IDENTIFICATION OF EROSION PRONE AREAS AT MACRO-WATERSHED LEVEL FOR REGIONAL DEVELOPMENT PLANNING IN NORTHERN ETHIOPIA

Kassa Teka

Most soil loss estimation studies in Ethiopia have focused at plot level and some at micro- to milli-watersheds (<10000 ha). However, these studies may not represent the entire area of a macro-watershed (> 50,000 ha) which is very essential for regional development planning. The aim of this study was, therefore, to estimate the soil loss rate and analyze the spatial distribution of soil erosion and locate the erosion high susceptible areas at the macro-watershed scale so as to help for regional development planning. The study area was the macro-watershed of the Geba River (5,133 km²). The RUSLE model, the most practical method of estimating soil erosion potential, was applied in this study. The results of the analysis showed that the average soil loss in the entire watershed was 6.34 ton ha⁻¹y⁻¹, while 7.31 ton ha⁻¹y⁻¹ was from arable land. These estimates are within the tolerable soil loss (2 - 16 ton ha⁻¹y⁻¹) for Ethiopia put forward by Hurni. More than 84% of the study area was classified under very slight soil loss (< 5 ton ha⁻¹y⁻¹). However, about 5% of the watershed was suffering from severe (25 – 45 ton ha⁻¹y⁻¹) or very severe soil loss (≥ 45 ton ha⁻¹y⁻¹). The highest soil loss was estimated from calcaric Fluvisols and areas with a slope steeper than 30%.

Key words: Soil Erosion, Macro-watershed, USLE, North Ethiopia

Department of Land Resources Management and Environmental Protection, College of Dryland Agriculture and Natural Resources, Mekelle University
E-mail: kassateka@yahoo.com

Received: March 3, 2017; Accepted: June 8, 2017

INTRODUCTION

Soil erosion has long been recognized as a severe problem for sustainable development worldwide (Hurni 1985 and 1998, Ananda and Herath 2003, Nyssen et al 2006 and 2009, Brhane and Mekonen 2009, Pimentel and Burgess 2013, Tesfahunegn et al 2013, Long and Davis 2016). The problem, however, varies with changes on climate, land cover, soil, topography, lithology and human activities (Ananda and Herath 2003). In the northern Ethiopian Highlands, most of the arable lands are located on slopes that are too steep to keep soil erosion under the rate of natural soil regeneration (Hurni 1987, Nyssen et al 2009, Tesfahunegn et al 2013). Estimated soil erosion losses by water from cultivated, grazing, bare and wood land soils in the Ethiopian Highlands respectively were 42, 5, 70, and 5 ton ha⁻¹y⁻¹ (Hurni 1987). A study by Nyssen et al (2009) in the May-Zegzeg micro-watershed (100 to 1000 ha), northern Ethiopia, revealed that the average soil loss rate by sheet and rill erosion was 9.7 ton ha⁻¹y⁻¹ while 3.5 ton ha⁻¹y⁻¹ was lost in exclosures and forest; 17.4 ton ha⁻¹y⁻¹ was lost in rangeland and 9.9 ton ha⁻¹y⁻¹ in arable land. Brhane and Mekonen (2009) estimated the average sheet and rill erosion at Medego milli-watershed (1000 to 10000 ha), northern Ethiopia, at 9.63 ton ha⁻¹y⁻¹. Independently computed, area specific long-term rates of soil loss by gully erosion in micro-watersheds of Dogua’ Tembien have resulted in a soil erosion rate between 2.3 and 7.4 ton ha⁻¹y⁻¹ (Nyssen et al 2006). Soil erosion by tillage was also identified as a cause to an increased soil erosion rate. Nyssen et al. (2008) showed that soil translocation due to tillage by the ox-drawn ard plough (on average 7.8 ton ha⁻¹y⁻¹) in the May-Zegzeg micro-watershed appears to be an important source of colluviation behind stone bunds and Lynchets.

The differences in the results of the above studies are mainly caused by the differences in their respective scale and method of analysis (Tesfahunegn et al 2013). Watersheds may be as small as the portion of a yard draining into a mud puddle or as large as the Geba Watershed which drains 5,133 km². At present, soil erosion assessment at the scale of a sub-watershed (10,000 to 50,000 ha) and macro – watershed (> 50,000 ha) for northern Ethiopia is very limited. Some of the soil loss estimates were derived from runoff plots (e.g. Hurni 1987 and Nyssen et al 2009) while others employed reservoir surveys (e.g., Haregeweyn et al 2006) and micro to milli watersheds (e.g., Brhane and Mekonen 2009).
Despite the fact that the advantages that runoff plots and micro-milli watersheds provide, results cannot easily be extrapolated to represent an entire macro-watershed (Haregeweyn et al 2006 and 2013, Tesfahunegn et al 2013). For sustainable watershed development planning, information at the level of macro-watershed is important.

To estimate soil erosion, various erosion models such as Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978); Chemical, Run-off and Erosion from Agricultural Management Systems (CREAMS) (Knisel 1980); Erosion-Productivity Impact Calculator (EPIC) model (Sharpley and Williams, 1990); Water Erosion Prediction Project (WEPP) (Nicks and Gander 1994); Revised Universal Soil Loss Equation (RUSLE) (Renald et al 1997); Soil and Water Assessment Tool (SWAT) (Arnold et al 1998); European Soil Erosion Model (EUROSEM) (Morgan et al. 1998); Water and Tillage Erosion Model (WATEM) (Van Oost et al 2000, Van Rompaey et al 2001); Tillage-Controlled Runoff Pattern model (TCRP) (Takken et al 2001); Sealing, Transfer, Runoff, Erosion, Agricultural Modification (STREAM) model (Souche`re et al 1998) and Limburg Soil Erosion Model (LISEM) (Jetten 2002) have been developed and used over many years worldwide. Among these models, the RUSLE has remained the most practical method of estimating soil erosion potential and the effects of different erosion factors on soil erosion (Nyssen et al 2009, Tesfahunegn et al 2013). The objectives of this paper were: i) using the rainfall, Digital Elevation Model (DEM), soil type map and land cover map, build the Soil Erosion Map and calculate the soil loss rates; ii) analyze the spatial distribution of soil erosion; iii) locate the erosion high susceptible areas for regional development planning. The study area was the macro-watershed of the Geba River (5,133 km²). The Tamil Nadu Agricultural University classified areas having an area of above 5000 ha as Macro-watershed (TANU 2013).

METHODOLOGY
The study area
The watershed of the Geba River (Figure 1) is situated in the eastern part of Tigray, north Ethiopia. The study area embraces a land area of about 5,133 km² with an elevation varying between 938 m and 3,298 m above sea level (m a.s.l). The Geba watershed is a sub catchment of the Tekeze river basin which is one of the major Ethiopian drainage basins (Zenebe 2009).

![Figure 1: Location of the Geba watershed in the Tekeze basin and Ethiopia (adapted from Zenebe 2009)](image_url)

The average annual rainfall in the Geba watershed varies between 450 and 950 mm per year. It is strongly seasonal and erratic (Haregeweyn et al 2008) with most of the precipitation falling in July, August and September which leads to a high
moisture stress during the other months of the year, constraining the rain-fed agriculture.

The geology of the Geba watershed is characterised by highly diversified sedimentary rocks, volcanic intrusions and Precambrian rocks (Gebreyohannes et al 2010). More than 50% of the Geba watershed consists of Mesozoic sediments which are found in the centre of the Geba watershed. On the basis of soil map produced by the UNDP, FAO and MOA in 1984, Zenebe (2009) produced a digital soil map for the Geba watershed. The map made a distinction between 7 soil types: calcareous Fluvisols, calcic Cambisols, chromic Cambisols, chromic Luvisols, eutric Cambisols, vertic Cambisols and lithic Leptosols.

In some places, traces of dry evergreen montane forest which is considered as the natural land cover can still be found. Its occurrence is, however, limited to isolated spots surrounding churches and in some remote parts of the Dess’a forest at the eastern border of the watershed. This natural vegetation consists of Juniperus procera and Olea europaea subsp. africana (Feoli et al 2002). Acacia etabaica is also an often reoccurring tree species. The natural land cover in the major part of the watershed is, however, strongly modified by human activity. Large areas are used for cropland and rangeland which often led to severe soil degradation (Munro et al 2008). Most parts of the watershed that are not used for arable farming are nowadays covered with shrubs and bushes (Teka et al 2014).

Agriculture in the Geba watershed is based on a mixed farming system whereby each farming household cultivates permanent arable fields and holds livestock. Crops dominantly grown in the study area are Eragrostis tef (Teff), Triticum durum (Wheat), Sorghum bicolor (sorghum), Zea mays (Maize) and Hordeum vulgare (Barley).

**Land cover classification and mapping**

The map of land cover types was created from Landsat Enhanced Thematic Mapper Plus (ETM+) imagery which was acquired from the USGS website (Glovis.usgs.gov). All images were taken in February 2003, during the dry season. More recent cloud-free imagery from this sensor is disturbed by the failure of sensor’s scan line corrector. The images consist of eight spectral bands with a spatial resolution of 30 meter (60 m - thermal, 15 m pan). Bands 1, 2, 3 and 4 were used to detect vegetation and distinguish between various vegetation types. Bands 5 and 7 were used to obtain additional information on moisture content and rock associations.

Since the landsat images were taken on different dates, a radiometric correction was required. First, the distorted border was removed from all bands in all scenes with a ‘Window-model’ in IDRISI the Tiga version software (Warner and Campagna 2009). Second, an empirical radiometric correction was carried out whereby values from corresponding pixels in the overlapping area between two images were plotted against each other, i.e. for each pixel the spectral value of a specific band on the first date was compared with the spectral value of the corresponding band on the second date. A regression line was, therefore, drawn through the different pixels with the help of SAS 9 software edition (SAS Institute Inc 2010). By applying the regression equation on the images of one date, the spectral values were ‘pulled’ to each other, correcting the differences due to the date of acquisition. Third, the bands under study were mosaicked using a ‘MOSAIC-model’. Finally, a supervised classification method was used to classify the dominant land cover types using 2033 ground control points collected in the field. Accordingly, eight initial land cover types were considered and described following the land cover description guideline proposed by Alemanyehu et al (2009).

Image classification was carried out by means of a maximum likelihood classification (Schowengerdt 2007) whereby all pixels were attributed to one of the identified land cover types. The original spatial resolution of the land cover map was 30 m x 30 m. In order to make it compatible with other data layers such as the available elevation model, it was resampled to a resolution of 90 m x 90 m using a ‘resample-model’.

**Mapping land units**

The study area was split up in homogeneous land units which are considered as the building blocks of the land cover pattern. A land unit is represented by a set of pixels characterized by the same value for the diagnostic attributes (Van Orshoven et al 2011). Pixels of 90 m x 90 m were considered to belong to the same land unit if they have the same land cover type, slope class, soil class and elevation class. The class ranges for the different variables are shown in Table 1. The resulting land unit map consists of 664 land units.
Slope gradient and elevation were derived from an elevation model produced by the Shuttle Radar Topography Mission (Farr et al. 2007). The DEM has a resolution of 90 m x 90 m and a vertical error of less than 16 m. For each pixel, the soil type was identified on the basis of the digital soil map produced by Zenebe (2009) (Table 1). This map is relatively generalized which decreases its accuracy, but has the advantage that it is available for the whole of Ethiopia which could facilitate possible future extrapolation of the model approach.

Assessment of average soil erosion rates
For the assessment of soil erosion rates in this study, the Revised Universal Soil Loss Equation (RUSLE, Renard et al. 1997) was adopted. The RUSLE assesses the long-term soil loss rate per unit area expressed in ton ha$^{-1}$y$^{-1}$. It is a multiplicative model of 6 factors (equation 1)

$$A = R * K * L * S * C * P$$

Where,
- $A$ = the average annual soil loss (in ton ha$^{-1}$y$^{-1}$),
- $R$ = the rainfall and runoff erosivity (in MJ.mm.ha$^{-1}$h$^{-1}$y$^{-1}$),
- $K$ = the soil erodibility factor (in ton.h.MJ$^{-1}$.mm$^{-1}$),
- $L$ = the topographical factor (dimensionless), with $L$ the slope length factor and $S$ the slope gradient factor,
- $C$ = the vegetation/land cover factor (dimensionless), and
- $P$ = the specific erosion control practices/management factor (dimensionless).

The model was validated for Ethiopian conditions by Hurni (1985) and accepted by many researchers such as Nyssen et al. (2009) and Tesfahunegn et al. (2013) for northern Ethiopia. The model was also validated at field through direct observation and farmers’ perception assessment by interviewing 135 farmers in Korir watershed and found to be 95% (accurate) (Abdelkerim Yonus 2014, M.Sc thesis).

The R-factor can be assessed if information on the rainfall intensity and its associated kinetic energy is available. Since this information is lacking for northern Ethiopia, a simplified approach proposed by Hurni (1985) for the Ethiopian conditions was adopted to assess the R-factor for the different rainfall station locations (equation 2).

$$R = 0.562 * Pr - 8.12$$

Where $Pr$ = the annual precipitation (in mm)

Nine stations (Sinkata/Freweyni, Hawzen, Atsbi, Wukro, Kuiha, Mekelle/Halila, Hagerselaam, Abi-Adi, Yeichilay and Tekeze–Hydropower) were used for the rainfall analysis. These stations are relatively well equipped to give rainfall data for more than 10 years. They are also well distributed and representing the entire watershed. An inverse distance weighing interpolation technique with power 2 was used to spatially interpolate the R-factor values to all pixels within the Geba watershed.

The K-factor that describes the soil erodibility for different soil types was assessed on the basis of equation 3 which was proposed by Nyssen et al (2009). Values for the required soil properties (Table 2) were obtained from World Soil Database (FAO et al. 2008).

$$K = [2.14I^{1.4}(10^{-5})C - a] + 3.25(b - 2) + 2.5(c - 3) + 0.013177e^{-0.08a - 0.04b}$$

### Table 1: Land characteristics used for the delineation of land units

<table>
<thead>
<tr>
<th>Land use classes</th>
<th>Soil class$^{\text{c}}$</th>
<th>Slope classes (%)$^{\text{a}}$</th>
<th>Elevation classes (m)$^{\text{b}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare land</td>
<td>calcic Fluvisols</td>
<td>0 - 2</td>
<td>&lt; 1500</td>
</tr>
<tr>
<td>Bush land</td>
<td>calcic Cambisols</td>
<td>2 - 10</td>
<td>1500 – 2300</td>
</tr>
<tr>
<td>Crop land</td>
<td>chromic Cambisols</td>
<td>10 - 15</td>
<td>&gt; 2300</td>
</tr>
<tr>
<td>Forest land</td>
<td>chromic Luvisols</td>
<td>15 - 30</td>
<td></td>
</tr>
<tr>
<td>Grass land</td>
<td>eutric Cambisols</td>
<td>&gt; 30</td>
<td></td>
</tr>
<tr>
<td>Impervious surfaces</td>
<td>vertic Cambisols</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrub land</td>
<td>lithic Leptosols</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water body</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^{\text{a}}$FAO (1990), $^{\text{b}}$Hurni (1998), $^{\text{c}}$Zenebe (2009)
Where: \( K \) = soil erodibility factor in ton.h.MJ^{-1}.mm^{-1}; \( M \) = particle size parameter = (% silt and very fine sand)* (100 - % clay); \( a \) = percentage organic matter; \( b \) = soil structure code ranging between 1 (very fine granular) and 4 (blocky, platy or massive); \( c \) = permeability class ranging between 1 (rapid) and 6 (very slow); \( d \) = percentage stone (rock fragment) cover at the soil surface. An average stone cover (Table 2) percentage in the study area (Geba watershed) collected in the field for each soil type was used.

### Table 2: Soil property values for the considered soil types (FAO et al 2008)

<table>
<thead>
<tr>
<th>Soil type</th>
<th>% silt and very fine sand</th>
<th>% Clay</th>
<th>M</th>
<th>% Organic matter</th>
<th>Soil structure code</th>
<th>Permeability class</th>
<th>Stone cover (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>calcaric Fluvisols</td>
<td>15</td>
<td>6</td>
<td>1410</td>
<td>0.41</td>
<td>3</td>
<td>2</td>
<td>46</td>
</tr>
<tr>
<td>calcic Cambisols</td>
<td>43</td>
<td>21</td>
<td>3397</td>
<td>0.65</td>
<td>2</td>
<td>4</td>
<td>33</td>
</tr>
<tr>
<td>chromic Cambisols</td>
<td>28</td>
<td>23</td>
<td>2156</td>
<td>0.98</td>
<td>2</td>
<td>4</td>
<td>39</td>
</tr>
<tr>
<td>chromic Luvisols</td>
<td>28</td>
<td>24</td>
<td>2128</td>
<td>0.83</td>
<td>2</td>
<td>4</td>
<td>35</td>
</tr>
<tr>
<td>eutric Cambisols</td>
<td>36</td>
<td>22</td>
<td>2808</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>31</td>
</tr>
<tr>
<td>vertic Cambisols</td>
<td>28</td>
<td>42</td>
<td>1624</td>
<td>0.96</td>
<td>1</td>
<td>4</td>
<td>23</td>
</tr>
<tr>
<td>lithic Leptosols</td>
<td>34</td>
<td>24</td>
<td>2584</td>
<td>1.61</td>
<td>2</td>
<td>3</td>
<td>73</td>
</tr>
</tbody>
</table>

The toposographic factor (\( LS \)) describes the impact of toposgraphy on the average soil loss. The toposographic factor can be split in a component that describes the slope length effect which is a proxy for the upslope area and the effect of the slope gradient (Wischmeier and Smith 1978). The values for the slope length and the slope gradient were derived from the Digital Elevation Model (DEM) using the Usle2D software designed by Desmet and Govers (1996). Usle2D is designed to calculate the \( LS \)-factor in the Universal Soil Loss Equation from a grid-based DEM. It requires a DEM of the study area and a file that identifies the parcels as input files. However, as there is no knowledge of the parcel delineation, the delineated land units were considered to be individual parcels.

The \( C \)-factor is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow (Pierce et al 1986). Different crops have a different canopy protection which also vary during the different seasons (Kaltenrieder 2008, Brhane and Mekonen 2009). The \( C \)-factor varies between 0 and 1. \( C \)-factor assessments for the different land cover types under consideration are shown in Table 3.

### Table 3: \( C \)-factors for the different land use types under consideration

<table>
<thead>
<tr>
<th>Land cover type</th>
<th>( C )-factor value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare soil</td>
<td>1</td>
<td>Eweg et al (1998), Hurni (1985)</td>
</tr>
<tr>
<td>Bush</td>
<td>0.05</td>
<td>Kaltenrieder (2008)</td>
</tr>
<tr>
<td>Crop</td>
<td>0.14</td>
<td>Nyssen et al (2009)</td>
</tr>
<tr>
<td>Forest</td>
<td>0.004</td>
<td>Nyssen et al (2009)</td>
</tr>
<tr>
<td>Grass</td>
<td>0.01</td>
<td>Nyssen et al (2009)</td>
</tr>
<tr>
<td>Shrub</td>
<td>0.42</td>
<td>Nyssen et al (2009)</td>
</tr>
<tr>
<td>Impervious surfaces</td>
<td>0</td>
<td>Eweg et al (1998)</td>
</tr>
<tr>
<td>Water</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

The \( P \)-factor refers to the farming practices and soil conservation measures. Such practices are abundantly present in the Geba-watershed in the form of stone bunds and terraces (Esser et al 2002, Woldemariam 2012). Woldemariam (2012) reported that the area of land terraced in Tigray amounted to approximately 80% of the region. Additional conservation practices that are adopted in the Geba watershed are contour ploughing and zero grazing. The \( P \)-factor for the entire watershed was assessed following the methodology (Table 4) proposed by Nyssen et al (2009).
Table 4: Conversion of stone and soil bund status into USLE’s P-factor (Nyssen et al 2009)

<table>
<thead>
<tr>
<th>Quality of stone and soil bunds</th>
<th>P for non arable land</th>
<th>P for arable land</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>1</td>
<td>0.90</td>
</tr>
<tr>
<td>Remains</td>
<td>0.8</td>
<td>0.72</td>
</tr>
<tr>
<td>Poor</td>
<td>0.6</td>
<td>0.54</td>
</tr>
<tr>
<td>Moderate</td>
<td>0.4</td>
<td>0.36</td>
</tr>
<tr>
<td>Good</td>
<td>0.2</td>
<td>0.18</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSIONS

Macro-watershed scale soil erosion estimates

The R-factors vary between 177 (in Tekeze station) and 338 MJ mm ha⁻¹h⁻¹y⁻¹ (in Hagere Selam station) which are lower than the estimates of the Soil Conservation Research Project (SCRP 1996) in the Maybar Soil Conservation Research Station, South Welo Zone (1982-1989) where annual rainfall values are higher than those of the study areas. However, it reflects a similar value to the average R-factor that is reported for northern Ethiopia by Nyssen et al. (2009) and Europe (Van der Knijff et al 2000).

The assessed K-factors (ton h MJ⁻¹ mm⁻¹) for the different soil types under consideration were calcaric Fluvisols (0.003), calcic Cambisols (0.015), chromic Cambisols (0.007), chromic Luvisols (0.008), eutric Cambisols (0.013), vertic Cambisols (0.008) and lithic Leptosols (0.002). The erodibility of these soils was relatively low in comparison with the reported values for other regions in Africa (e.g. Robert and Hilborn 2000) which can be explained by the high stone cover percentage ranging from 23% (for vertic Cambisols) to 73% (lithic Leptosols).

In most of the study area, the rock fragment cover corresponds with the study of Nyssen et al (2009) for northern Ethiopia. According to the study of Nyssen and others, rock fragment cover in experimental plots in northern Ethiopia ranges from 2% under forest to 50% in rangeland. Rock fragments at the soil surface reduce the effect of splash as well as runoff rates and overland flow velocity (Poesen et al 1994, Nyssen et al 2001 and 2009). They have a similar effect as the permanent presence of litter (Römkens 1985) which is in turn a K-factor (Wischmeier and Smith 1978).

Nyssen et al (2001) found that reducing rock fragment cover from 20% to 0% resulted in a three-fold increase of soil flux due to water erosion.

Figure 2 shows the assessed mean annual soil erosion rates (in ton ha⁻¹y⁻¹) in the Geba watershed.

Figure 2: Assessed mean annual soil erosion rates (ton ha⁻¹y⁻¹)
The soil erosion rate values were put in classes of which the boundaries were proposed in a study of Singh and Phadke (2006). According to their terminology, 5.07% of the watershed is suffering from severe or very severe soil loss.

**Table 5: Soil loss classes in the Geba Watershed**

<table>
<thead>
<tr>
<th>Soil loss description*</th>
<th>Soil loss range (ton ha⁻¹y⁻¹)</th>
<th>Area (km²)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very slight</td>
<td>0 – 5</td>
<td>4330.52</td>
<td>84.37</td>
</tr>
<tr>
<td>Slight</td>
<td>5 – 10</td>
<td>279.17</td>
<td>5.44</td>
</tr>
<tr>
<td>Moderate</td>
<td>10 – 25</td>
<td>262.97</td>
<td>5.12</td>
</tr>
<tr>
<td>Severe</td>
<td>25 – 45</td>
<td>109.78</td>
<td>2.14</td>
</tr>
<tr>
<td>Very severe</td>
<td>≥ 45</td>
<td>150.52</td>
<td>2.93</td>
</tr>
</tbody>
</table>

*values & description adapted from Singh and Phadke (2006)

The overall average soil loss (6.34 ton ha⁻¹y⁻¹) which is far smaller than the results obtained from the highlands of northern Ethiopian (19 ton ha⁻¹y⁻¹) from 11 reservoirs in the central highlands of Tigray (Tamene and Vlek 2008); 9.7 ton ha⁻¹y⁻¹ from 42 plots in northern Ethiopia (Nyssen et al 2009); 9.63 tons ha⁻¹y⁻¹ at milli-watershed scale (1000 to 10000 ha) for northern Ethiopia (Brhane and Mekonen 2009); and 12 ton ha⁻¹y⁻¹ for Ethiopia (SCRP 1996). This is mainly related to the cumulative effect of the huge environmental rehabilitation activities implemented in the last two and half decades; the large size of the watershed where surface roughness is high compared to small watersheds and experimental plots, and the lower annual rainfall in the area compared to other parts of the country. It is, however, greater than the assessment, 4.5 ton ha⁻¹y⁻¹, for Adwa (northern Ethiopia) (Dragan et al 2003). The average soil loss in the study area is within the tolerable soil loss (2 - 16 ton ha⁻¹y⁻¹) for Ethiopia as put forward by Hurni (1985), the mean global (15 ton ha⁻¹y⁻¹) and the mean Africa (9 ton ha⁻¹y⁻¹) (Lawrence and Dickinson 1995) soil erosion rate. Nevertheless, taking the global soil formation rate at 1 ton ha⁻¹y⁻¹ (Pimentel and Kounang 1998), the soil in the study area is being lost 6 or more times faster than the rate of renewal and sustainability.

**Soil erosion and land cover types**

The land cover map that was produced for the Geba watershed is shown in Figure 3. Shrub land is the dominant land cover type occupying 29% while forest land occupies the lowest area, only 1% (see Table 6).

**Figure 3: Land cover map of the Geba-watershed derived from LANDSAT imagery**

These results are to a large extent in line with assessments made by Zenebe (2009), who assessed different land cover fractions in the Geba watershed based on landsat imagery of the year 2000 and reported the following area percentages: 0.5% forest cover, 7.3% grass land, 3.2% built-up area, 0.1% water body and 46% arable land. The percentage of arable land reported by Zenebe (2009) is significantly higher than the assessment made in this study. This can be explained by the fact that this study makes a distinction between bare land and cropland, which is not done in Zenebe’s study.
Table 6: Area of the different land covers types and their soil loss rate

<table>
<thead>
<tr>
<th>Land use type</th>
<th>Area (km²)</th>
<th>% of total area</th>
<th>Mean Soil loss (ton ha⁻¹ y⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare land</td>
<td>1357</td>
<td>26</td>
<td>18.27</td>
</tr>
<tr>
<td>Bush land</td>
<td>666</td>
<td>13</td>
<td>1.04</td>
</tr>
<tr>
<td>Crop land</td>
<td>932</td>
<td>18</td>
<td>7.31</td>
</tr>
<tr>
<td>Forest land</td>
<td>66</td>
<td>1</td>
<td>0.09</td>
</tr>
<tr>
<td>Grass land</td>
<td>132</td>
<td>3</td>
<td>0.89</td>
</tr>
<tr>
<td>Shrub land</td>
<td>1499</td>
<td>29</td>
<td>0.22</td>
</tr>
</tbody>
</table>

The average soil loss in agricultural fields in the study area (Table 6) is below the estimated soil erosion rate, 9.9 ton ha⁻¹ y⁻¹, on cultivated areas for northern Ethiopia (Nyssen et al 2009); 35 ton ha⁻¹ y⁻¹ for the South Welo zone (SCRP 1996); 42 ton ha⁻¹ y⁻¹ for Ethiopia (Hurni 1987) and 30 ton ha⁻¹ y⁻¹ worldwide (Pimentel and Kounang 1998). Regardless, the farmland is often left bare between plantings for several months of the year which exposes the soil to wind and water erosion; it is classified as slightly susceptible to erosion. The implemented soil bunds and trenches in most of the farmlands, and the initiation of zero farmland grazing in some areas in the last decades might have resulted in reduced soil loss compared to the findings of others in Ethiopia. However, the erosion status in this land cover type is 7 or more times higher than the rate of renewal and sustainability proposed for the globe by Pimentel and Kounang (1998) which is related to their topographic location in which often occupy steep and hilly, the cropping system in which poor farmers raise row crops such as maize and sorghum which are highly susceptible to erosion. This calls for more intensive land rehabilitation and management activities.

The estimated average soil loss from bare land in the study watershed is about 4 times less compared to the SCRP’s estimate (70 ton ha⁻¹ y⁻¹) in totally degraded land for Ethiopia (SCRP 1996). Furthermore, the estimated average soil loss from grassland was lower than the amount (5 ton ha⁻¹ y⁻¹) estimated for Ethiopia (SCRP 1996) and 6 ton ha⁻¹ y⁻¹ worldwide (USDA 1994).

The implemented stone terraces in most bare soils, soil bunds and trenches in most grassland coupled with zero grazing in both land use types in the last decades might have resulted in reduced soil loss as compared to the findings of others in Ethiopia. Soil loss from forest land, bush land and shrub land was equivalent to the reported soil loss of 1 ton ha⁻¹ y⁻¹ for bushland and shrub land (SCRP 1996) for Ethiopia. These, however, are less than the soil loss amount (3.5 ton ha⁻¹ y⁻¹) in exclosures and forest for northern Ethiopia (Nyssen et al 2009). The vegetation cover in the study area has paramount effect on reducing soil erosion. Singh and Kaur (1989) confirmed that in forested areas, a minimum of 60% forest cover of the landscape is necessary to prevent soil erosion. Furthermore, Trimble and Mendel (1995) in Utah and Montana estimated an increase in erosion rates by approximately 200 times as the amount of ground cover decreased from 100% to less than 1%.

Soil erosion and soil type
The soils: calcareic Fluvisols, calcic Cambisols, chromic Cambisols, chromic Luvisols, eutric Cambisols, vertic Cambisols and lithic Leptosols (Figure 4) respectively cover an area (km²) of 256, 103, 443, 917, 1091 and 2040. Soil loss from calcareic Fluvisols, calcic Cambisols, chromic Cambisols, chromic Luvisols, eutric Cambisols, vertic Cambisols and lithic Leptosols respectively was 20.72, 7.47, 3.91, 9.15, 11.87, 1.32 and 4.07 ton ha⁻¹ y⁻¹. The highest soil loss was estimated from calcareic Fluvisols and was beyond the maximum tolerable soil loss (16 ton ha⁻¹ y⁻¹) for Ethiopia put forward by Hurni (1985). This can be related to their location in the landscape where most of the flood passes through. Many studies (e.g. Liniger and Thomas 1998) suggested that Leptosols which are characterized by low organic matter content and weak structural development are subjected to high rates of water runoff. This, however, was not the case in the study watershed. This can be related to the huge soil and water conservation measures implemented in the study area with a special focus on highly degrade/bare areas. Esser et al (2002) reported that the area of land that was terraced between 1988 and 1995 in Tigray amounted to approximately 418,500 ha which was about 8% of the total area of the region. This, however, increased to an area cover of more than 80% of the region in 2012 (Woldemariam 2012).
About 2715 km$^2$ of the land has a slope gradient of 0-2% and 2-10%; 612 km$^2$ has a slope gradient between 10-15%, 868 km$^2$ has a slope gradient between 15 and 30% and 937 km$^2$ has a slope steeper than 30% (Figure 5). The soil loss from each slope class respectively was 0.01, 1.85, 4.14, 7.59 and 20.11 ton ha$^{-1}$y$^{-1}$.

Steep slopes (> 30%) were prone areas to erosion. The influence of slope steepness on soil erosion was also explained in other areas. At the milli-watershed scale in northern Ethiopia, the lowest soil loss (about 1.59 ton ha$^{-1}$y$^{-1}$) was estimated on flat plains (< 2% slope) while the highest soil loss (35.43 ton ha$^{-1}$y$^{-1}$) was from steep slopes (30-50%) (Brhane and Mekonen 2009). Similarly, in the Philippines, where more than 58% of the land has a slope of greater than 11%, and in Jamaica, where 52% of the land has a slope greater than 20%, soil erosion rates were as high as 400 ton ha$^{-1}$y$^{-1}$ (Lal and Stewart 1990).
CONCLUSIONS
The study was conducted in the macro-watershed of the Geba River (5133 km²) with the objectives to: (i) build the Soil Erosion Map and calculate the soil loss rates; ii) analyze the spatial distribution of soil erosion; iii) locate the erosion prone areas for regional development planning. The results of the analysis showed that the assessed mean annual soil erosion rates (in ton ha⁻¹y⁻¹) in the Geba Watershed was 6.34 ton ha⁻¹y⁻¹ which is relatively small compared to the results from plot level and small-watershed scale studies in the highlands of northern Ethiopia. About 84% of the study watershed was classed to a very slight erosion rate (only about 5% of the area was classified as severe to very severe erosion area). This is mainly related to the size of the watershed in which big watersheds do have high surface roughness resulting in low mean soil loss values. It is further influenced by the huge environmental rehabilitation measures implemented in the last two or more decades. Hence, the average soil loss in the study area is within the tolerable soil loss (2 - 16 ton ha⁻¹y⁻¹) for Ethiopia. Nevertheless, taking the global soil formation rate at 1 ton ha⁻¹y⁻¹, the soil in the study area is being lost 6 or more times faster than the rate of renewal and sustainability.

The soil erosion in the study watershed was also assessed in relation to the existing land cover type, slope classes and soil types. The highest erosion was recorded on bare land (18.7 ton ha⁻¹y⁻¹) while the lowest was on forest land (0.1 ton ha⁻¹y⁻¹).

The highest soil loss was estimated from calcaric Fluvisols and was beyond the maximum tolerable soil loss (16 ton ha⁻¹y⁻¹) for Ethiopia put forward by Hurni. Steep slopes (> 30%) which occupy 18.25% of the study area were prone areas to erosion contributing a mean annual soil loss of 20.11 ton ha⁻¹y⁻¹ compared to the 0.01 ton ha⁻¹y⁻¹ under level (0-2%) lands.

From this study, it is clear that steep slopes (> 30% slope), bare lands and calcaric Fluvisols were the most erosion susceptible areas as compared to the other land characteristics. These, therefore, require a special attention before they reach their unrecoverable stage.

ACKNOWLEDGEMENTS
The author would like to thank the farmers, Mekelle University, Agricultural Development Agents and local administrators of the study villages for their assistance during the field work.

REFERENCES
Feoli E, Vuerich LG, Zerihun W (2002): Evaluation of environmental degradation in northern Ethiopia using GIS to integrate vegetation, geomorphological, erosion and


