in the northwest lowlands of Ethiopia. Thus, the general objective of the study is to roughly calculate the annual soil loss of Genda-wuha watershed, in the northwest lowland of Blue Nile basin Ethiopia using USLE/GIS approach and identify high erosion risk areas.

2 Research Methodology

2.1 Study Area Description

This study was conducted in Genda-wuha watershed which is located in northwestern Gondar Zone of Amhara National Regional State (ANRS) at about 862 km northwestern of Addis Ababa, Ethiopia. The watershed extends from 12°35'9″N to 12°43'24″N latitude and 37°4'23″E to 36°25'25″E longitude and altitude ranging from 746 to 2275 meter above sea level (m.a.s.l) with the total area of 154,548ha as delineated using watershed modeling system (WMS) watershed delineator tool (Figure 1). According to the traditional classification of the climatic zone [28] (Table 1), the Genda-wuha watershed is part of Woyna-Dega and Kola Agro-climatic zones (Figure 2).

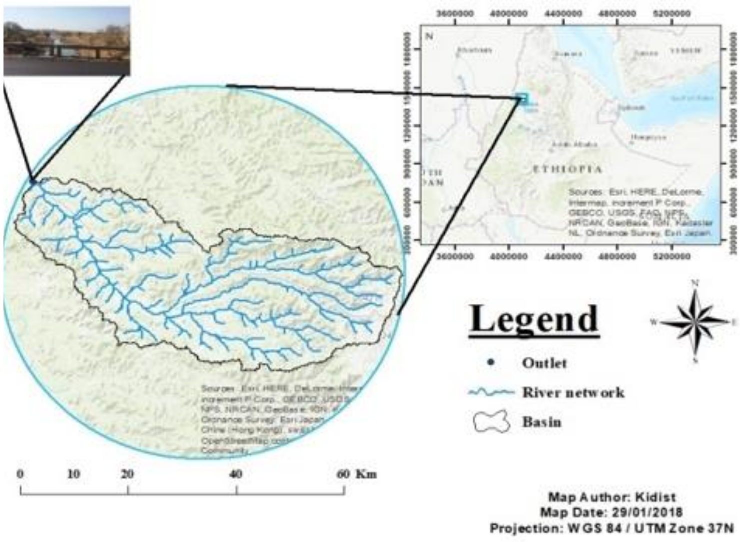

Figure 1: *Location map of the studied watershed in the northwestern lowlands of Ethiopia*

Average mean annual precipitation (1998 to 2013) obtained from Metema meteorology station ranges from 850-1100 mm. The highest rainfall occurred during the summer season, which starts around mid-June to end of September. Relatively less rainfall occurs during the winter season, which lasts from December to January. The mean minimum and maximum annual temperature extend from 16.8^{0}C to 39.3^{0}C. The watershed exhibited a slope range of flat to very steep slopes (0° to 66°) with a mean slope of 12.13°. The largest portion of the study area is covered by sandy; course textured soil and the smaller portion laid on silt soil textures. Major soil unit of the study watershed identified as Eutric Cambisol by FAO digital soil map of the world [29].

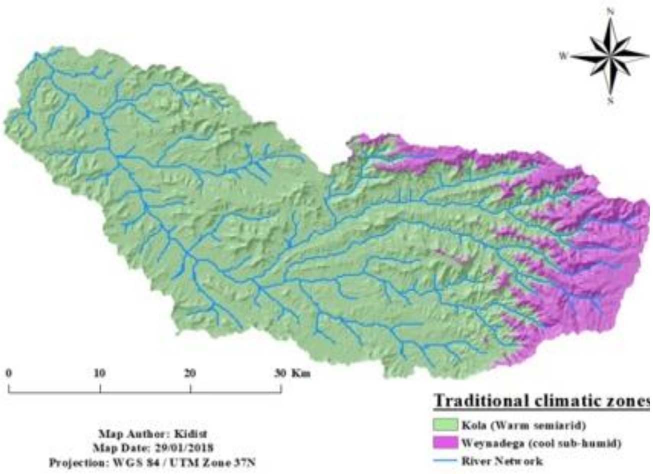

Figure 2: *Traditional classification of agro-climatic zones of the study watershed [28]*

2.2 Data sources

Different data sources were referred to analyze the soil loss in the study area. A shuttle radar topography mission (SRTM) digital elevation model (DEM) (Figure 3) with 30-meter resolution developed by USGS Earth Explorer was implemented for calculating the slope length and slope gradient factor of the study watershed (Figure 4). Soil sample data obtained from soil sample was also used for calculating the soil erodibility factor (K value). Analysis of rainfall erosivity factor (R value) was derived from annual rainfall data from meteorology station and digitally processed satellite images from LANDSAT 8 was used to generate the cover management C factor. The flowchart which illustrates the estimation of soil loss in the study watershed by USLE model using GIS application is displayed in Figure 5.

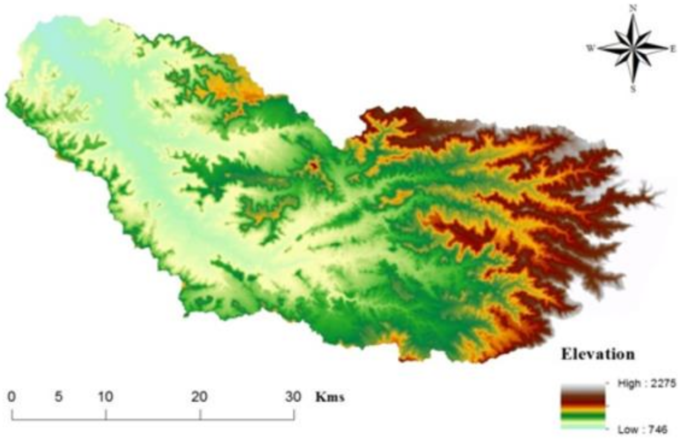

Figure 3: *Digital elevation model (DEM) of the study watershed*

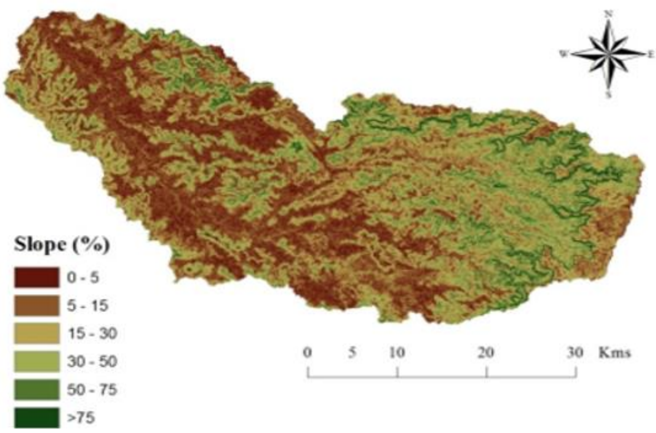

Figure 4: *Slope map of the study watershed*

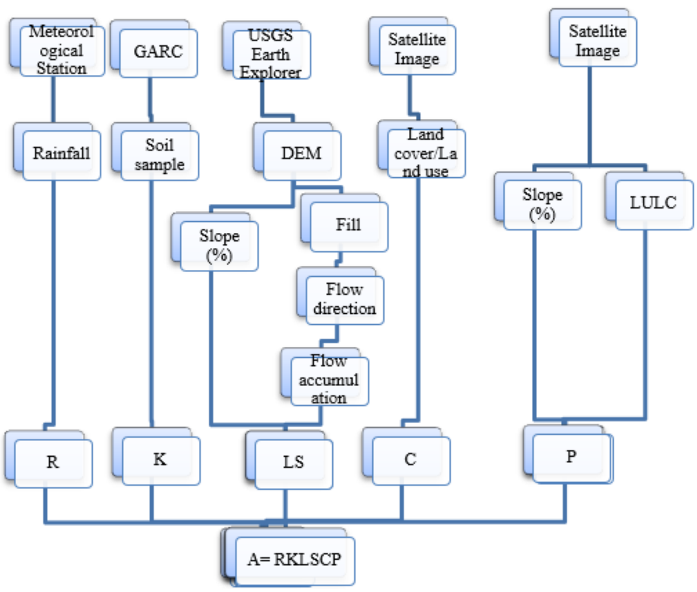

Figure 3: *Flowchart showing analysis of soil loss based on USLE model and GIS application*

2.3 Derivation of USLE Parameters

2.3.1 Rainfall Erosivity Factor (R factor)

Rainfall erosivity index is a factor established by blowing energy from raindrop per storm event, the kinetic energy of rainfall, and maximum 30-minute rainfall intensity. The R factor is estimated as the rainfall erosivity of specific rainstorm events and averaged these value over several years [30]. The value of R factor for the study watershed was estimated through the equation proposed by [31] (Equation 1).

$$R = -8.12 + 0.562 * P \qquad \text{Equation (1)}$$

Where, R= Rainfall erosivity; P= mean annual precipitation (mm/yr). The mean annual rainfall data of 16 years (1998-2013) data collected from Metema meteorology station was used to estimate the R factor value for each grid cell of the study area using equation (1).

2.3.2 Soil Erodibility Factor (K factor)

For this study, the soil erodibility (K factor) value determinant factors such as a percentage of topsoil sand, silt, clay and organic carbon (OC) were randomly collected over 53 locations within the study watershed. The method for indirect estimation of K factor was based on the equation, which utilized the soil physical properties (texture and organic matter content) as input data [7]. In this study, a formula developed by [32] and also utilized by [33] was applied in order to calculate K values of the study watershed.

$$K = A * B * C * D * 0.1317 \qquad \text{Equation (2)}$$

A= is a factor that lowers the soil erodibility for soils with high coarse-sand content and higher for soils with little sand; B= gives low K factors for soils with high clay to silt ratios; C= reduces K values in soils with high organic content; D= lowers K values for soils with an extremely high sand content

where:

$$A = [0.2 + 0.3\exp(-0.0256SAN(1 - (\frac{SIL}{100})))]$$

Equation (2.1)

$$B = [SIL/(CLA + SIL)]^{0.2}$$

Equation (2.2)

$$C = [1.0 - (\frac{0.25C}{C + \exp[(3.72 - 2.95C)]})] \qquad \text{Equation (2.3)}$$

$$D = [1.0 - (\frac{0.70SN1}{SN1 + \exp[(-5.41 + 22.9SN1)]})]$$

Equation (2.4)

Where: SAN, SIL, and CLA are a percentage of sand, silt, and clay, respectively; C is the organic carbon (OC %) content, and SN1 is sand content subtracted from 1 and divided by 100. Then by using an Arc GIS format the excel data was added on the layer and exported to create an output feature class, in Arc GIS "spatial analyst tool" so that the shapefile point datasets were interpolated by IDW (Inverse Distance Weighted) and extracted by the watershed through masking to develop the K factor map.

2.3.3 Slope length and Slope steepness factor (LS factor)

The influence of topography on soil erosion in USLE is described by the dimensionless LS factor [34, 35]. In this study, the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) with a resolution (grid cell) of 30m by 30m which is available by USGS Earth explorer was used to generate slope surface layer through "Spatial Analyst Tool Surface Slope" in Arc GIS environment. The DEM was used to computed the flow accumulation and slope steepness and slope and flow accumulation maps were calculated by using "Spatial Analyst Tool Map Algebra Raster Calculator" to calculate and map the LS value as shown in Equation (3). The LS map was generated through the following formula developed by [36] and utilized by [37].

$$LS = \left(\frac{Length}{22.1}\right)^m (0.065 + 0.045S + 0.0065S^2)$$

Equation (3)

Where: S = slope gradient (%); the value of "M" is an exponent varies from 0.2 – 0.5 depending on the slope as shown in Table 1 [36].
For determination of length value, the method proposed by [38] was applied as displayed in Equation (3.1).

$$Length = (Flow\ Accumulation * Cell\ Size)$$

Equation (3.1)

Where: Flow accumulation is a grid theme of flow accumulation expressed as a number of grid cells while cell size is the length of a cell side in meter (m). Flow accumulation was derived from the DEM, after conducting fill and flow direction processes in Arc GIS environment [39, 40] in line with Arc Hydro tool and was calculated by raster calculator of the map algebra expression whereas, the value of S was directly derived from 30m resolution DEM.

Table 1: "*M" Values for the different slope classes [36]*

M values	Slope (%)
0.5	>5
0.4	3-5
0.3	1-3
0.2	<1

2.3.4 Cover management factor (C factor)

The land use/land cover map was used for the estimation of soil erosion cover-management factor (C factor) [41]. In this study supervised maximum likelihood classification of LANDSAT 8 data acquired on 05 March 2017 from Land Sat was used to prepare the land use/land cover map of the study watershed. The raster landuse/land cover map of the study area was converted to a vector format and a corresponding C factor was assigned to each landuse classes based on cover values proposed by [41]. After assigning C factors for each landuses in the watershed, the resulting map was converted to a raster C factor map with 30m cell size.

2.3.5 Support practices factor (P factor)

The P-factor for this study was determined using an alternative method that utilizes slope and landuse data as suggested by [36] and this method has also been applied by different scholars [16, 23, 24] (Table 2).

Table 2: *The P values which were used in the study watershed for the different slope classes of agricultural land were adapted based on [23]*

Land use type	Slope (%)	P value
Cultivated land	0- 5	0.1
	10-May	0.12
	20-Oct	0.14
	20-30	0.19
	30-50	0.25
	50-100	0.33
Other landuse	All	1

Generally, the method classifies the land cover into agricultural land and other landuses. Meanwhile, during the fieldwork different datasets related to management practices of the study watershed were collected. Consequently, values for P factors were assigned considering local management practices and the weighed value was taken for similar landuses.

2.4 Soil Loss Analysis

The average annual soil loss analysis was calculated based on a grid cell analyses by multiplying the respective USLE factor values (R, K, LS, C, and P) interactively using "Spatial Analyst Tool Map Algebra Raster Calculator" in Arc GIS environment.

$$A = R * K * LS * C * P$$

Where A is the annual soil loss (Mg ha^{-1} $year^{-1}$); R is the rainfall erosivity factor [MJ mm h^{-1} ha^{-1} $year^{-1}$]; K is soil erodibility factor [Mg ha^{-1} MJ^{-1} mm^{-1}]; LS = slope length factor (dimensionless); C is management factor (dimensionless); and P is conservation practice factor (dimensionless).

3 Results and Discussions

3.1 Rainfall Erosivity Factor (R factor)

According to [42], soil loss rate is closely related to rainfall partly through the detaching and transport power of raindrop that striking the soil surface and partly through the contribution of surface runoff. The average annual rainfall of Genda-wuha watershed is 950mm and the resulting value of R factor in the study watershed which was calculated using equation 1 was 525.78 MJ mm ha^{-1} $year^{-1}$.

3.2 Soil Erodibility Factor (K Factor)

The soil erodibility is a complex concept and it is influenced by many soil properties, which could be an expression of its inherent resistance to particle detachment and transport by erosion processes, such as splash erosion, surface runoff or both [43]. Soil erodibility depends fundamentally on the amount of organic matter in the soil and the texture of the soil [44]. The soil erodibility or K factor normally varies from near zero to about 0.6 and it is very low for soils with high infiltration capacity, such as well-drained sandy soils or friable tropical clays with high in hydrous oxides of iron and aluminum or kaolinite [45]. Generally, soils with high infiltration capacities and moderate soil structural stability have a K factor of 0.2 to 0.3, while the most easily eroded soils with low infiltration capacities will have a K factor of 0.3 or highest [45]. Erodibility factor for the study watershed ranges from 0.019 - 0.26 Mg ha^{-1} MJ^{-1} mm^{-1} (Figure 6).

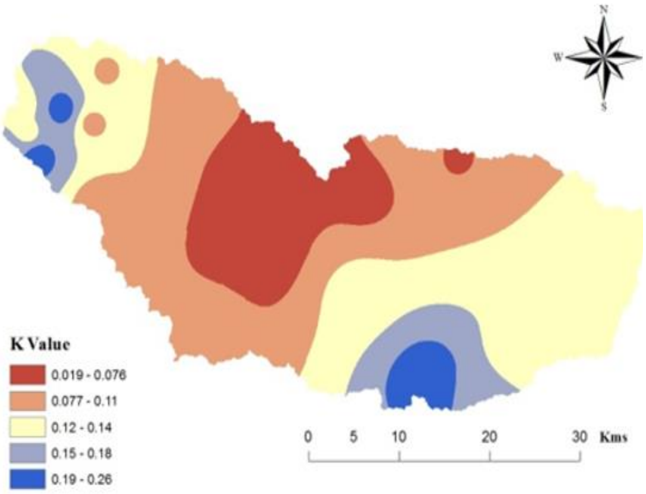

Figure 6: *Soil erodibility map of the study watershed*

3.3 Slope length and Steepness factor (LS factor)

The LS factor dataset for the study are was determined using a high-resolution (30m) Digital Elevation Model (DEM), resulting in an improved delineation of areas at risk of soil erosion and the value of LS factor for the watershed ranges from 0 to 15.2 (Figure 7).

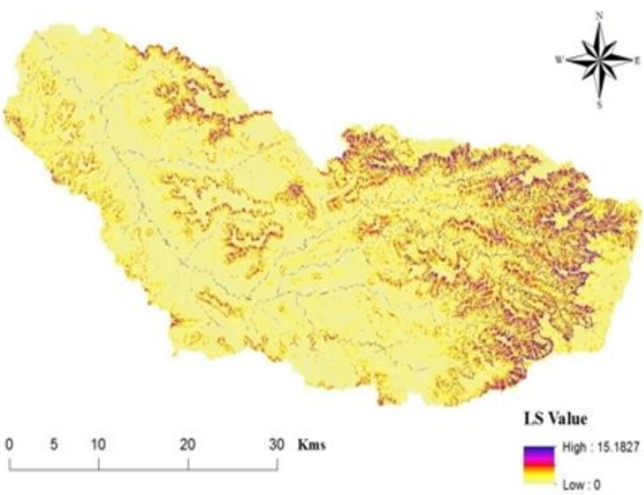

Figure 7: *Slope length and steepness (LS factor) map of the study watershed*

3.4 Cover Management Factor (C Factor)

The cover management factor (C values), indicates the influence of crop cover systems on the soil erosion rate [30]. C Factor is used to determine the relative efficiency of crop management practices in terms of preventing soil loss. During this study, eight landuse and land cover classes were recognized, these include mixed forest land, natural grassland, shrubland, annual cropland, open woodland, annual crop associated with a sparsely vegetated area, bare land, and open space with little or no vegetation (Table 3).

Table 3: *Cover management practice (C factor) values in the study watershed*

Land Use /Land Cover type	Area (ha)	C-factor value	References
Mixed forest land	2504.80	0.1	[46]
Natural grassland	294.46	0.01	[23, 31, 42]
Shrub-land	29658.21	0.25	[47]
Annual crop associated with sparsely vegetated area	957.87	0.29	[48]
Annual cropland	118119.01	0.343	[48]
Open woodland	2839.99	0.27	[49]
Bare-lands	152.66	0.15	[50]
Open space with little or no vegetation	21.18	0.13	[51]

Since the introduction of the USLE, experimental studies have suggested different values for different cover types and management practices [30, 36]. The C-factor values suggested by different researchers for different crop and surface cover types were employed (Table 3), although it is difficult to apply those values to other environmental settings. Based on the land cover classification map, the analysis of crop management factor (C values) was made by changing the coverage to the grid base. A corresponding C value was assigned to each landuse class using the “reclass” method in Arc GIS environment.

The values of the C factor were within the range of 0.01 to 0.343 and the spatial display of the C factor is shown in Figure 8. The resulting map C factor indicates that in the central part of Genda-wuha watershed, the soil is very sensitive to erosion processes, due to agricultural activities; therefore, the values of C factor in thus location are high.

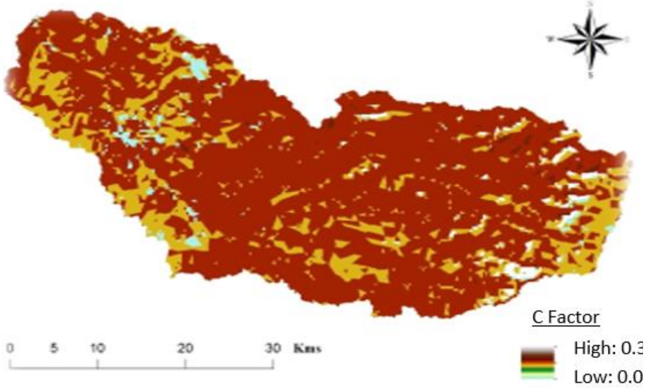

Figure 8: *Cover management factor (C factor) map of the study watershed*

3.5 Control practice (P factor)

The conservation practices factor (P factor) reflects the impacts of soil conservation practices that reduce the volume and rate of surface runoff and thus reduce the total soil erosion rate [52]. Based on the field visit and local farmers interview there were no management practices, thus, the P-values suggested by [23] was used and this technique considers only two types of landuses (agricultural and non-agricultural) (Table 2). Thus, a corresponding P-value was assigned and mapped to each landuse type using the "reclass" method in Arc GIS environment (Figure 9).

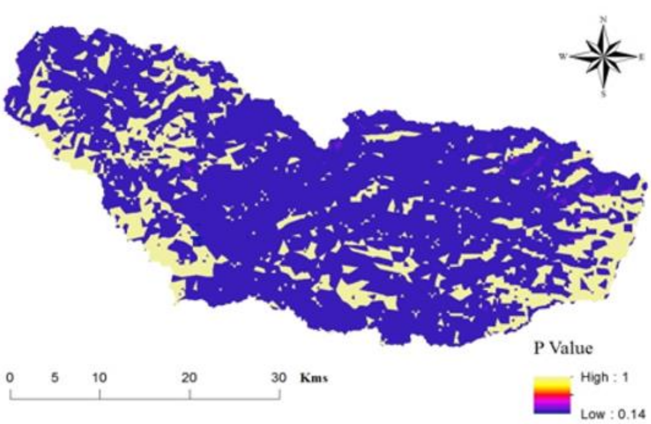

Figure 9: *Control practice factor (P factor) map of the study watershed*

3.6 Average Annual Soil Loss

All factors layers R, K, LS, C, and P were computed and specialized previously by using GIS technology, are combined together to obtain average annual soil loss rate layer. The total soil loss in the study area was 1,220,929.2 Megagram (Mg) per year from 154,548.5 ha and the estimated soil loss for Genda-wuha watershed varied from 0 to 75.36 Mg $ha^{-1}yr^{-1}$. The average annual soil loss for the entire watershed was estimated to be 7.9 Mg $ha^{-1}yr^{-1}$. According to [25], the soil loss severity classes of the watershed was divided into four ordinal classes these are very high risk (>20 Mg), high risk (10 to 20 Mg), moderate risk (5 to 10 Mg) and low risk (0 to 5 Mg) with area coverage of 14,821.15 ha, 6120.1 ha, 5919.19 ha, and 127,687.53 ha respectively. Table 4 illustrations the area and proportion of each of the soil erosion potential categories of the study watershed and 82.62% of the area was estimated to be low erosion rates varying from 0 to 5 Mg ha^{-1} yr^{-1} and these areas correspond primarily to the nearly flat areas. Meanwhile, the estimated soil losses from 5 to 10 Mg $ha^{-1}yr^{-1}$ are found in 3.83% and from 10 to 20 Mg ha^{-1} yr^{-1} are found in 3.96% of the study area, which corresponds primarily to the mountain and valley areas. The estimated average annual soil loss >20 Mg ha^{-1} yr^{-1} are found in 9.59% of the study area which indicated a high erosion occurrence (Figure 10). The high values of soil erosion could be the result of the combined effects of steep slopes, high rainfall and intensive cultivation, overgrazing, and land clearing by fire specifically on the mountainous areas of Genda-wuha watershed.

Table 4: *Soil erosion severity zones of the study watershed with erosion rate and area coverage*

Soil erosion severity class (Mg/ha/year)	Soil erosion severity	Area (ha)	Percent (%)
0-5	Low	127687.53	82.62
5-10	Moderate	5919.19	3.83
10-20	High	6120.1	3.96
>20	Very high	14821.15	9.59

According to [53], the average annual soil loss ranges can be classified as very slight (0 – 4.99 Mg ha^{-1} yr^{-1}), slight (5 – 9.99 Mg ha^{-1} yr^{-1}), moderate (10 – 24.99 Mg ha^{-1} yr^{-1}), severe (25 – 44.99 Mg ha^{-1} yr^{-1}) and very severe (> 44.99 Mg ha^{-1} yr^{-1}), thus, based on these categories the mean annual soil loss of the study watershed (7.9 Mg ha^{-1} yr^{-1}) is under slight class of soil erosion (5 – 9.99 Mg ha^{-1} yr^{-1}).

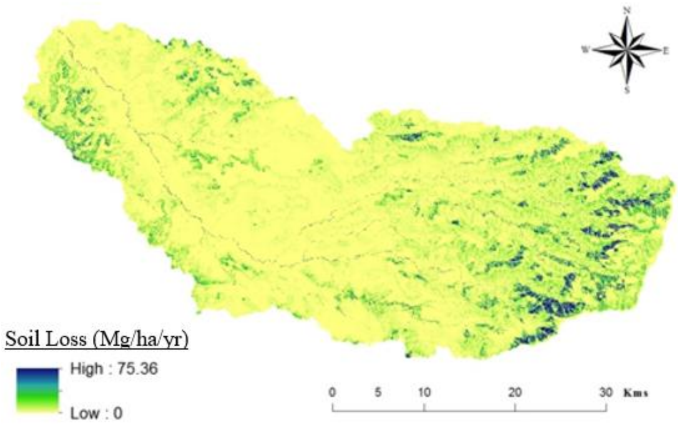

Figure 10: *Soil erosion map of the study watershed*

4 Conclusions

This study utilized USLE equation with GIS techniques to assess the annual soil loss and identify the most erosion contributing areas in Genda-wuha watershed. Soil loss estimation was carried out based upon the principles defined in the USLE, which includes the rainfall erosivity, soil erodibility factor, slope length factor, management factor, and conservation practice factor. The input parameters of the model were compiled in raster model format with a grid resolution of 30 meters. The spatial distribution map of soil loss of Genda-wuha watershed has been generated and the estimated average annual soil varied from 0 to 75.9 Mg $ha^{-1}yr^{-1}$. The mean annual soil loss from the entire watershed was 7.9 Mg $ha^{-1}yr^{-1}$, which could be categorized under the slight class of soil erosion. The highest soil erosion is strongly the result of the combination of steep slopes, high rainfall, intensive cultivation, land clearing by fire and overgrazing on the mountainous areas of the study watershed. However, the most parts of the watershed (82.62%) was estimated to be low erosion rates varying from 0 to 5 Mg ha^{-1} yr^{-1} and these areas correspond primarily to nearly flat areas. Since the USLE is restricted to rill and inter-rill erosion while the actual soil erosion is likely to include all types of water erosion within the watershed, which implies that the modeled values could be expected lower than the observed. Nevertheless, the method can be applied in data scarce parts of the northwest lowlands of Ethiopia for assessment and delineation of erosion-prone areas and prioritization for conservation. In general, for long term sustainable soil resources management and erosion control particularly in steeper parts of the watershed, conservation of existing vegetation cover and replanting appropriate vegetations should be done.

5 Declarations

5.1 Acknowledgments

We would like to recognize the contribution by the staff of the University of Gondar, College of Agriculture and Rural Transformation, Department of Natural Resources Management and Gondar Agricultural Research Center, Soil and Water Management Research Directorate.

5.2 Competing Interests

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

How to Cite this Article:

K. Tsegaye, H. Addis, and E. Hassen, “Soil Erosion Impact Assessment using USLE/GIS Approaches to Identify High Erosion Risk Areas in the Lowland Agricultural Watershed of Blue Nile Basin, Ethiopia”, *Int. Ann. Sci.*, vol. 8, no. 1, pp. 120-129, Nov. 2019. doi:10.21467/ias.8.1.120-129

References

[1] L. Oldeman, R. Hakkeling, and W. G. Sombroek, "World map of the status of human-induced soil degradation: an explanatory note," ed: International Soil Reference and Information Centre, 2017.

[2] H. K. Addis, A. Abera, and L. Abebaw, "Economic benefits of soil and water conservation measures at the sub-catchment scale in the northern Highlands of Ethiopia," *Progress in Physical Geography: Earth and Environment*, Sep 26 2019. doi: 10.1177/0309133319878118

[3] D. Chalise, L. Kumar, and P. Kristiansen, "Land degradation by soil erosion in Nepal: a review," *Soil Systems*, vol. 3, p. 12, 2019. doi: 10.3390/soilsystems3010012

[4] C. Tundu, M. J. Tumbare, and J.-M. Kileshye Onema, "Sedimentation and its impacts/effects on river system

and reservoir water quality: case study of Mazowe catchment, Zimbabwe," *Proceedings of the International Association of Hydrological Sciences,* vol. 377, pp. 57-66, 2018. doi: 10.5194/piahs-377-57-2018

[5] M. C. Duniway, A. A. Pfennigwerth, S. E. Fick, T. W. Nauman, J. Belnap, and N. N. Barger, "Wind erosion and dust from US drylands: a review of causes, consequences, and solutions in a changing world," *Ecosphere,* vol. 10, p. e02650, 2019. doi: 10.1002/ecs2.2650

[6] H. Zhang, Y. Gao, D. Sun, L. Liu, Y. Cui, and W. Zhu, "Wind Erosion Changes in a Semi-Arid Sandy Area, Inner Mongolia, China," *Sustainability,* vol. 11, p. 188, 2019. doi: 10.3390/su11010188

[7] H. K. Addis and A. Klik, "Predicting the spatial distribution of soil erodibility factor using USLE nomograph in an agricultural watershed, Ethiopia," *International Soil and Water Conservation Research,* vol. 3, pp. 282-290, 2015. doi: 10.1016/j.iswcr.2015.11.002

[8] H. Addis, A. Klik, T. Oweis, and S. Strohmeier, "Linking Selected Soil Properties to Land Use and Hillslope-A Watershed Case Study in the Ethiopian Highlands," *Soil & Water Research,* vol. 11, 2016. doi: 10.17221/117/2015-SWR

[9] P. S. Bindraban, M. van der Velde, L. Ye, M. Van den Berg, S. Materechera, D. I. Kiba, *et al.*, "Assessing the impact of soil degradation on food production," *Current Opinion in Environmental Sustainability,* vol. 4, pp. 478-488, 2012. doi: 10.1016/j.cosust.2012.09.015

[10] G. W. Gella, "Impacts of integrated soil and water conservation programs on vegetation regeneration and productivity as indicator of ecosystem health in Guna-Tana watershed: evidences from satellite imagery," *Environmental Systems Research,* vol. 7, p. 2, 2018. doi: 10.1186/s40068-018-0105-1

[11] I. Lopes, A. A. Montenegro, and J. L. de Lima, "Performance of Conservation Techniques for Semiarid Environments: Field Observations with Caatinga, Mulch, and Cactus Forage Palma," *Water,* vol. 11, p. 792, 2019. doi: 10.3390/w11040792

[12] J. C. Ribeiro Filho, H. A. D. Q. PALÁCIO, E. ANDRADE, J. C. N. D. SANTOS, and J. B. Brasil, "Rainfall characterization and sedimentological responses of watersheds with different land uses to precipitation in the semiarid region of Brazil," *Revista Caatinga,* vol. 30, pp. 468-478, 2017. doi: 10.1590/1983-21252017v30n222rc

[13] W. Wei, L. Chen, B. Fu, Z. Huang, D. Wu, and L. Gui, "The effect of land uses and rainfall regimes on runoff and soil erosion in the semi-arid loess hilly area, China," *Journal of hydrology,* vol. 335, pp. 247-258, 2007. doi: 10.1016/j.jhydrol.2006.11.016

[14] D. A. Mhiret, D. C. Dagnew, T. T. Assefa, S. A. Tilahun, B. F. Zaitchik, and T. S. Steenhuis, "Erosion hotspot identification in the sub-humid Ethiopian highlands," *Ecohydrology & Hydrobiology,* vol. 19, pp. 146-154, 2019. doi: 10.1016/j.ecohyd.2018.08.004

[15] M. Belayneh, T. Yirgu, and D. Tsegaye, "Potential soil erosion estimation and area prioritization for better conservation planning in Gumara watershed using RUSLE and GIS techniques'," *Environmental Systems Research,* vol. 8, p. 20, 2019. doi: 10.1186/s40068-019-0149-x

[16] H. S. Gelagay and A. S. Minale, "Soil loss estimation using GIS and Remote sensing techniques: A case of Koga watershed, Northwestern Ethiopia," *International Soil and Water Conservation Research,* vol. 4, pp. 126-136, 2016. doi: 10.1016/j.iswcr.2016.01.002

[17] R. Benavidez, B. Jackson, D. Maxwell, and K. Norton, "A review of the (Revised) Universal Soil Loss Equation ((R) USLE): with a view to increasing its global applicability and improving soil loss estimates," *Hydrology and Earth System Sciences,* vol. 22, pp. 6059-6086, 2018. doi: 10.1080/089030699263212

[18] M. Hajigholizadeh, A. M. Melesse, and H. R. Fuentes, "Erosion and sediment transport modelling in shallow waters: A review on approaches, models and applications," *International journal of environmental research and public health,* vol. 15, p. 518, 2018. doi: 10.3390/ijerph15030518

[19] W. H. Wischmeier and D. D. Smith, *Predicting rainfall-erosion losses from cropland east of the Rocky Mountains: Guide for selection of practices for soil and water conservation* vol. 282: Agricultural Research Service, US Department of Agriculture Washington DC, 1965.

[20] K. G. Renard, C "RUSLE: Revised universal soil loss equation," *Journal of soil and Water Conservation,* vol. 46, pp. 30-33, 1991.

[21] M. Zhu, "Soil erosion assessment using USLE in the GIS environment: a case study in the Danjiangkou Reservoir Region, China," *Environmental Earth Sciences,* vol. 73, pp. 7899-7908, 2015. doi: 10.1007/s12665-014-3947-5

[22] S. G. Dashtaki, H. A. Bahrami, M. Naderi, J. Alexandre, and M. Dematte, " Soil loss estimation using RUSLE model, GIS and remote sensing techniques: A case study from the Dembecha Watershed, Northwestern Ethiopia," *Geoderma Regional,* 2017. doi: 10.1016/j.geodrs.2017.06.003

[23] W. Bewket and E. Teferi, "Assessment of soil erosion hazard and prioritization for treatment at the watershed level: case study in the Chemoga watershed, Blue Nile basin, Ethiopia," *Land Degradation & Development,* vol. 20, pp. 609-622, 2009. doi: 10.1002/ldr.944

[24] A. Shiferaw, "Estimating soil loss rates for soil conservation planning in the Borena Woreda of South Wollo Highlands, Ethiopia," *Journal of Sustainable Development in Africa,* vol. 13, pp. 87-106, 2011.

[25] L. Tadesse, K. Suryabhagavan, G. Sridhar, and G. Legesse, "Land use and land cover changes and Soil erosion in Yezat Watershed, North Western Ethiopia," *International Soil and Water Conservation Research,* vol. 5, pp. 85-94, 2017. doi: 10.1016/j.iswcr.2017.05.004

[26] G. Woldemariam, A. Iguala, S. Tekalign, and R. Reddy, "Spatial modeling of soil erosion risk and its implication for conservation planning: the case of the Gobele watershed, east Hararghe zone, Ethiopia," *Land,* vol. 7, p. 25, 2018. doi: 10.3390/land7010025

[27] M. Yibeltal, A. Tsunekawa, N. Haregeweyn, E. Adgo, D. T. Meshesha, D. Aklog, *et al.*, "Analysis of long-term gully dynamics in different agro-ecology settings," *Catena,* vol. 179, pp. 160-174, 2019. doi: 10.1016/j.catena.2019.04.013

[28] H. Hurni, W. A. Berhe, P. Chadhokar, D. Daniel, Zeleke Gete, M. Grunder, and G. Kassaye. "Soil and water conservation in Ethiopia: guidelines for development agents." 2016.

[29] Fao/Iiasa/Isric/Isscas/Jrc, "Harmonized world soil database (version 1.2)," *FAO, Rome, Italy and IIASA, Laxenburg, Austria,* 2012.

[30] K. G. Renard, G. R. Foster, G. Weesies, D. McCool, and D. Yoder, *Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE)* vol. 703: United States Department of Agriculture Washington, DC, 1997.

[31] H. Hurni, *Soil Conservation Manual for Ethiopia: A Field Guide for Conservation Implementation*, 1985.

[32] J. R. Williams, "The erosion-productivity impact calculator (EPIC) model: a case history," *Phil. Trans. R. Soc. Lond. B,* vol. 329, pp. 421-428, 1990. doi: 10.1098/rstb.1990.0184

[33] J. A. A. Anache, C. G. V. Bacchi, E. Panachuki, and T. A. Sobrinho, "Assessment of methods for predicting soil erodibility in soil loss modeling," *São Paulo, UNESP. Geociências,* vol. 34, pp. 32-40, 2015.

[34] R. D. Van Remortel, M. E. Hamilton, and R. J. Hickey, "Estimating the LS factor for RUSLE through iterative slope length processing of digital elevation data within Arclnfo grid," *Cartography,* vol. 30, pp. 27-35, 2001. doi: 10.1080/00690805.2001.9714133

[35] R. D. Van Remortel, R. W. Maichle, and R. J. Hickey, "Computing the LS factor for the Revised Universal Soil Loss Equation through array-based slope processing of digital elevation data using a C++ executable," *Computers & Geosciences,* vol. 30, pp. 1043-1053, 2004. doi: 10.1016/j.cageo.2004.08.001

[36] W. H. Wischmeier and D. D. Smith, "Predicting rainfall erosion losses-a guide to conservation planning," *Predicting rainfall erosion losses-a guide to conservation planning.,* 1978.

[37] M. Nakil and M. Khire, "Effect of slope steepness parameter computations on soil loss estimation: review of methods using GIS," *Geocarto international,* vol. 31, pp. 1078-1093, 2016. doi: 10.1080/10106049.2015.1120349

[38] I. D. Moore and G. J. Burch, "Physical Basis of the Length-slope Factor in the Universal Soil Loss Equation 1," *Soil Science Society of America Journal,* vol. 50, pp. 1294-1298, 1986. doi: 10.2136/sssaj1986.03615995005000050042x

[39] D. M. Theobald, *GIS concepts and ArcGIS methods*: Conservation Planning Technologies, 2007.

[40] R. Johnson, "GIS technology for disasters and emergency management," *An ESRI white paper,* 2000.

[41] P. Panagos, P. Borrelli, K. Meusburger, C. Alewell, E. Lugato, and L. Montanarella, "Estimating the soil erosion cover-management factor at the European scale," *Land use policy,* vol. 48, pp. 38-50, 2015. doi: 10.1016/j.landusepol.2015.05.021

[42] R. P. C. Morgan, *Soil erosion and conservation*: John Wiley & Sons, 2009.

[43] G. Buttafuoco, M. Conforti, P. Aucelli, G. Robustelli, and F. Scarciglia, "Assessing spatial uncertainty in mapping soil erodibility factor using geostatistical stochastic simulation," *Environmental Earth Sciences,* vol. 66, pp. 1111-1125, 2012. doi: 10.1007/s12665-011-1317-0

[44] R. P. Stone and D. Hilborn, *Universal soil loss equation, USLE*: Ministry of Agriculture, Food and Rural Affairs, 2000.

[45] N. C. Brady and R. R. Weil, "The Nature and Properties of Soils 13th Edition," *Agroforest. Syst,* vol. 54, p. 249, 2002.

[46] H. Elwell, "Modelling soil losses in Southern Africa," *Journal of Agricultural Engineering Research,* vol. 23, pp. 117-127, 1978. doi: 10.1016/0021-8634(78)90043-4

[47] H. Eweg and R. v. Lammeren, "The application of a geographical information system at the rehabilitation of degraded and degrading areas: a case study in the Highlands of Tigray, Ethiopia," *Wageningen Agricultural University Netherlands,* pp. 79, 1996.

[48] P. Panagos, K. Christos, B. Cristiano, and G. Ioannis, "Seasonal monitoring of soil erosion at regional scale: an application of the G2 model in Crete focusing on agricultural land uses," *International Journal of Applied Earth Observation and Geoinformation,* vol. 27, pp. 147-155, 2014. doi: 10.1016/j.jag.2013.09.012

[49] M. M. Bakker, G. Govers, A. van Doorn, F. Quetier, D. Chouvardas, and M. Rounsevell, "The response of soil erosion and sediment export to land-use change in four areas of Europe: the importance of landscape pattern," *Geomorphology,* vol. 98, pp. 213-226, 2008. doi: 10.1016/j.geomorph.2006.12.027

[50] M. Alejandro and K. Omasa, "Estimation of vegetation parameter for modeling soil erosion using linear Spectral Mixture Analysis of Landsat ETM data," *ISPRS Journal of Photogrammetry and Remote Sensing,* vol. 62, pp. 309-324, 2007. doi: 10.1016/j.isprsjprs.2007.05.013

[51] L. Borselli, P. Cassi, and D. Torri, "Prolegomena to sediment and flow connectivity in the landscape: a GIS and field numerical assessment," *Catena,* vol. 75, pp. 268-277, 2008. doi: 10.1016/j.catena.2008.07.006

[52] P. Panagos, P. Borrelli, K. Meusburger, E. H. van der Zanden, J. Poesen, and C. Alewell, "Modelling the effect of support practices (P-factor) on the reduction of soil erosion by water at European scale," *Environmental science & policy,* vol. 51, pp. 23-34, 2015. doi: 10.1016/j.envsci.2015.03.012

[53] R. Singh and V. Phadke, "Assessing soil loss by water erosion in Jamni River Basin, Bundelkhand region, India, adopting universal soil loss equation using GIS," *Current Science,* pp. 1431-1435, 2006. http://www.jstor.org/stable/24091996.