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ABSTRACT
Soil erosion is one of the major causes of land degradation in arid and semi-arid areas like Ethiopia, including Tigray Highlands, which is highly affected by the risk of desertification. Tackling on-site effects of soil erosion requires understanding of the rates of soil loss as well as identification of the major controlling factors that accelerate or slow down these processes. The study aims to quantify the soil loss by erosion process and to specify the main factor affecting the Erosion development in the study area. The Study area was Kilte Awulaelo District which is situated in the eastern part of Tigray region, Ethiopia. Soil erosion models (such as RUSLE) use mathematical expressions to represent the relationships among various factors and processes occurring in the landscape. The RUSLE analysis has been applied to this case study. ArcGIS\textsuperscript{TM} and Excel software were used for all the calculations procedures of RUSLE values and to produce the soil erosion risk map. The final quantitative RUSLE values showed the loss quantity of soil in t/ha/year, ranging from less than 1 to very high soil loss rates (223.6 t/ha/y). The data shows also that Topography (LS) factor was the most effective factor controlling the erosion process followed by the support practices (P) factor. The study showed that stone bands are successful management practice to conquer the soil erosion dilapidations. This study demonstrates that Remote Sensing and GIS are effective tools in generating spatial and quantitative information on soil erosion studies and risk assessment mapping.

Key words: Erosion Risk Mapping, Soil Erosion; RUSLE; GIS; Remote sensing; stone bands, Ethiopia.


INTRODUCTION
Soil erosion is one of the biggest global environmental problems resulting in both on-site and off-site effects. The economic implications of soil erosion are more serious in developing countries because of lack of capacity to cope with it and also to replace lost nutrients. These countries have also high population growth which leads to intensified use of already stressed resources and expansion of production to marginal and fragile lands. Such processes aggravate erosion and productivity declines, resulting in a population-poverty-land degradation cycle.
Fast population growth, cultivation on steep slopes, removing of vegetation, and overgrazing are the major factors that increases soil erosion in Ethiopia. Ethiopia losses annually over 1.5 billion tons of topsoil from the highlands by erosion, that could have added about 1 to 1.5 million tons of grain to the country’s harvest (Taddese, 2001).

In Tigray (Northern Ethiopia), soil moisture has been identified as the most limiting factor in agricultural production; on the other hand, loss of rain water through runoff as well as the induced soil loss has been determined as a critical problem in the region in the last three decades (Tewodros et al., 2009). The severity of soil erosion in such regions is the result of the mountainous and hilly topography, torrential rainfall and low degree of vegetation cover. According to (Hamilton, 1977), deforestation started already 2000 years ago. In many parts of Tigray, soil erosion has made the cultivation of old farmland impossible and farmers are forced to constantly cultivate new and more marginal areas (Esser and Vagen, 2002). Therefore, erosion hazard is significantly substantial in the study area. Soil erosion (Figure 1) creates strong environmental impacts and high economic costs due to the effect on agricultural production, infrastructure and water quality (Breetzke, 2004). Also, soil loss is one of the major factors affecting sustainability of agricultural production.

Rainfed crop production is the main economic activity for over 85% of the Tigray population. In such situations erosion processes have to be controlled to avoid severe soil loss which reduces the fertility of the soils. For these reasons, studies on soil erosion and water conservation were carried on in this area suggesting new management techniques to combat erosion risk (Nyssen et al., 2007). Antropic activities like uncontrolled grazing, deforestation due to high demand for agricultural lands and firewood collection to supply the needs of the increasing population are principal causes of soil erosion in the study area.

Soil conservation planning and erosion risk maps, typically created using erosion models, are becoming more and more important. Soil erosion models are widely used to calculate the soil erosion rates and it uses mathematical expressions to symbolize the relationships between different factors and processes occurring in the landscape. These factors generally include topography, meteorological variables, soil properties, and land use and land cover features.

Soil erosion models can be divided into two main groups: empirical models and physically-based models. A large number of erosion models are based on the famous empirical model Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) (e.g., Agricultural Non Point Source Pollution (AGNPS), Areal Nonpoint Source Watersheets Environment Response Simulation (ANSWERS), the Erosion Productivity Impact Calculator (EPIC) and Soil and Water Assessment Tool (SWAT). Other models aim at a representation of the catchment in a cascade of planes and channel elements like Kinematic and Runoff Erosion model (KINEROS2) and the European Soil Erosion Model (EUROSEM) or they are not intended for use at catchment scale like Chemical, Runoff and Erosion for Agriculture Management Systems (CREAMS). An extensive description and discussion of these models can be found in (Merrit et al., 2003).

USLE model is the most empirical erosion model widely used. It was developed for sheet and rill erosion based on a large set (i.e., 10,000 plots) of experimental data from agricultural plots and is only valid when applied to a field area up to approximately 1 ha. Although the USLE has been developed in the USA, it was used throughout the world (Bartsch et al., 2002) because it seemed to meet the needs of researchers better than any other available tool. USLE concept has been modified and
adapted during the past 45 years by a large number of researchers. The Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997), ANSWERS and RUSLE-3D (Mitasova et al., 1999) are all based on USLE and represent modifications or improvement of the former. In order to quantify the soil loss, RUSLE analysis has been applied to this case study, according to all the affecting variables that allowed to be considered, adapting some calculations proved to be efficient (Desta et al., 2005) in this study area environment. RUSLE, were chosen to assess the soil erosion rates because (1) data requirements are not too complex or unattainable, within the context of a developing country like Ethiopia, (2) the models are compatible with Geographical Information System (GIS), and (3) they are easy to implement and understand from a functional perspective (Milward and Mersy 1999).

Figure 1- Severe soil erosion effect.

It is obvious from literatures that spatial modelling and geographic information systems (GIS) are becoming progressively more suitable tools in fields of research like forestry, agriculture, hydrogeology and soil science (Köhl and Gertner 1997, Bocchi et al., 2000, Basso et al., 2001, Panagopoulos et al., 2002). Also the joint use of GIS and USLE/RUSLE has been demonstrated to be an successful approach for estimating the quantitative erosion and the spatial distribution of erosion risks (Fernández et al., 2003; Hoyos, 2005; Jabbar and Chen, 2005; Erdogan et al., 2006; Fu et al., 2006; Irvem et al., 2007; Saroingsong et al., 2007).

This study was conducted in northern Ethiopia in order to assess rates of soil loss, investigate controlling factors, and analyze spatial patterns and management alternatives. To avoid erosion impacts, it is important to know the severity of the problem and the main controlling factors. Since the landscape differs in sensitivity to erosion due to differences in their geomorphological, geological, and vegetation attributes, it is also essential to recognize high erosion risk areas in order to plan site-specific management interventions. This calls for the assessment of the soil conservation potential of different management practices. The objectives of this study includes quantifying the soil loss by the erosion process, specifying main factors
affecting the Erosion development, categorizing areas which have been affected by soil erosion and finally generating erosion risk map for the study area.

MATEIALS AND METHODS

Description of the Study Area:

Kilte Awulaelo District (Figure 2) is situated in the eastern part of Tigray region, one of the nine Regional States of Ethiopia. Located in the north-eastern part of the country, Tigray is subdivided into seven zones: North-West, West, Central, East, South East, South, and Mekele and into 47 districts. The Kilte Awulaelo district (Woreda) is subdivided into seventeen parishes (Tabia) and it is located between 13°33’ and 13°58’ North latitude and 39°18’ to 39°41’ East longitude. The elevation range of the area goes from 1760 to 2720m, the mean annual temperature ranges between 16° and 20°C, and the annual rainfall range is around 500-1000 mm (United Nations Office for the Coordination of Humanitarian Affairs).

Morphologically, Kilte Awulaelo District is partitioned into four main land systems. The northern part of the district comprises the Negash batholite, the Negash hilly relief on metavolcanics and glacial bedrock, the Negash folds. In the Negash batholite, the prevalent lithologies are grey granite, granodiorite and quartz diorite. Generally the shape of this land system is circular. With regard to the Negash hilly relief, glacial white quartz sandstones and metavolcanic green schist with marble and quartzite characterised the parent materials. The Negash folds resulting from the tectonic activities in the region are essentially comprised for the lithology of metasedimentary pebbly slate, grey-green slate, black limestone, and dolomite. The central and southern parts of Kilte Awulaelo District are the domain of Mekele plateau, which occupies two-thirds of the study area. Actually, in the centre, the Jurassic limestones are found in the Antalo and Agula Formations. In the south, the Adigrat red sandstones are widespread. The presence of numerous ridges such as Tsariya, Hila Hasen, Kokway, Imba and Hada Afa ridges, is the evidence that the region is subjected to intense tectonic forces.

Many of studies have been done on the Tigray region. Among these studies, Regosols, Leptosols, Arenosols, Vertisols, Luvisols, Phaeozems, Cambisols and Calcisols were found to be the dominant soil types in the study area (Descheemaeker et

**RUSLE Calculation:**

The factors causing erosion such as climate, soil properties, vegetation cover and management practices are considered for estimating soil loss. The RUSLE equation is a multiplicative function of five factors controlling the rill and inter-rill erosion (Renard et al., 1997) and can be expressed as:

\[ A = R \times K \times LS \times C \times P \]  

(1)

Where:

- A is the mean annual soil loss expressed in ton\,ha\,*yr\(^{-1}\)
- R is rainfall and runoff erosivity index (in MJ\,* mm\,*ha\,*yr\(^{-1}\))
- K is soil erodibility factor (in ton\,*ha\,*h\,/ha\,*MJ\,*mm\(^{-1}\))
- LS is slope steepness and slope Length factor (dimensionless)
- C is the cover factor (dimensionless)
- P is the conservation practice factor (dimensionless).

**Erosivity Index - R factor:**

The R factor is called erosivity index, which means the active force of the rain which cause detachment and successive transport of soil particles. Precipitation is a very important erosion factor particularly in arid areas, where the soil is usually directly exposed to rain drops and its composing particles do not have a great cohesion power. From these bases the R factor expresses the power of the rain to start an erosion process. Traditionally, R is calculated for each rainfall event as the kinetic energy of a rainstorm, times its maximum intensity over 30 minutes divided by 100 (erosion index, Wischmeier, 1959 cited in Arnoldus, 1977):

\[ R = E \times I_{30} \]  

(2)

In this case study it has been found that the most applicable equation is the one which had been used in northern Ethiopia by Nyssen (2005), (adapted by Hurni, 1985 for Ethiopian conditions)

\[ R = 0.55 \times P - 24.7 \]  

(3)

where:

- P is the annual precipitation in millimeters based on the five-year mean annual rainfall measured at nearby rain gauges (Nyssen et al., 2005).

To compute this calculation Worldclim raster data for annual precipitation (with spatial resolution of 1Km) have been used (http://www.worldclim.org) and processed in ArcGIS software to get R values in the entire study area. Finally, R factor data for each sampling site have been extracted from this grid sheet and exported in excel format to join them with other RUSLE factors data.

**Soil Erodibility - K factor**

K factor is soil erodibility factor, which represents both susceptibility of soil to erosion and the rate of runoff. It depends on a lot of biological and chemical soil characteristics such as its mineralogical composition, particle size, permeability and the presence of organic matter. The granulometry can be considered as the most important agent influences K factor. This is an empirical formula expressing soil loss for a specific soil present in standard rectangular plots of 22.1m of length (along the maximum sloping direction) and with 9% steepness, free of vegetation and leaved in a seedbed condition.
\[
K = \frac{2.1 \times 10^{-4} (12 - OM) \times M^{1.14} + 3.25 \times (s - 2) + 2.5 \times (p - 3)}{100}
\]

(4)

Where:

OM is the percentage of organic matter;
M is the particle size parameter defined as:
\[
M = \left( \% \text{Fine Sand} + \% \text{Silt} \right) \times (100 - \% \text{Clay})
\]

(5)

Where:

Fine Sand is considered the soil fraction between 0.1 and 0.05mm;
Silt, the fraction between 0.05 and 0.002mm;
Clay is the particles measuring less than 0.002mm (USDA classification cited in Renard et al., 1997).

“s” is the soil structure code. The structure codes “s”, derived from Wischmeier and Smith monogram, 1978, are:
- 1: very fine granular (<1mm)
- 2: fine granular (1-2mm)
- 3: medium coarse granular (2.5-5mm)
- 4: blocky, platy or massive (5-10mm).

‘p’ is the permeability soil class. Permeability classes are derived from soil texture (USDA 1983 cited in Renard et al., 1997) and range from value 1 (rapid to very rapid drainage), given to sand, less susceptible to erosion for its good infiltration, up to value 6 (very slow drainage), given to silty-clay and clay soils, characterized by a high water retention capability, but allowing overflow once soil is saturated. ‘p’ values have been corrected for the presence of rock fragments in the soil, shifting the permeability class of one level up if the rock fragments abundance was greater than 40%.

Because the surface horizon is the one most affected by erosive processes, the texture, structure, granulometry and organic matter content refers only to the first soil horizon observed in each sampling site during the fieldwork. The results coming from the application of K equation have been corrected by the abundance of stone cover on the soil, which plays an important role in erosion reduction (modified from Kassam, 1992). Finally, K values have been multiplied by 0.1317 to convert them in S.I. units (t*ha*h/ha*Mj*mm), as suggested by Renard et al. (1997). The K value for each sample plot was calculated, and then each soil type was associated with a K value assuming that the same soil type has the same K value throughout the study area (D LU et al., 2004).

**Slope Steepness and Length - LS factor**

The topographic factor is a very important parameter in water soil erosion, since the gravity force is playing a decisive role in surface runoff. LS factor takes in account together the steepness (S), which increase the velocity of runoff, and the length (L) of a slope, which contributes to enlarge the ground surface affected by runoff. This dimensionless factor has been calculated using two equations to estimate the topographic parameter; one for slopes up to 20% gradient and one for steeper slopes (Arnoldus, 1977).

For slopes up to 20%:
\[
LS = \left( L \right)^{0.5} \times \left( 0.0138 + 0.00965S + 0.00138S^2 \right)
\]

(6)

For slopes over 20%:
\[
LS = \left( \frac{L}{22.2} \right)^{0.6} \times \left( \frac{S}{9} \right)^{1.4}
\]

(7)
where:
- \( L \) is the slope length expressed in meters;
- \( S \) is the slope steepness in percentage.

The data used have been collected during the fieldwork. The slope has been measured by clinometers, while the length has been recorded keeping in mind the following definition: “slope length is the horizontal distance from the origin of overland flow to the point where either the slope gradient decrease enough that deposition begins or runoff becomes concentrated in a defined channel” (Wischmeier and Smith, 1978).

**Cover Management - C factor**

This is the cover management parameter and it ranges between 0 (ideal case when there is no soil loss) and 1, corresponding to the greater amount of soil loss. This dimensionless factor measures the ratio of soil loss between a specific area with given cover management conditions and an experimental plot under reference conditions "clean tilled continuous fallow conditions" (Renard et al., 1997).

As management-cover situations can vary a lot from one place to another, a sub factor approach to estimate C values was proposed in the Revised Universal Soil Loss Equation (Foster, 2003, RUSLE user’s guide).

\[
C = C_c \times G_c \times S_r \times R_h \times S_b \times S_c \times A_m
\]  

(8)

where:
- \( C_c \) is the canopy subfactor;
- \( G_c \) is the ground cover subfactor;
- \( S_r \) is the soil roughness subfactor;
- \( R_h \) is the ridge height subfactors
- \( S_b \) is the soil biomass subfactor;
- \( S_c \) is the soil consolidation subfactor;
- \( A_m \) is the soil moisture subfactor.

This computed method for C factor is very useful because it is land use independent, considering in each management cover situation the characteristics affecting this parameter. This procedure has been applied in the sampling sites situated in areas covered by natural vegetation, considering only the first two sub factors \( C_c \) and \( G_c \) since these were the available data. The resultant equation becomes:

\[
C = C_c \times G_c
\]  

(9)

Canopy sub factor \( (C_c) \) is defined as vegetative cover present over the soil, able to intercept raindrops. This interception reduces the impact energy of water drops on the soil. Water collected on the vegetation cover can also reach the soil flowing along stems, contributing to delay the oncoming of water on the ground available for runoff. These possible effects are comprised in the \( C_c \) subfactor, computed with the following equation:

\[
C_c = 1 - f_c \times \exp\left(-0.1h_e\right)
\]  

(10)

where:
- \( f_c \) is the canopy cover fraction;
- \( h_e \) is the effective fall height.

For the canopy cover fraction, the total woody cover percentage recorded in the field using the field guide for percentage cover estimation (FAO, 2006). The portion of the canopy above ground cover has been assumed to have no effect on water erosion, therefore \( f_c \) has been corrected in effective canopy cover \((f_{ce})\), using the following formula (Foster, 2003):
\[ F_{ce} = f_c \cdot (1 - f_s) \]  
(11)

where:
\(f_c\) is the soil fraction covered by ground cover, and in this study it corresponds to the grass percentage cover.

For \(h_f\) it has been decided to take an average number of 0.5 m, since the majority of the natural vegetation is composed by shrubs passing this height. In fact the effective height does not correspond to the maximum height of the vegetation, but to the height from where water drops start to fall without obstacles toward the ground.

The ground cover variable \((G_c)\) considers everything covering the soil or touching it directly and protecting it from the direct drops impact. The ground cover also obstructs water overflow above the ground. \(G_c\) sub factor has been found with an exponential equation (Foster 2003, RUSLE user’s guide):

\[ G_c = \exp^{(-b*f_s)} \]  
(12)

where:

‘b’ is a coefficient varying with surface roughness. The lower value taken by this coefficient corresponds to a soil modified by inter rill erosion (sheet erosion), while the higher value to a soil affected by rill erosion. In this study mainly sheet erosion has been detected, so it has been used “b” value of 0.025, corresponding to a smooth surface, permitting only inter rill erosion.

‘f_s’ is the covered soil fraction. During the fieldwork a wide stone cover has been noticed, then it has been decided that only this cover contribution should be considered because it is stronger than grass cover, even when the rainy season starts, the grass cover is small and dry and its role against erosion can be regarded as negligible compared to rock fragment cover.

To analyze the agricultural cover lands representing above half of all sampling sites, the computation of C factor adopted refers to a different procedure, using Kassam methodology (Kassam, 1992). The main crops in the study area are wheat, teff, and barley. They all have very similar characteristics such as the shape of the plant, growing rates during the year, and growing length period. Thus, a growth cycle of 150 days has been stated as representative for all the main crops. This growing period has been divided in four stages following Kassam method: Establishment (E), Early vegetative (EV), Late vegetative (LV) and Maturation (M), which correspond, respectively, to 10%, 25%, 25% and 40% of the total growth cycle. For each stage, correspondent LAI (Leaf Area Index) values have been calculated as percentage of the maximum LAI achieved by the crop during its vegetative period. Crop cover has been consequently retrieved with the following formula:

\[ C = 100 \cdot (1 - \exp^{(KL)}) \]  
(13)

Where:

L is LAI value;

K is a constant based on the geometry of the crops and counts 0.7 for wheat, teff and barley.

Finally C factor has been found entering a table converting cover values to C RUSLE factor values for annual crops. Among the four growing stages, only the first period has been taken into account because it is the most dangerous situation for erosion, since it is the time when rains start and the soil is still not covered by any plant. As after harvesting all crop residues are usually collected and the soil remains free from every type of cover.
**Support Practice - P factor**

P is the support practice factor and reflects the impact of support practices and the average annual erosion rate. It is the ratio of soil loss with a specific support practice on croplands to the corresponding loss with upslope and downslope tillage. This factor considers any practice applied by humans to reduce erosion degree and soil loss amount deriving from water erosion process. It includes a variety of agriculture management activities such as tillage and planting along contour lines (contouring), fields alternated to sod strips along the contours (strip cropping), tree lines planted along agricultural fields and terracing. This last practice "terracing" consists of breaking the slope by moving part of the soil to build successive steps. Something similar has been observed during the fieldwork. Even if slopes are not really broken removing soil, they are fractioned by a series of stone bunds built along the contour lines (Figure 3). This is considered a useful strategy to reduce runoff and collect the soil moved by sheet erosion along the slope. In a recent study by Nyssen et al., (2007), P factor for this practice was estimated equal to 0.32, thus the same value has been used for each sampling site where these characteristic constructions have been observed (in agricultural land and in places covered by natural vegetation).

![Figure 3- Stone bunds on hills.](image)

**RESULTS AND DISCUSSION**

**R factor**

The effects of rain are manifold, where the first contribution of precipitations to the erosion starts when rain drops touch the soil causing the “splash erosion”. Depending on the energy of the drops (size, height from which they start to fall) and on the characteristics of the terrain on which they fall down, it will be a great or little detachment and displacement of soil particles. In a following phase, when the rainfall event is so strong that not all the water is penetrating the soil, the water which accumulates on the ground (facilitated by low soil permeability) starts to flow following
the maximum sloping direction and digging more and more big and deep channels (rills and gullies). Detachment occurs when the erosive forces of raindrop impact and flowing water exceed the soil’s resistant to erosion (Kinnell, 2005). Erosivity index (R factor) do not show relevant variations (from 227 to 482 MJ* mm\ha*yr), that can probably be explained with little scale topographical variations, which play a determinant role in rain distribution above the study area.

**K factor**

It has been found that the erodibility of a soil increases proportionally with the amount of fine sand and silt content (Giordani and Zanchi, 1995). In fact, finer textured soils, very rich in clay, are more resistant to particles detachment, because of their great cohesion, while coarser textured soils allow to a high infiltration of water, avoiding superficial runoff. Even the organic matter content is important for stating erodibility, as it contributes to increase particle aggregation (by the presence of chelating agents) and water infiltration. All the factors mentioned above are grouped in one equation (eq. 4), valid for soils with less than 70% of silt plus very fine sand (Wischmeier and Smith, 1978). In this case study, indeed, K factor values do not present a very high variability (from 0.001 to 0.073) (D LU et al., 2004). This may be due to the homogeneity of soil types and characteristics in the study area.

**LS factor**

Since characteristic stone bunds constructions have been found in the study area, the removal of rock fragments for this purpose accelerates soil loss by water (Poesen et al., 1994; Nyssen et al., 2001). What is more, the relatively clear water that passes through the stone bunds has greater erosion potential in the downslope (Hairsine and Rose, 1992). These two factors are on average thought to compensate for the effects of the decreased slope length (L) due to the stone bund building. Several studies showed a relationship between the slope of the watershed and the erosion rate; the higher the slope, the higher the erosion risk (Hoyos, 2005, Andrade et al., 2010, Jha and Paudel, 2010). The data showed that factors taking into account the topography (LS factor) are affecting in a stronger way the erosion process (Adediji et al., 2010, Jha and Paudel, 2010).

**C factor**

Cover is usually referred to the vegetation, which has a strong influence on protecting soil from water erosion. In fact it can reduce erosive rain force being an obstacle for rain drops falling from the sky. Also, soil erodibility can be diminished by vegetation roots, which produce some chemical bonding matters able to compact soil particles, as well as they absorb water for their photosynthetic activities reducing the amount of runoff water. In fact, impact energy is proportional to water drop mass (estimated from drop diameter) and to drop water velocity (related to drop fall height). Water drops falling from vegetation branches can be greater than raindrops reaching the canopy (because of their accumulation on leaves), but the reduced fall height reduces anyway their erosivity (a height less than 10 m is considered good to reduce erosivity power) (Foster, 2003). C factor values ranged from 0.39 for the areas covered by dense natural vegetation to 1 for bare soils where there is no natural vegetation cover and plowed agriculture fields (Andrade et al., 2010).

**P factor**

Nyssen et al., 2007, showed that three main advantages of stone bunds application against erosion were demonstrated:
1- The accumulation rate of sediments behind “stone lines” is almost equivalent to the soil loss due to sheet and rill erosion, even if some amount is still lost for tillage erosion.

2- Water infiltration is improved surrounding stone bunds, keeping moisture for at least two months after the rainy season.

3- Crop yields are slightly improved.

Another interesting practice that has been noticed in some places in the study area is the digging of some subsequent holes immediately above the stone bunds, in which soil and water flowing from upslope are collected. Data shows that stone bunds practices positively affects RUSLE values, which are still in a tolerable range, even if C factor in agricultural fields is the maximum (equal to 1). According to BoANR (Bureau of Agriculture and Natural Resources, Tigray, Ethiopia), stone bunds are soil and water conservation techniques that have been practiced from 1991 to 2009. Moreover, the effects of stone bunds on runoff reduction have been also assessed (Desta, 2003). Data showed a great positive effect of P factor on the erosion process. This is due to stopping the erosion process throw cutting the slope by stone bunds and reducing the runoff.

**Soil erosion risk map**

RUSLE was firstly developed for the USA, but also has been proven valuable for estimation of soil erosion loss in other regions of the world (Millward and Mersey, 1999; Reusing et al., 2000; Angima et al., 2003, Ma et al., 2003). The final quantitative RUSLE values (eq. 1) shows the quantity loss of soil in ton/ha per year, ranging from less than 1 to very high soil loss rates (223.6 t/ha). This data range is comparable with literatures (Sonnelved et al., 2001, Jha and Paudel, 2010) but much lower than other cases (Adediji et al., 2010, Andrade et al., 2010) and much higher than other cases (Panagopoulos and Ferreira, 2010a; Panagopoulos and Ferreira, 2010b). This may be because of the different environmental conditions "factors" where these studies were conducted. For a better visual understanding of these quantities, RUSLE values have been grouped in five classes of soil erosion risk following Bergsma classification (Table. 1) (Bergsma, 1986, D LU et al, 2004).

<table>
<thead>
<tr>
<th>Soil Erosion Risk Class</th>
<th>RUSLE VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>(0 to 5 ton/ha* y)</td>
</tr>
<tr>
<td>Low</td>
<td>(5 to 12 ton/ha* y)</td>
</tr>
<tr>
<td>Medium</td>
<td>(12 to 25 ton/ha* y)</td>
</tr>
<tr>
<td>High</td>
<td>(25 to 60 ton/ha* y)</td>
</tr>
<tr>
<td>Very High</td>
<td>more than (60 ton/ha* y)</td>
</tr>
</tbody>
</table>

*Table 1- Soil erosion risk Classes and equivalent RUSLE values (Bergsma, 1986)*

The first two classes are considered in the range of soil loss tolerance values. Medium and high classes need conservation applications to maintain a sustainable productivity, while the last class (very high), is very dangerous because it can be destructive in few years if no intervention are done and soil loss level is maintained constant in the future. Not relevant (NR) polygons correspond to villages, urban areas and water bodies, which has not been considered in the evaluation.

Soil erosion risk map (Figure 4) has been generated by applying the final RUSLE values on the land unit map which had been created in ArcGIS. Figure 2 shows the soil erosion risk map for the study area. In order to better understand the results, it is
important to analyze them in relation with soil, morphological and topographical characteristics, paying attention even to the land cover.

The results show that, Very Low and Low classes are scattered in all over the study area due to the randomization of the Land Units and represent almost 76.14% of the study area. The Very Low class is occupying 50.67% of the study area in correspondence to river valleys or footslopes, where the low slope gradient allows the accumulation of materials transported by water or gravity. These types of soils are deeper and have better permeability than in other places of the study area because of the flat morphology which enables conserving of soil sediments lost by erosion processes from neighboring hills. Low class is occupying 25.46% of the study area and has been found in the Negash synclinorium and "Mekele Plateau" only. The increasing of soil loss amount is mainly due to slightly greater inclinations in comparison with the previous landforms. In the synclinorium the reasons for low soil loss values are related mainly to the protective role of natural vegetation cover and even to the shortness of slope length because of the stone bunds (Foster, 2003). The Medium class in the study area is only in Negash batholite and Mekele "Plateau" formations as 5.53% of the study area, occupying some scarp strips along Negash batholite geological Formation and the central part of Mekele "Plateau". In this case, the combination of the different factors computing soil loss rates gives an intermediate situation.

![Erosion Risk Map](image)

*Figure 4- Erosion risk map showing RUSLE classes estimated over the study area.*
The High class is mainly concentrated in the Mekele "Plateau" and in a small unit in Negash hilly relieves representing 17.36% of the study area. In both places slope length factor is increasing considerably and the absence of stone bunds along the contours allows a significant loss of soil, which is not sufficiently stopped by land cover (scrubs). The most dangerous situation (Very High class), has been found in correspondence to strongest slopes, absence of soil conservation practices and low vegetation cover to face the strong water erosion. Fortunately this class is occupying only 0.98% of the study area in Negash synclinorium and the southern east part of Mekele "Plateau" (Agula and Antalo formations). The uncertainties regarding data sources may introduce larger uncertainties in soil erosion estimates. Great attention should be paid to the evaluation and preprocessing of data sources, such as data interpolation, conversion, and registration (D LU et al, 2004).

CONCLUSION

In conclusion, it can be said that soil erosion risk map has been created from the combination of many parameters interacting each others in a complex way generating the final quantitative RUSLE values. The data showed that factors affecting in a stronger way the erosion process are the one taking into account the topography (LS factor), and support practices (P factor), followed by the Cover parameter (C factor). The study showed that stone bands are effective human practice to overcome the soil erosion dilapidations in the study area. So, it is recommended to encourage farmers and decision maker to apply this practice in areas which highly affected by erosion. This study expresses that Remote Sensing and GIS are useful tools in generating spatial and quantitative information on soil erosion studies and risk assessment mapping. Future work should focus on the ideal support practices such as stone bunds to overcome the erosion process.

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