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Estimation of Soil Erosion Using RUSLE in GIS Frame Work: In the Case Study of Wanka Catchment in Estie District, Amhara, Ethiopia

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Abstract: Today soil erosion by water is the most critical natural degradation problems that remove surface top soil by depressive action of rainfall intensity followed by runoff. Due to this reason USLE model have been used to estimate total annual soil loss of the catchment. The objective of this study is to estimate the total annual soil loss using USLE in GIS framework in Wanka catchment. The methodology of this study was used to combine the six USLE's significant physical input factors such as Rainfall erosivity factor, soil erodibility factor, land cover factor, topographic factor and support practices factor to estimate soil loss of the study area. These factor was converted to raster layer format in GIS and multiplied together to estimate soil loss in ton per hectare per year of the study area with raster calculator. Finally the study showed that the estimation of annual soil loss of the catchment have been ranged between 0 to 169.321 ton/ha/year. These result used as threshold for the implementation of effective soil and water conservation measures to minimize soil loss risk in this catchment. In addition to the soil loss result, as seen in filed survey the catchment was prone to land degradation with unwise use of natural resource this should have been require a decision for the management and protection of natural resources.

Keywords: Erosion, GIS, RUSLE, Wanka Catchment

1. Introduction

Soil erosion is the most chronic environmental and economic problems of the present situation. Soil erosion is the detachment and transport of surface loose soil by the process of sheet erosion, rill erosion, gully erosion and stream bank erosion then, deposit huge amounts of silt in to downstream reservoirs and valleys [1]. Soil particles is highly removed from upper earth surface with the impact of storm rainfall [2]. As the storm continues for long period of time the land surface become saturate and overland flow begin to transport top fertile soil depending on soil texture, structure, slope, vegetation cover and management practices. But not all surface soils dragged once upon a time within flowing water, in case fine particle travel long distance, rather relatively large particle nearly deposited due to, decreased in slope and water transporting capacities [3].

When to attempt to identify the major cause of sever soil erosion, it is a complex process due to its interaction with geological condition, local climate, soil characteristics, land use/cover and unwise manmade causes. To estimate soil loss in any catchment, universal soil loss equation (USLE) is the primary model used for large area long term average annual soil loss in ton per hectare per year [4]. The six input parameter for USLE models, are: soil erodibility (K), slope length (LS), cover factor (C), and management practice (P) and rainfall erosivity (R), which reflects the raindrop effect and the runoff rate, derived from the rainfall [5].

2. Location of Study Area

The study area has an area of 22457.6 hectares, it is found in upper Blue Nile basin and located in wanka catchment in Estie district, Amhara Region, Ethiopia. The geographical location of the study area is about 387217.424904 E and 1295137.866290 N respectively, within an average elevation of 2268 meter above sea level. According to the Ethiopian meteorology agency Annual averages rainfall of this area is 1220 mm. The annual average temperature of the study area is 20.5°C. In the study area agriculture cover 16949.6 hectares from total catchment area of 22457.64 hectares [6].

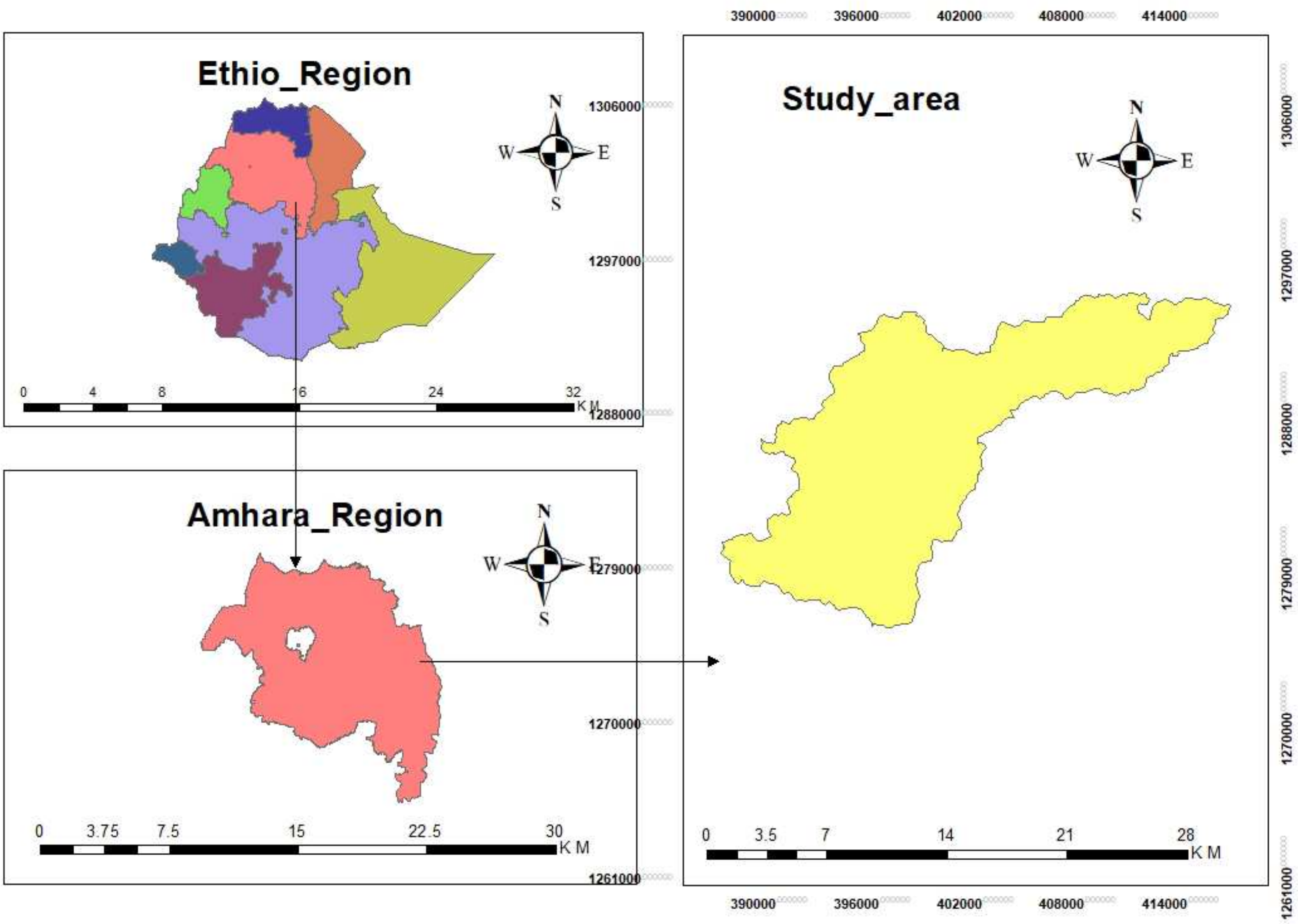

Figure 1. Location map of the study area.

2.1. Materials and Methods

Table 1. Input data.

No	Data Type	Source	Description
1	Rainfall data	Ethiopian Meteorological Station	Precipitation data for 32 years (1987–2019) of four ppt station
2	Soil data	Amhara soil map shape file Laboratory field sample analysis results	The soil map prepared by From Amhara soil shape file with UTM (1984)
3	Land use	Satellite image (Landsat)	Extracted from satellite image

Land Use

Land use/land cover type can affect infiltration, amount of surface runoff and ground water flow by falling of rainfall. Land cover of the study area is forest, plantation, shrub, open woody cover and land use is cultivated and grass land. Agricultural land generate more runoff in less rainfall as compared to forest land, because in crop land less amount of rainfall satisfy shortage of moisture more quickly.

2.2. Methods

The USLE is the recent empirical model used for the estimation of long term average annual soil erosion (t/ha/y), by weighting and overlaying the six factors: erosivity, erodibility, topographic factor, and cover factor and management practices [7]. GIS is used to analysis the USLEs input parameter and USLE model estimate average annual soil loss of the targeted area [8]. For the prediction of soil loss, six input parameters are convert to raster data for the processing of map layer weighting and overlay operations [9].

Revised Universal Soil Loss Equation

Site visit on physical observation to collect the input data such as erosivity, erodibility, cover factor, topographic factor and management practices for the analysis of annual soil loss are tedious, more expensive and time consuming practice [10]. In any study area there is no actual prediction of soil removal process from the land surface by runoff, because there are other soil transporting agents like wind. But beyond that science based physical model was produced in the last several year that is universal soil loss equation (USLE) to estimate annual soil removal in ton per hectare per year in a specific catchment [11]. Understanding the process and type of erosion has a great value in the process of conserving soil by different possible measures (physical and biological measures). The erodibility factor, erosivity factor, topographic factor, cover factor, and management practices all these factors are prepared (reclassify, assign weightage and overlay) with ArcGIS framework for estimating annual soil loss in the catchment [12]. Water erosion is the removal of soil from the land surface by the depressive action of rainfall and runoff relationship. The major factor affecting water erosion summarized according to the descriptive equation [13]:

$$A = R \times K \times LS \times C \times P \tag{1}$$

Where: A annual soil loss (t/ha/yr);

R erosivity factor;

K erodibility factor;

LS topographic factor;

C cover factor;

P management practice factor.

a) Rainfall runoff erosivity factor (R-factor)

The most important climatic factor influencing erosion by water is rainfall, the potential ability of rain cause to erosion is erosivity. When the rain droplets strikes the bare earth surface, it breakdown soil aggregate and detach soil particles (make it loose), fine material from the soil are removed, less fertile sand and gravels left behind. The number, size and velocity of drops determine the impacts of raindrops per unit area. Large drops increase the sediment carrying capacity and the velocity of raindrops. Continuous bombardment in rain storm by millions of raindrops cause damage by beating the bare soil in to the flowing mud. The R factor quantifies the effect of raindrop impacts, represent amount and rate of runoff associated with rainfall events. The R factor calculated as total storm times maximum 30 minute intensities [14]. Therefore, the erosivity factor was calculated from the spatial regression analysis of average annual rainfall using Thiessen polygon interpolation method [15]. It is given by a regression equation:

$$R=-8.12 + 0.562P \tag{2}$$

Where R rainfall erosivity factor

P average annual rainfall (mm).

b) Soil erodibility factor (K-factor)

The K factor is the rate of soil loss per rainfall erosion and it represent average long term response of a specific soil and combined effect of rainfall, runoff and infiltration. It is expressed as the change in soil loss per applied external forces. We know from observation that the same rainfall cause more erosion in one field than on other. This is due to the difference in soil erodibility (due to soil nature), which is the vulnerability or susceptibility of soil to erosion. The soil erodibility is can be derived through the analysis of soil properties, texture, structure and depth of top [16]. The soil erodibility characterized by removal of top soil, amount and rate of dragging sediment particle and this factor is obtained by direct measurement of surface runoff [17].

c) Slope Length factor (LS-factor)

Topographic factor is the combination of L and S factors. The steepness of land influence the rate of soil erosion because of runoff over steeper slopes carries more soil than gentle slopes and due to gravity influence rainfall have not enough time to infiltrate in to soil. Therefore, the steeper the slope of the land have the greater runoff [18]. When the velocity and volume of runoff increase the power of rainfall will be tremendous. Due to this the amount of material of a given size that can be transported by rolling is increased. The length of slope is the factor, which accumulates more runoff water with an increase in slope length [19]. To compute the slope length in ArcGIS environment a flow accumulation grid layer is required and the raster calculator formula is as follow:

$$\mathrm{L} = \mathrm{power}\frac{\text{“Flow accumulation”}*20}{(22.1,0.6)} * \mathrm{power}\frac{\text{“sin”}(\text{slope}*0.01745)}{(0.09,1.3)} \tag{3}$$

This formula is used to calculate slope length with raster calculator in ArcGIS expressed as percent dividing by 100.

Where L slope length

d) The cover management factor (C-factor)

The C factor is used to determine the relative effectiveness of soil and crop management system in terms of preventing soil loss. It is the ratio of comparing the soil from the land under a specific crop and management systems and the resulting value from this calculation is a generalized C factor value for a specific crop that does not account for crop rotation. A good vegetation cover of the ground can nearly avoid the effect of climate, soil erosion by intercepting of rain drips, decreasing runoff velocity and root effect. The effect of vegetation and grass cover on reducing soil erosion in nonagricultural areas and the management practices represent the effect of cropping activities in agricultural areas. For accurate estimation of soil erosion, it is important to create a reliable map of vegetation cover for C factor. Therefore soil erosion decrease with the increase in vegetation cover of the area.

e) The support practice factor (P-factor)

The P factor is known as the support practices factor. It reflects the effects of practices that reduce the amount and rate of the water runoff and thus reduce the amount of erosion. The P factor represent the ratio of soil loss by a support practice to that of straight row farming up and down the slope activities. P values vary from 0 to 1 where the highest value corresponding to the bare soil without support activities. In common practices the support practices are terracing, grass waterway and contour strip cropping [20].

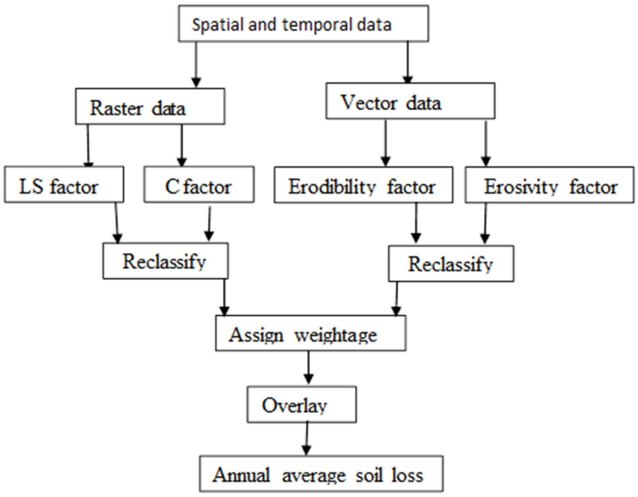

Figure 2. *Methodology of the study area.*

3. Results and Discussion

The study was provided an analysis to estimate annual soil loss in the Wanka catchment. The USLE model needs the input parameter of: rainfall erosivity (R-factor), soil erodibility (K-factor), land cover (C-factor), slope length (LS-factor) and support practices (P-factor) to estimate the annual average soil loss in the study area.

3.1. Rainfall and Runoff Erosivity Factor (R)

In this study area there is one meteorological station within the catchment and other two are around the catchment. The R-factor was calculated by using interpolation techniques of this three metrological station rainfall data from 1990 to 2020 years and the value is expressed in raster layer format. The R-factor was calculated from thirty years rainfall data that obtained from the three metrological station.

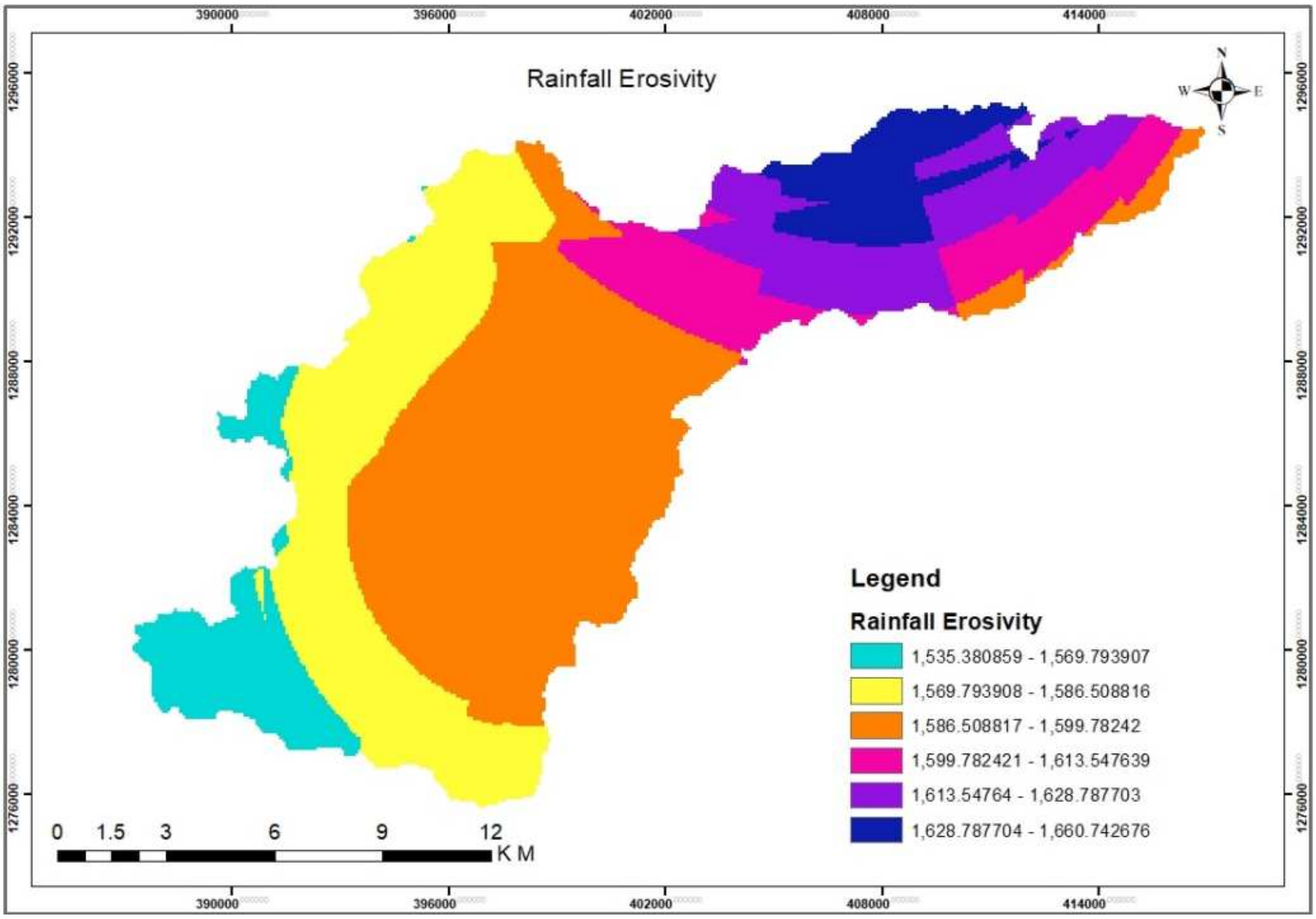

Figure 3. *Spatial distribution of R-factor over the catchment.*

3.2. Soil Erodibility Factor (K)

In study area there are three types of soil group that are Lithic Leptosols (fall under textural class of sandy loam, cover an area of 5723.8 ha, 25.5%), Chromic Luvisols (loamy texture, cover 10571.9 ha, 47%) and Haplic Luvisols (loamy texture, cover 6160.51ha, 27.5%) (Figure 4). The K-factor is the rate of soil loss per rainfall erosion index and derived through the analysis of a soils texture and its percentage of organic matter. Based on this study, the soil erodibility factor of the catchment was identified and the value range was between 0 and 0.15 [21].

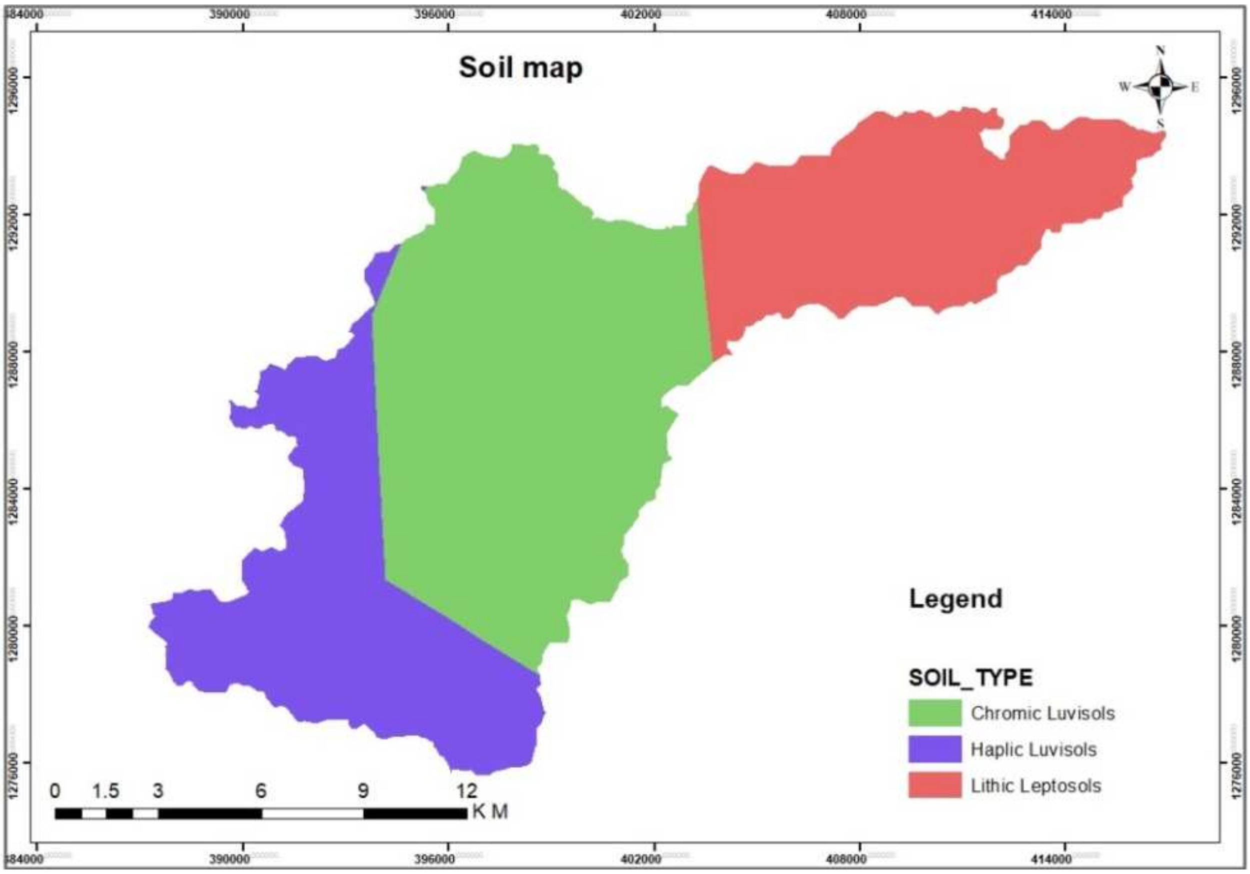

Figure 4. *Main soil group of the catchment.*

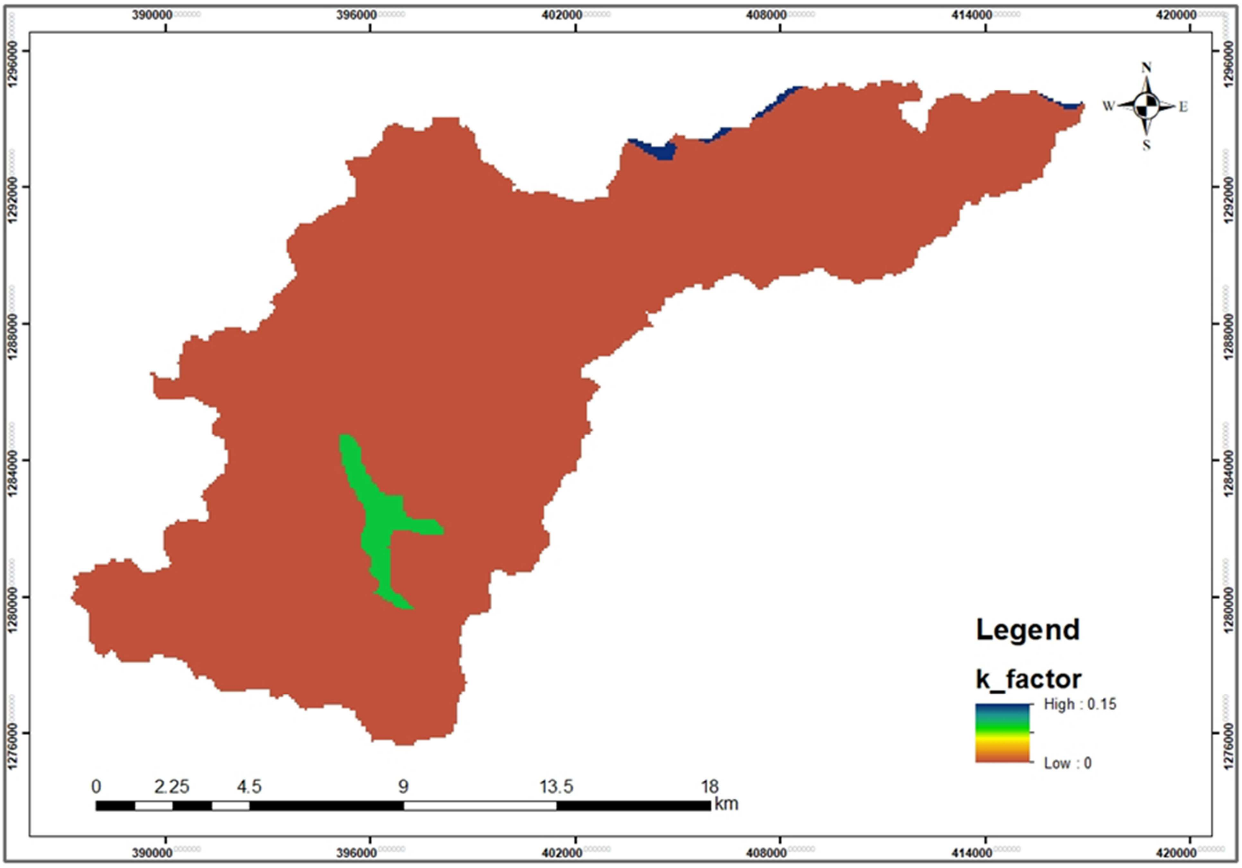

Figure 5. *Spatial distribution of K-factor over the catchment.*

Table 2. *Soil group characteristics in the catchment.*

Soil type	Area Ha	HSG	Texture
Lithic Leptosols	5723.757	A	Sandy loam
Chromic Luvisols	10571.887	B	loam
Haplic Luvisols	6160.513	B	loam
Sum Area	22456.157		

HSG= hydrological soil group.

3.3. Slope Length Factor (LS-factor)

The threshold for the LS factor determination was DEM and it was calculated using unit stream power equation with raster calculator. The LS factor represent the effect of slope length and slope steepness on the soil erosion. The slope length and slope steepness factors are the ratio of actual horizontal length to the measured slope length of 22.1m and the ratio of actual slope to the measured slope of 9% respectively (Figure 6).

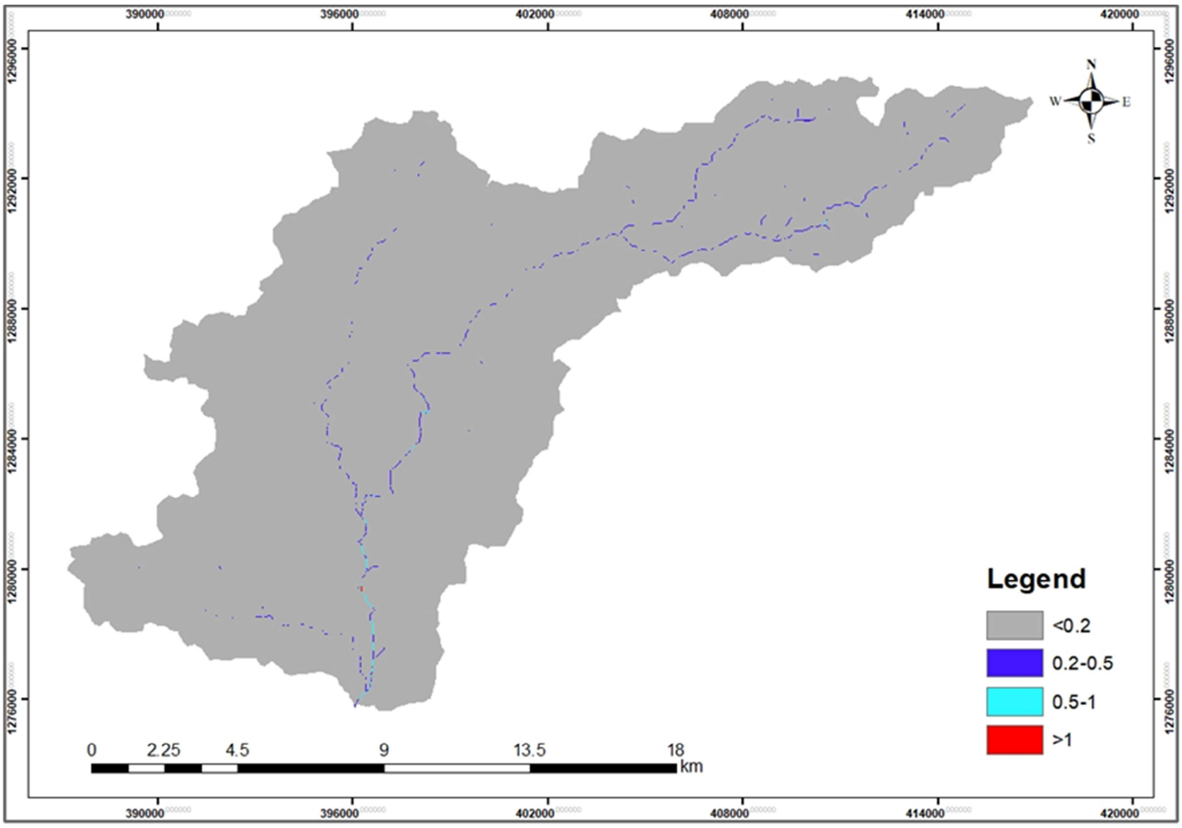

Figure 6. *Spatial distribution of Ls factor over the catchment.*

3.4. The Cover Management Factor (C-factor)

The land cover management, which account for the protection with ground cover, forest cover, crop cover and grass cover is the one important input factor for USLEs model. C factor was estimated as soil loss from the field under cover condition compared with the loss from continuous up and downslope tillage activities. The C factor in the catchment is range from 0.01 and 0.2 and its value is high in southern part of the catchment where most of the area is covered with cultivated land [22]. In contrast, at the middle to east part and northern part of the catchment there is a small coverage of grass, afro alpine and plantation forest.

Table 3. *The distribution of land use land cover in catchment.*

Cover type	Area (hectare)	Area (percent)
Afro-alpine	540.37	2.4
Cultivation Land	17000	75.65
Grass Land	4171.53	18.56
Plantation	198.47	0.883
Shrub Land	560.18	2.49
Total	22457.6	100

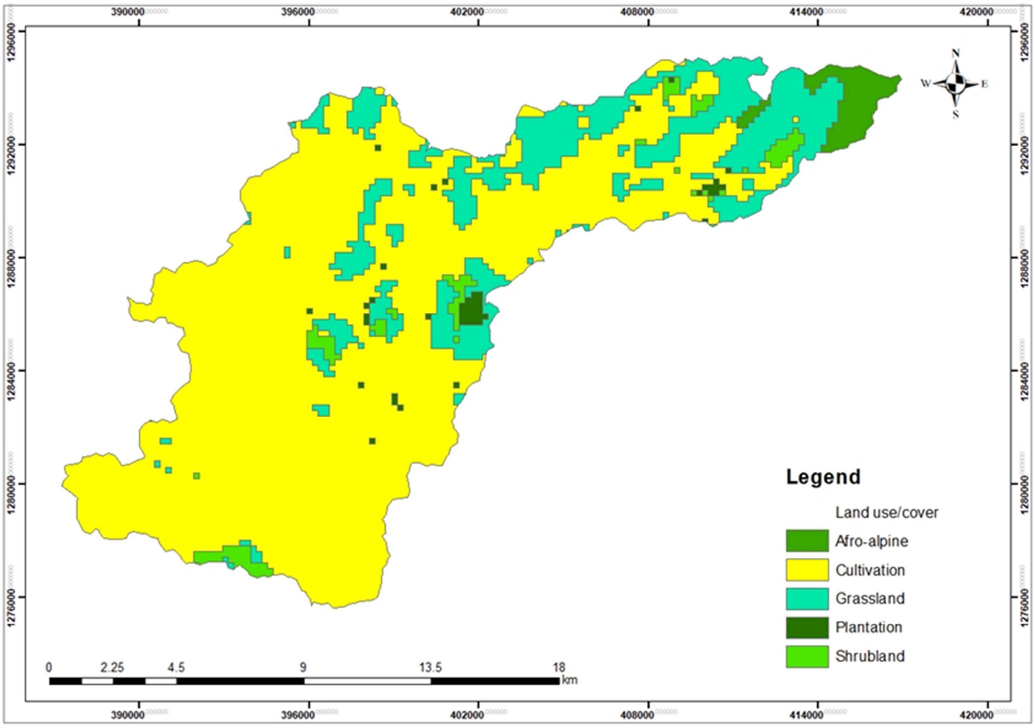

Figure 7. The distribution of land use land cover in catchment.

3.5. The Support Practice Factor (P-factor)

The P factor refers to the practices which are used to control soil loss in the study area and the values are determined according to the soil and water conservation activities. P values are defined as the ratio of soil lost from the filed with the support practices to unwise agricultural measures. In some part of the study area there was practiced soil bund, stone faced terracing and biological soil and water conservation activities. But in some part of the study area until know there is unwise use of tillage (up and down ploughing), deforestation and over grazing. By these reason the values of support practices (P- factor) is ranges from 0.1 to 1, where the highest values are correspond to bare land without any support practices and the lowest values are lay in conserved areas.

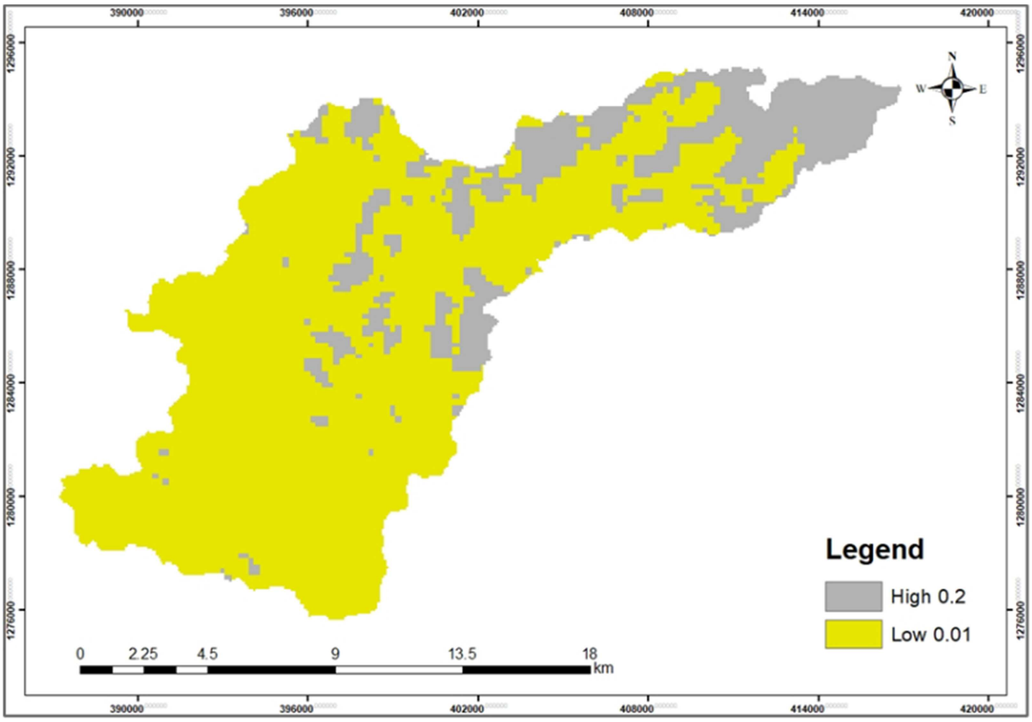

Figure 8. Spatial distribution of C-factor over the catchment.

3.6. Estimating Soil Erosion

Once the six parameters are calculated in the raster format over the whole study area, soil loss was computed using ArcGIS raster calculator tool. Here there was computed the value of USLE annual average soil loss in ton/ha/year and its value ranges from 0 to 169.321 ton/ha/year in the study area. As seen from the result (figure 10), in Northern and North east part of study area there was experiences soil loss and it ranges from 0 to 169.321 ton/ha/year, due to slope and human activities.

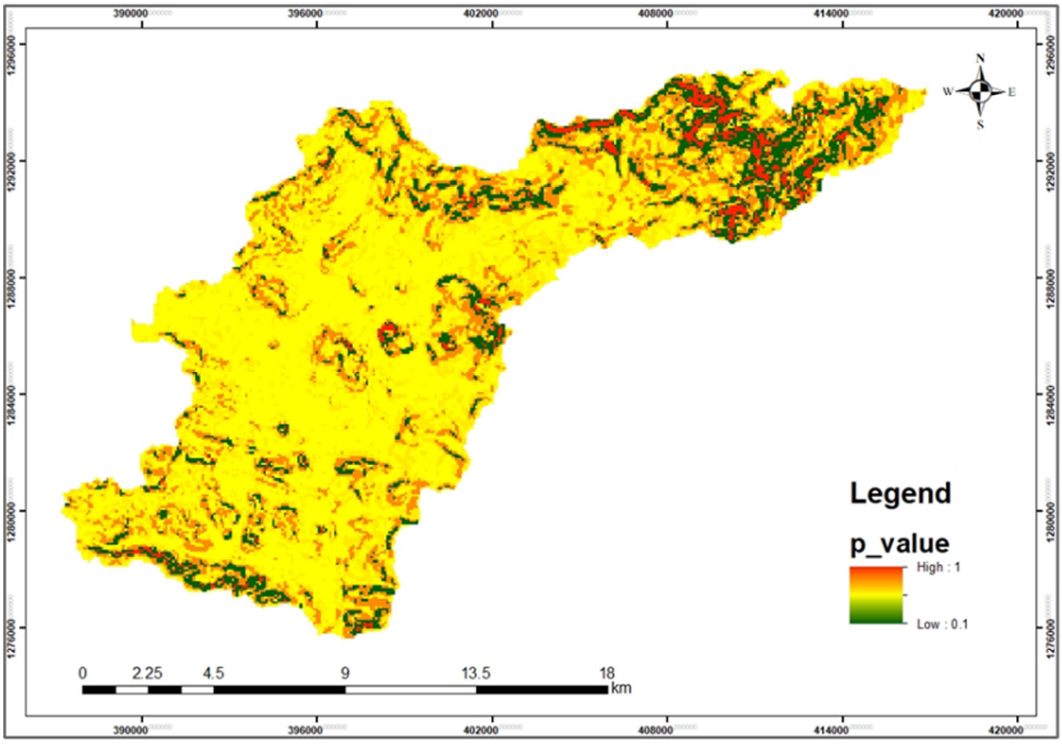

Figure 9. *Annual soil loss.*

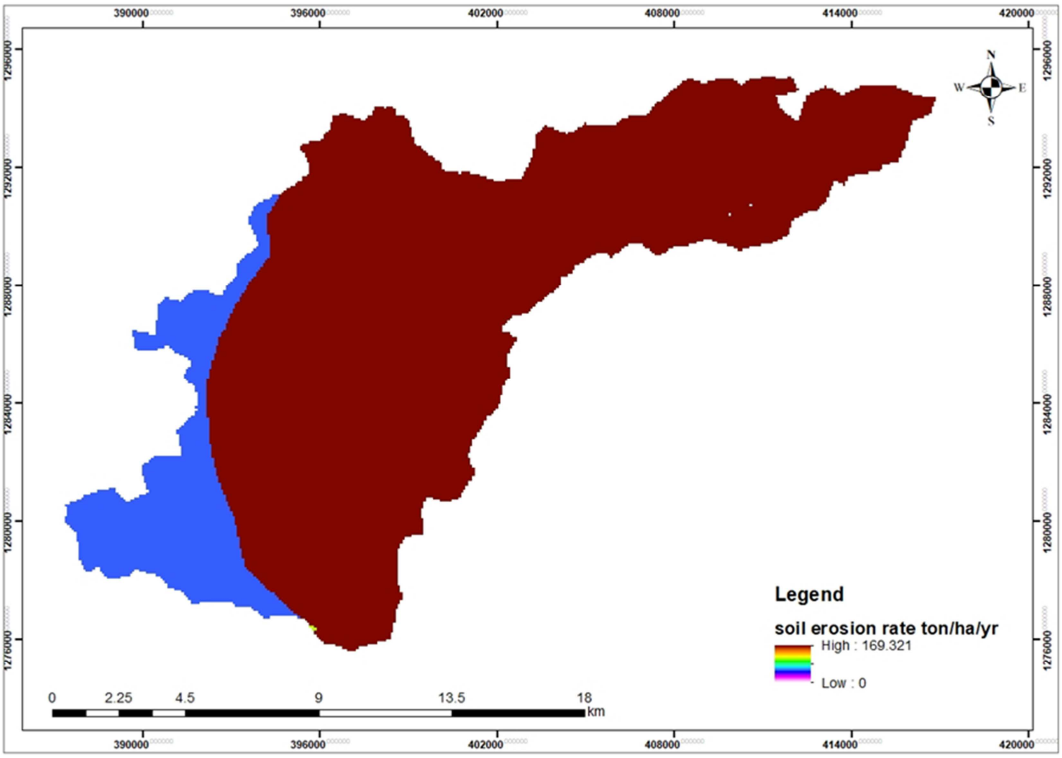

Figure 10. *Spatial distribution of soil loss over the catchment.*

4. Conclusion

In this study, catchment scale assessment of soil loss has been done for Wanka catchment and erosion was estimated based on USLE in ArcGIS 10.3 by multiplying rainfall erosivity factor, topographic factor, soil erodibility factor, cropping management factor and conservation practices factor using raster calculator function tool. The USLE was used to estimate the annual average soil loss rate (A) in ton/ha/year and the results indicated that the catchment soil loss have been up to 169.321 ton/ha/year [23]. The study results constitute valuable support that should help the decision-makers in implementing suitable soil and water conservation practices in the whole catchment in order to reduce the amount of soil loss.

References

[1] Kumar, Suresh. (2019). Geospatial approach in modeling soil erosion processes in predicting soil erosion and nutrient loss in hilly and mountainous landscape *Remote sensing of northwest Himalayan ecosystems* 355-380.

[2] Quan, Xin, He, Jijun, Cai, Qiangguo, Sun, Liying, Li, Xueqing, & Wang, Shuo. (2020). Soil erosion and deposition characteristics of slope surfaces for two loess soils using indoor simulated rainfall experiment. *Soil and Tillage Research, 204*: 104714.

[3] Han, Zhen, Zhong, Shouqin, Ni, Jiupai, Shi, Zhonglin, & Wei, Chaofu. (2019). Estimation of soil erosion to define the slope length of newly reconstructed gentle-slope lands in hilly mountainous regions. *Scientific Reports, 9*: 1-11.

[4] Senanayake, Sumudu, Pradhan, Biswajeet, Huete, Alfredo, & Brennan, Jane. (2020). A review on assessing and mapping soil erosion hazard using geo-informatics technology for farming system management. *Remote Sensing, 12*: 4063.

[5] Koirala, Pooja, Thakuri, Sudeep, Joshi, Subesh, & Chauhan, Raju. (2019). Estimation of soil erosion in Nepal using a RUSLE modeling and geospatial tool. *Geosciences, 9*: 147.

[6] Khorrami, Behnam, Heidarlou, Hadi Beygi, & Feizizadeh, Bakhtiar. (2021). Evaluation of the environmental impacts of urbanization from the viewpoint of increased skin temperatures: a case study from Istanbul, Turkey. *Applied Geomatics, 13*: 311-324.

[7] Atoma, Habtamu, Suryabhagavan, K. V., & Balakrishnan, M. (2020). Soil erosion assessment using RUSLE model and GIS in Huluka watershed, Central Ethiopia. *Sustainable Water Resources Management, 6*: 1-17.

[8] Erkal, Tevfik. (2013). Assessment of soil erosion in the Ihsaniye watershed area, Afyonkarahisar, Turkey. *Scientific Research and Essays, 8*: 388-397.

[9] Boardman, John, & Evans, Robert. (2020). The measurement, estimation and monitoring of soil erosion by runoff at the field scale: Challenges and possibilities with particular reference to Britain. *Progress in physical geography: earth and environment, 44*: 31-49.

[10] Rahaman, S. Abdul, Aruchamy, S., Jegankumar, R., & Ajeez, S. Abdul. (2015). Estimation of annual average soil loss, based on RUSLE model in Kallar watershed, Bhavani basin, Tamil Nadu, India. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2*: 207.

[11] Preetha, Pooja P., & Al-Hamdan, Ashraf Z. (2019). Multi-level pedotransfer modification functions of the USLE-K factor for annual soil erodibility estimation of mixed landscapes. *Modeling Earth Systems and Environment, 5*: 767-779.

[12] Behera, Madhusmita, Sena, Dipaka R., Mandal, Uday, Kashyap, Pradeep S., & Dash, Sonam S. (2020). Integrated GIS-based RUSLE approach for quantification of potential soil erosion under future climate change scenarios. *Environmental Monitoring and Assessment, 192*: 1-18.

[13] Bekele, Bagegnehu, Muluneh, Alemayehu, & Wondrade, Nigatu. (2019). Geographic information system (GIS) based soil loss estimation using universal soil loss equation model (USLE) for soil conservation planning in Karesa watershed, Dawuro zone, south West Ethiopia. *International Journal of Water Resources and Environmental Engineering, 11*: 143-158.

[14] Alemu, Woubet G., & Melesse, Assefa M. (2020). Impacts of longterm conservation measures on ecosystem services in Northwest Ethiopia. *International Soil and Water Conservation Research, 8*: 47-55.

[15] Duarte, L., Teodoro, A. C., Gonçalves, J. A., Soares, D., & Cunha, M. (2016). Assessing soil erosion risk using RUSLE through a GIS open source desktop and web application. *Environmental monitoring and assessment, 188*: 1-16.

[16] Yang, Xihua, Gray, Jonathan, Chapman, Greg, Zhu, Qinggaozi, Tulau, Mitch, & McInnes-Clarke, Sally. (2017). Digital mapping of soil erodibility for water erosion in New South Wales, Australia. *Soil Research, 56*: 158-170.

[17] Panagos, Panos, Borrelli, Pasquale, Meusburger, Katrin, van der Zanden, Emma H., Poesen, Jean, & Alewell, Christine. (2015). Modelling the effect of support practices (P-factor) on the reduction of soil erosion by water at European scale. *Environmental science & policy, 51*: 23-34.

[18] Panagos, Panos, Borrelli, Pasquale, & Meusburger, Katrin. (2015). A new European slope length and steepness factor (LS-Factor) for modeling soil erosion by water. *Geosciences, 5*: 117-126.

[19] Teshome, Asirat, Halefom, Afera, Teshome, Menberu, Ahmad, Imran, Taddele, Yihun, Dananto, Mihret,... Szucs, Peter. (2021). Soil erosion modelling using GIS and revised universal soil loss equation approach: a case study of Guna-Tana landscape, Northern Ethiopia. *Modeling Earth Systems and Environment, 7*: 125-134.

[20] Zhu, Mingyong. (2015). Soil erosion assessment using USLE in the GIS environment: a case study in the Danjiangkou Reservoir Region, China. *Environmental Earth Sciences, 73*: 7899-7908.

[21] Ghosal, Kaushik, & Das Bhattacharya, Santasmita. (2020). A review of RUSLE model. *Journal of the Indian Society of Remote Sensing, 48*: 689-707.

[22] Benavidez, Rubianca, Jackson, Bethanna, Maxwell, Deborah, & Norton, Kevin. (2018). 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, 22*: 6059-6086.

[23] Maqsoom, Ahsen, Aslam, Bilal, Hassan, Usman, Kazmi, Zaheer Abbas, Sodangi, Mahmoud, Tufail, Rana Faisal, & Farooq, Danish. (2020). Geospatial assessment of soil erosion intensity and sediment yield using the revised universal soil loss equation (RUSLE) model. *ISPRS International Journal of Geo-Information, 9*: 356.