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Research Article

Soil Erosion Risk Assessment and Mapping Using GIS in Angacha Watershed, North Gonder, Ethiopia

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Abstract

Soil erosion is one of the most challenging problems faced by farmers and natural resource managers worldwide and which threats to agricultural production. Increasing the awareness and providing information amongst scientists and policy makers about the soil degradation problem is now an urgent requirement. Therefore this study is aimed to assess erosion risk and quantify soil loss at watershed level. GIS simulating model using a universal soil loss equation (USLE) was applied to analyze the amount of soil loss in Angacha watershed of Ethiopia. The result of the analysis depicted that the amount of soil loss in Angacha watershed ranges from 0 to 41.15 t/ha/year. The mean annual soil loss of the watershed is 28.84 t/ha/year. This study also identified erosion prone areas and mapped for planning of soil and water conservation measures based on the slope classes of the watershed.

Keywords: Soil erosion, farmers, natural resource managers, soil degradation, soil loss equation.

Introduction

Soil erosion is one of the most important and challenging problems faced by farmers and natural resource managers worldwide (Lal, 1995; Cebecauer and Hofierka 2008). Because of soil erosion, vast areas of once fertile lands have been rendered unproductive. It is estimated that of the world's total land area of 13.4 x 10^9 ha, about 2.0 x 10^9 ha is degraded to some extent (World Resources Institute, 1993). Asia and Africa combined account for a total of 1.24 x 10^9 ha of the degraded land, with water erosion the most prominent degrading process (UNEP, 1993). According to Lal (1995), by the year 2020, yield reduction due to soil erosion may be as much as 16.5% for the African continent and about 14.5% for sub-Saharan Africa. Regardless of the methods used in the assessment of these rates, the message is clear: the situation is alarming worldwide and something must be done. Soil erosion is also one of the major threats to agricultural production in Ethiopia (Wagayehu and Drake, 2003; Admasu, 2005; Tamene, 2005; Bewket and Teferi, 2009). A research reported by Vancampenhout (2006) showed that the north Ethiopia highlands including Gondar are among the areas mostly affected by soil erosion and consequently reducing crop yields. The main causes of soil erosion are still inappropriate agricultural practices, deforestation, overgrazing and construction activities (Holden, 1993; Yassoglou *et al.*, 1998). Increasing the awareness amongst scientists and policy makers about the soil degradation problem in Ethiopia particularly in North Gondar is now an urgent requirement. Also there is not much information to what extent soil erosion in the area and the amount of soil loss is not estimated yet. The identification of areas that are vulnerable to soil erosion can be helpful for improving knowledge about the extent of the areas affected and, ultimately, for developing measures to keep the problem under control whenever possible (Gitas *et al.*, 2009). In an attempt to quantify erosion in North Gonder particularly in Angacha watershed using modern digital techniques like; GIS based USLE model is very crucial (Reusing, 2000). Therefore, this study is aimed to quantify the amount of soil loss from the catchment and classify the catchment based on severity of erosion and mapping which provides factual information to implement appropriate SWC measures.

Materials and methods

Location of the study area: The project area is located in Amhara region, North Gonder, Gondar Zuria Woreda. The project area is located between 12°28''-12°30''N and 37°27''- 37°33'' E.

Climate: The climate of Angacha watershed pressurized irrigation project is marked by rainy season from May to October, with monthly rainfall varying 67 mm in October to 306 mm in July.

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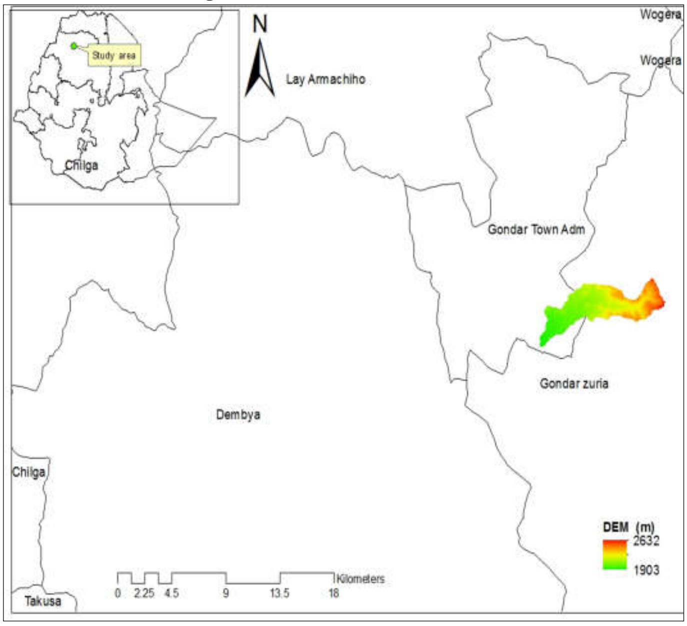
Fig. 1. Map of the study area.



Rainfall in the project area is monomodal. Temperature variation throughout the year is minor. Maximum temperature varies from 23°C in July to 30°C in March, whereas minimum temperature ranges from 11°C in January to 15.6°C in April and May. Humidity varies from 39% in March 79% in August. Wind speed is low, thus minimizing potential evapo-transpiration values between 101 mm /month in July and 149 mm/month in March. Sunshine duration is reduced to 4.2 -4.9 hours during July and June respectively.

Soil type and vegetation

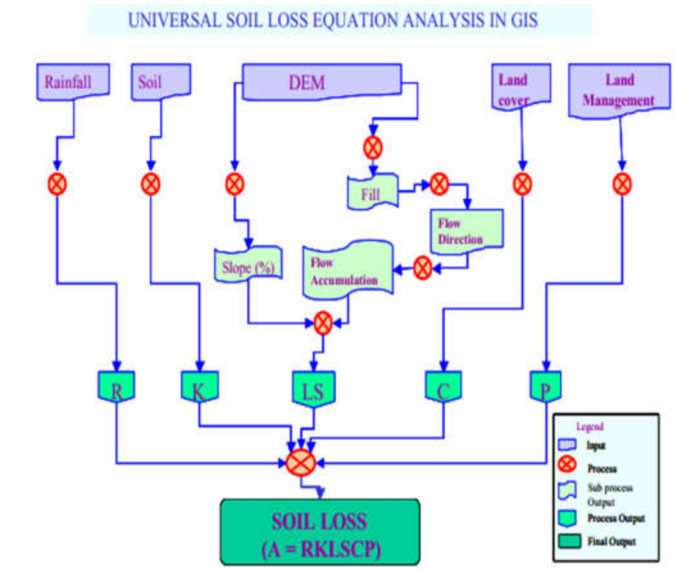
Land use and farming system: Traditional agricultural activities, both livestock's and crop production, are practiced in the project area. Crop production is mainly depending on the availability of the adequate rainfall, however, due to insufficient and fluctuating rainfall, the production is unreliable.

Methodology: The universal soil loss equation was employed to assess the amount of soil loss existed in the basin. The universal soil loss equation is an empirical model developed by Wischmeir and Smith (1978) to estimate soil erosion from fields. Mathematically the equation is denoted as:

A (tons/ha/year) = R * K* L * S * C * P

Where, A is the mean annual soil loss, R is the rainfall erosivity factor, K is the soil erodability factor, L is the slope length factor, S is the slope steepness factor, C is the crop management factor and P is the erosion control practice or land management factor.

The USLE was applied in GIS based on the flow chart as shown below:



The analysis of each process factors was derived as follows:

Rainfall Erosivity Factor (R): Soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to run-off. Rainfall erosivity index is a factor established by blowing energy from rain drop per storm event, kinetic energy of rainfall, and maximum 30 minute rainfall intensity. Although there are many methods of calculating rainfall erosivity, the values for the R factor was estimated according to the equation proposed by (Hurni, 1985; Shiferaw, 2011).

R = -8.12 + 0.562 * P

Where, R= Rainfall erosivity; P= mean annual precipitation (mm/yr)

The mean annual rainfall data of 15 years was taken from available stations to calculate R factor. Then the calculated R factor for each station was converted to raster surface with 30m grid cell using interpolation techniques.

Soil Erodability Factor (K): Soil Erodability Factor (K) defines as mean annual rainfall soil loss per unit of R for a standard condition of bare soil, recently tilled up and down with slope with no conservation practices and on a slope of 5° and 22 m length (Morgan, 1994). The value of K ranges from 0 to 1. Soil texture, organic matter, structure and permeability were determined in soil laboratory to calculate value of soil erodiblity (K) from Nomograph. Composite soil samples were taken for organic matter and texture analysis.

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Slope length and Slope steepness (LS): The slope length and slope steepness can be used in a single index, which expresses the ratio of soil loss as defined by (Wischmeier and Smith, 1978).

$$LS = (X/22.1)^m (0.065 + 0.045\,S + 0.0065\,S^2)$$

Where X= slope length (m) and S= slope gradient (%)
The values of X and S were derived from DEM. To calculate the X value, Flow Accumulation was derived from the DEM after conducting FILL and Flow Direction processes in ArcGIS.
X = (Flow accumulation * Cell value)
By substituting X value, LS equation will be:
$LS = (\text{Flow accumulation} * \text{Cell value}/22.1)^m(0.065 + 0.045\,s + 0.0065\,s^2)$
Moreover slope (%) also directly derived from the DEM using the same software.

Crop Management factor (C): The crop management factor represents the ratio of soil loss under a given crop to that of the base soil (Morgan, 1994).
The land use map was used for analyzing the c - value. After changing the coverage to grid, a corresponding C- value was assigned to each land use classes using Re-class method in ArcINFO 9.

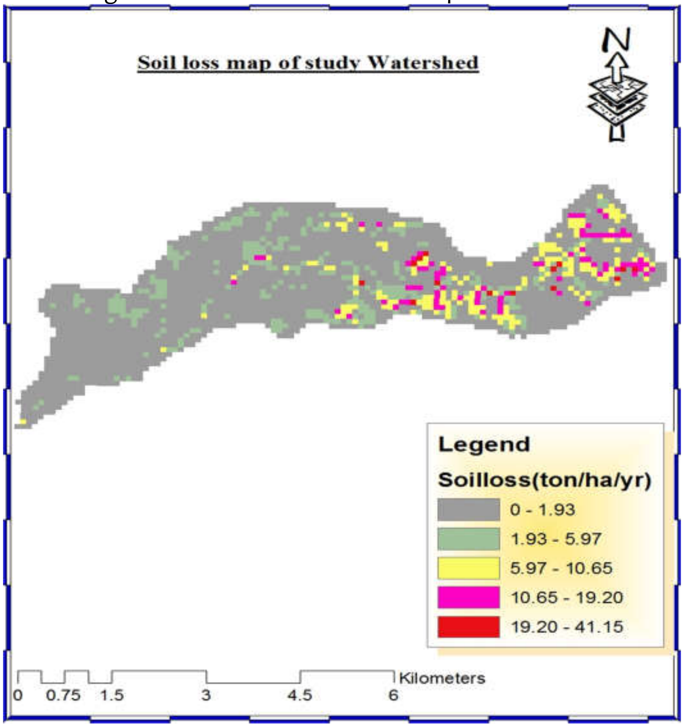
Erosion Management Practice Factor (P-value): These management activities are highly depends on the slope of the area. P value was calculated by delineating the land in to two major land uses, agricultural land and other land and based on the slope percent to assign different P value. The agricultural land sub - divided in to six classes based on the slope percent to assign different P–value. In this study, the researchers were employing same technique to assign the P-value of the catchment.

Phases of the research: The study was conducted in to two phases which involves estimating the amount of soil loss in the first phase and secondly erosion mapping based on severity of erosion in the catchment.

Results and discussion

Based on the analysis, the amount of soil loss in the Angacha watershed is about 41.15 ton per year from two thousand hectare. As shown in the Fig. 2, the amount of soil loss of each parcel of land in the basin ranges from 0-41.15 t/ha/year. The mean annual soil loss of the watershed is 28.84 t/ha/year. The result of study falls within the ranges of the findings of FAO (1984). According to the estimate of FAO (1984), the annual soil loss of the highlands of Ethiopia ranges from 1248 –23400 million ton per year from 78 million of hectare of pasture, ranges and cultivated fields throughout Ethiopia.

Fig. 2. Amount of soil loss of each parcel of land.



The spatial locations of the high spot area for soil erosion in the study revealed that the potential soil loss is typically greater along the steeper slope banks of tributaries. Other high soil erosion areas are dispersed throughout the basin and are typically associated with high erosion potential land uses. Plain area of the basin showed the least vulnerable to soil erosion.

Rainfall Erosivity Factor (R): Soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to run-off. Rainfall erosivity index is a factor established by blowing energy from rain drop per storm event, kinetic energy of rainfall, and maximum 30 minute rainfall intensity. Although there are many methods of calculating rainfall erosivity, the values for the R factor was estimated according to the equation proposed by Hurni (1985).

$$R = -8.12 + 0.562 * P$$

Where, R= Rainfall erosivity
P= mean annual precipitation (mm/yr)

The mean annual rainfall data of 15 years was be taken from available stations to calculate R factor. Then the calculated R factor for each station was converted to raster surface with 30m grid cell using interpolation techniques (Fig. 3).

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Fig. 3. Rainfall Erosivity Factor (R).

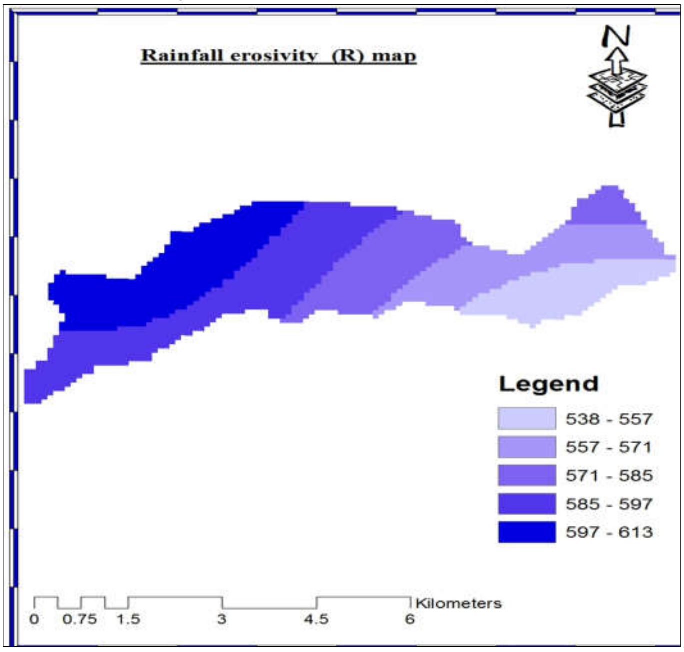

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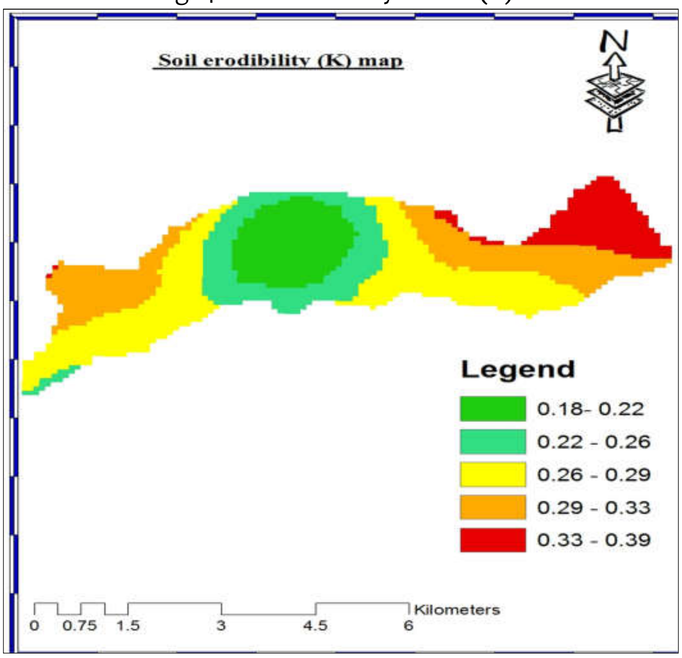
Fig. 4. Soil Erodability Factor (K).



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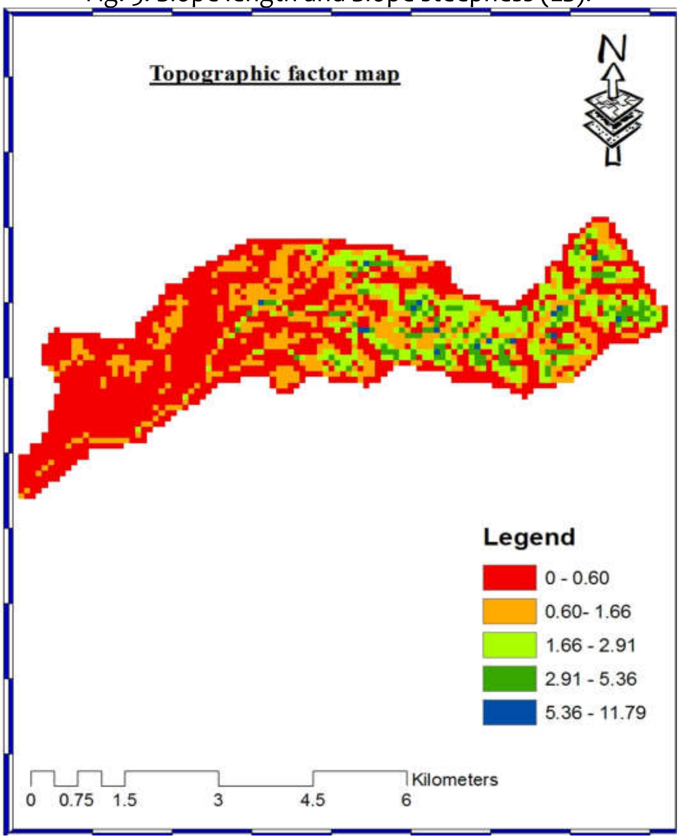
By substituting X value, LS equation will be:
$LS = (\text{Flow accumulation} * \text{Cell value} /22.1)^m (0.065 + 0.045 s + 0.0065 s^2)$
Moreover slope (%) also directly derived from the DEM using the same software (Fig. 5).

Fig. 5. Slope length and Slope steepness (LS).



Crop Management factor (C): The crop management factor represents the ratio of soil loss under a given crop to that of the base soil (Morgan, 1994). The land use map was used for analyzing the c - value. After changing the coverage to grid, a corresponding C- value was assigned to each land use classes using Re-class method in ArcINFO 9 (Fig. 6).

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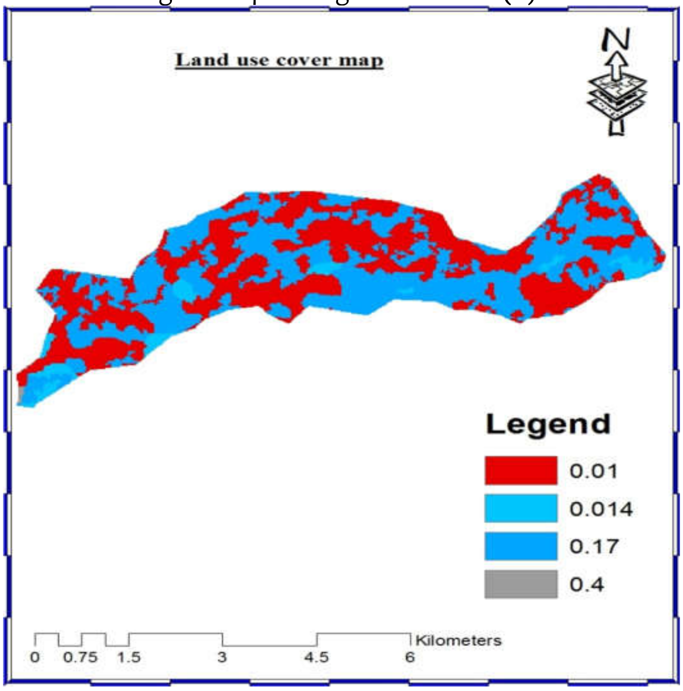
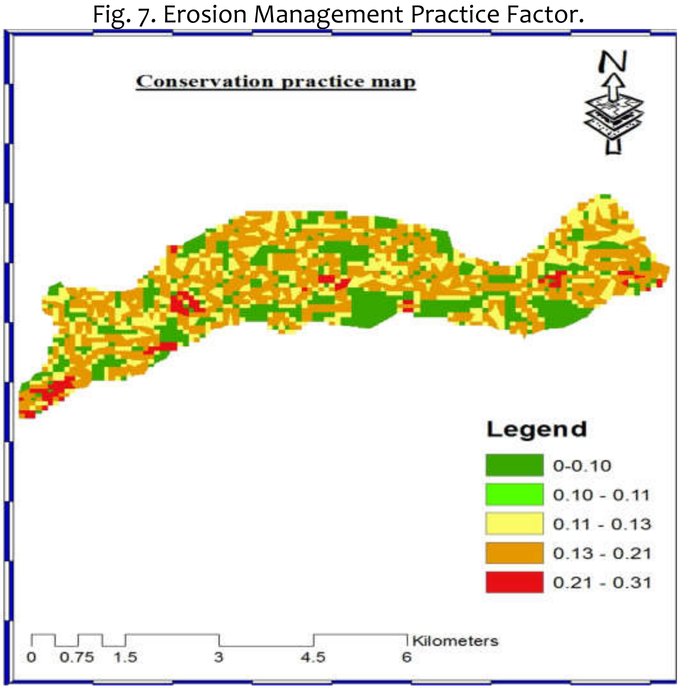
Fig. 6. Crop Management factor (C).



Erosion Management Practice Factor (P-value): These management activities are highly depends on the slope of the area. P value was calculated by delineating the land in to two major land uses, agricultural land and other land and based on the slope percent to assign different P value. The agricultural land sub-divided in to six classes based on the slope percent to assign different P–value. In this study, the same technique was employed to assign the P-value of the catchment (Fig. 7).

Fig. 7. Erosion Management Practice Factor.



Conclusion

Using USLE in combination with GIS allowed analysis of erosion risks in Angacha watershed. Most of the parts of this watershed have experienced intensive soil erosion behavior, which is beyond the tolerable soil loss level. This threatens the annual crop production and the productivity of the land impacting the local farmers' food security (Brevik, 2013). Besides, since the watershed is upstream to Lake Tana the erosion may also have off-site consequences in the lake and have the possibility to modifying its nature and function due to sedimentation and pollution problems.

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