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Soil Erosion Estimation Using Revised Universal Soil Loss Equation Integrated with Geographic Information System by Different Resolution Digital Elevation Model Data in Weyto Sub-Basin, Southern Ethiopia

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ABSTRACT: Soil erosion is a global environmental challenge for developing countries including Ethiopia that require regular monitoring to take corrective measures. In this context, this study was focused on estimating soil erosion using the Revised Universal Soil Loss Equation (RUSLE) integrated with Geographical Information System (GIS) technique for which it applied 30 m and 200 m resolution Digital Elevation Model (DEM) data to generate slope gradient and length. Rainfall erosivity, soil erodibility, land cover/use and management factors data were obtained from existing studies and field-based assessments where the data were used to estimate the soil erosion using RUSLE model in ArcMap under two different DEM resolution scenario. The model estimated an average of 1.38 and 1.86 million tons of annual soil loss by water using 200 and 30 meters resolution DEM data, respectively, while keeping other factors constant. The erosion estimated using higher (30 m) resolution DEM data was more realistic than low (200 m) resolution data , as the higher resolution DEM data allowed less generalization. In high resolution DEM data, the slopes generated were also more in line with ground reality. Based on the case study of Weyto sub-basin in Southern Ethiopia, we thus conclude that the GIS technique and remote sensing data can be used in RUSLE based erosion risk prediction for large areas even at basin, sub-basin and macro watershed level. We suggest that the accuracy of the prediction can be improved by using high resolution (large scale) input data disaggregated by micro- and sub-watersheds.

Keywords/Phrases: *Ethiopia, Geographical Information System, Land degradation, Modelling, Revised Universal Soil Loss Equation, Soil Erosion*

INTRODUCTION

Nearly one-third of the global land used for agriculture has been affected by soil degradation in the historic past, where most of this damage was caused by water and wind erosion (Nana-Sinkam, 1995; Scherr, 1999; Hurni et al., 2008). The problem is persisting in developing countries mainly in Sub-Sahara African (SSA) nations. The drivers of soil erosion by water in the subcontinent are attributed to natural (e.g. topographic features) and manmade (e.g. land use pattern) causes (Nana-Sinkam, 1995; Scherr, 1999; FAO, 2004; Vlek et al., 2008). Like most SSA nations, soil erosion induced land degradation in Ethiopia is exceedingly high, where the problem is acute in tits highlands (Hurni, 1993; Bekele Shiferaw and Holden, 1999; Shimeles Damene et al., 2013; 2020). For instance, Hurni (1993) estimated 42 ton per ha annual losses of fertile topsoil from crop lands of the Ethiopian highlands. Various studies in Ethiopia indicated that most farmlands are severely affected by water erosion, particularly in the highlands (e.g., Hurni, 1993; Bojö and Cassells, 1995; Lulseged Tamene et al., 2006; Shimeles Damene et al., 2012; Habtamu Sewnet and Amare Sewnet, 2016; Balabathina et al., 2019; Nyssen et al., 2019; Atoma et al., 2020; Yared Mesfin et al., 2020). The soil erosion induced land degradation imposed chronic food insecurity across Ethiopia highlands (Bekele Shiferaw and Holden, 1999; Kebrom Tekle, 1999), resulting in economic losses of about US$ 106 million annually at national level (Bojö and Cassels, 1995) and also caused various environmental hazards including recurrent drought (Bekele Shiferaw and Holden, 1999; Kebrom Tekle, 1999). Consequently, for combating the land degradation in the highlands, various efforts have been put in place by Ethiopia's Ministry of Agriculture over the

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past four decades, mainly on cultivated lands. These interventions on farmlands include construction of physical measures like contour bund, hillside terraces, check dams and biological measures such as tree planting at homestead and on farms, afforestation and closure of degraded lands for self-restoration (Shimeles Damene et al., 2013; Hurni et al., 2016). Understanding and mitigating erosion coupled with the associated land and environmental degradation is critical because of its possible adverse effects, such as loss of nutrients, river and reservoir siltation, water quality degradation, and decreases in land productivity (Bagherzadeh, 2014). Moreover, in connection to the construction of small to large-scale irrigation dams and huge hydropower generating dams (such as the Great Renaissance, Gilgel Gibe I –IV, Koysha, Melka Wakena and Tana Beles), the country has been striving its best to restore the environment and protecting dams from siltation through implementing integrated watershed management (IWSM) e.g soil and water conservation (SWC) interventions and planting billions of tree seedlings. Although the country has been investing considerable finance and mobilizing local people in IWSM, SWC and tree planting, the result of the intervention is not supported by regular monitoring and often lacks a robust tool and methodology to track changes and understand possible impacts. Despite the various efforts of the government in protecting land from soil erosion induced land degradation, very limited studies have been conducted yet to test and identify the best input data use in estimating soil loss in Ethiopia.

The universal soil loss equation (USLE) developed by Wischmeier and Smith (1965; 1978) and modified by Renard et al., (1997) that come as the revised universal soil loss equation (RUSLE) which enhanced the prediction power of the model for erosion estimation. Thus RUSLE become a comprehensive mathematical model that uses different soil erosion factors to estimate soil loss although it still has same limitations. Despite its persisting limitations, the RUSLE model is still in use to estimate soil erosion by water, particularly at a watershed level (Panagos et al., 2015a; Phinzi and Ngetar, 2019; Almaw Fenta et al., 2020). RUSLE parameters can be developed based on small-scale studies of agricultural plots (Benavidez et al., 2018), using this model in large-scale conditions can prove extremely different from the small agricultural plot conditions, and hence the model may lead to error extrapolation (Wischmeier and Smith, 1978; Renard et al., 1997). In this regard, Hurni (1985) developed reference criteria for the different erosion factors to estimate soil erosion under Ethiopian condition. This days researchers have been integrating RUSLE model with the Geographic Information System (GIS) and Remote Sensing (RS) techniques to estimate the soil erosion by water at affordable cost and time (Fu et al., 2005; Kouli et al., 2009; Demirci and Karaburun, 2012; Habtamu Sewnet and Amare Sewnet , 2016; Ganasri and Ramesh, 2016; Ayele Desalegn et al., 2018; Bouhadeb et al., 2018; Asnake Yimam and Amare Bantider 2019; López-García et al., 2020; Yared Mesfin et al., 2020).. The model is also widely used as flexible tool (Kumar and Kushwaha, 2013; Panditharathne et al, 2019) that has been adapted to landscape and watershed scales, combined with GIS and RS techniques (Panditharathne et al, 2019). Nonetheless, most studies do not compare the RS data at different resolutions on the precision of soil erosion prediction as the model has been accused of having error in estimation of sediment redistribution in small drainage units before the runoff heading to large drainage system (Nearing, 1997; Cohen et al., 2005; Kinnell, 2005; Nearing, et al., 2005; Panagos et al., 2015b). In this regard, high resolution RS data such as digital elevation model (DEM) from which the topographic factor (slope length and gradient) is calculated, could help to divide the watersheds into small compartments and thus might reduce the effect of aggregated estimation errors. It is well known that the topographic factors (including slope length and gradient) is the most sensitive in soil loss prediction modelling (Panditharathne et al, 2019). Therefore, this study is aimed at evaluating the RUSLE model using 30 m and 200 m resolutions DEM data to demonstrate the difference in the erosion estimation prediction power. For the purpose, we have used the case study of Weyto sub-basin in Southern Ethiopia.

MATERIALS AND METHODS

Description of Weyto sub-basin

Weyto sub-basin is found in the Southern Nations, Nationalities, and Peoples' Region (SNNPR) of Ethiopia (Figure 1). Geographically, the sub-basin is located between 5°23´00´´ and 6°15´00´´ North latitude and 36°35´00´´ and 37°25´00´´ East longitude and covers a total area of 438,384 ha.

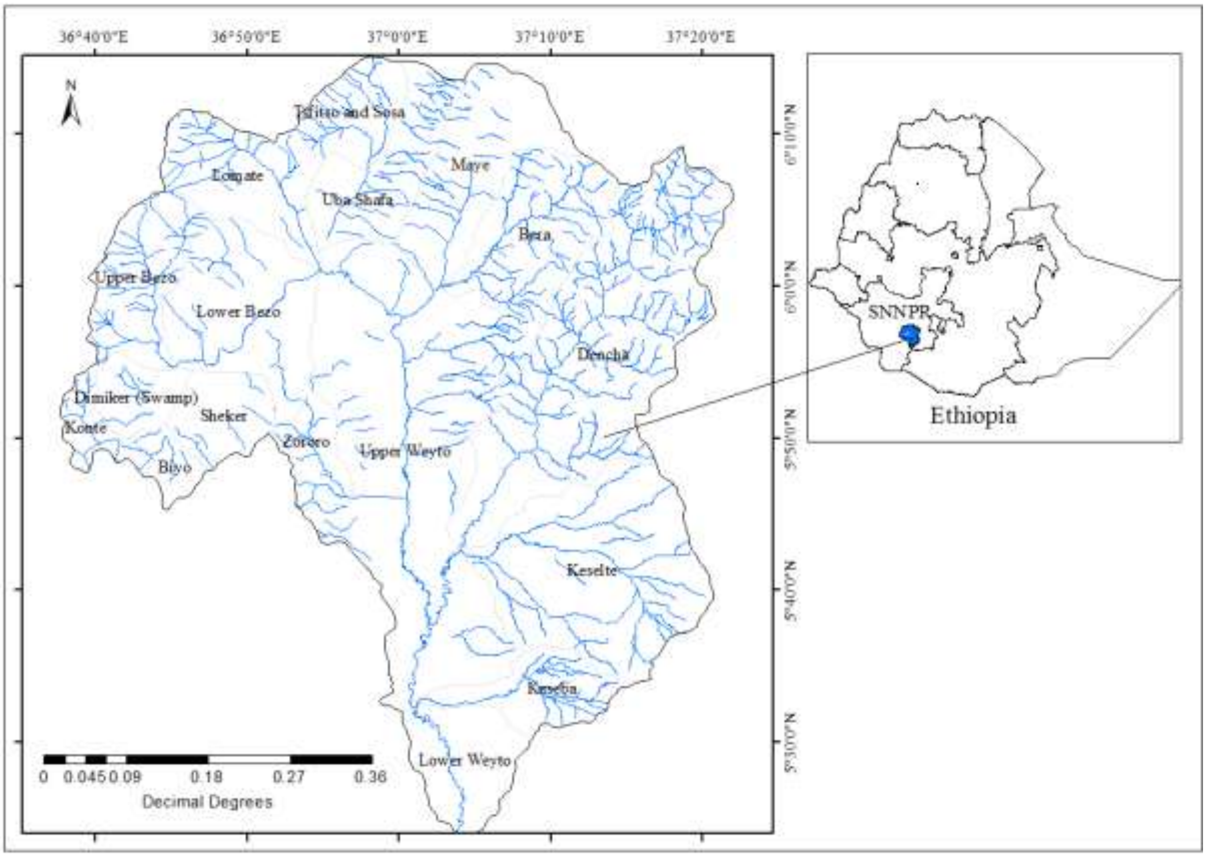

Figure 1. Location map of Weyto sub-basin.

The sub-basin is characterized by a wide range of biophysical features in terms of climate, agro-ecology, soil, geology, land use/cover, drainage pattern and density. The study area has diverse landform and geology. The topography has various characteristics such as plain, valley plains, plateaus, ridges, hills, medium and high mountains. The sub-basin consists of 17 major- and sub-watersheds (Figure 1). The watersheds in the highland areas (e.g., Tsfitso-Sosa, Dencha, Uba Shafa and Upper Bezo) have narrow and steep landforms. In contrast, watersheds located in the lowland areas (e.g. upper and lower Weyto, Lower Bezo) are relatively wider in size and characterized by gentle slope. The geology is predominantly volcanic and sedimentary formation such as unwelded pumiceus pyroclastic, ignimbrite, tuff, water lain pyroclastic and undivided alluvial fluvitile and lacustrine sediments; and meta sedimentary genesis originated from biotite, quartz, feldspar, gneiss, granite rhyolite and trachyte (Halcrow and GIRD, 2007). The diverse geology and geomorphology have resulted in a variety of soil types, where the major soil types are Cambisols (66.4%), Nitisols (15%), Luvisols (10%), Vertisols (7.6%) and very few (<1%) Arenosols (Halcrow and GIRD, 2007).

The sub basin has a bimodal rainfall pattern that annually varies from 678 mm at the Weyto meteorological station (at 570 metre a.s.l. elevation.) to 2,107 mm at the Gerese station (at an elevation of 2,329 m.a.s.l) (Figure 2). Nearly 70% of the rainfall occurs in the first (March to May) and second (September to November) rainy seasons which contributes about 24% to 50% and 19% to 35% of annual rainfall respectively. The mean annual temperature varies from 16°C in the highlands to 28°C in the lowlands. As shown in Figure 2, the mean monthly minimum temperature ranges from 10.2°C (at 2,280 m a.s.l.) to 23.6°C (at 1,158 m a.s.l.) (). The mean monthly maximum temperature reaches over 34°C in the lowlands between December and March and the temperature sometime rises as high as 40°C.

According to the local classification system (Hurni, 1998), the sub-basin lies within four agro-ecological zones namely: *kolla* (warm), *weyna dega* (mild), *dega* (cool) and *wurch* (cold) that cover 63%, 26%, 10.5% and 0.5% area, respectively.

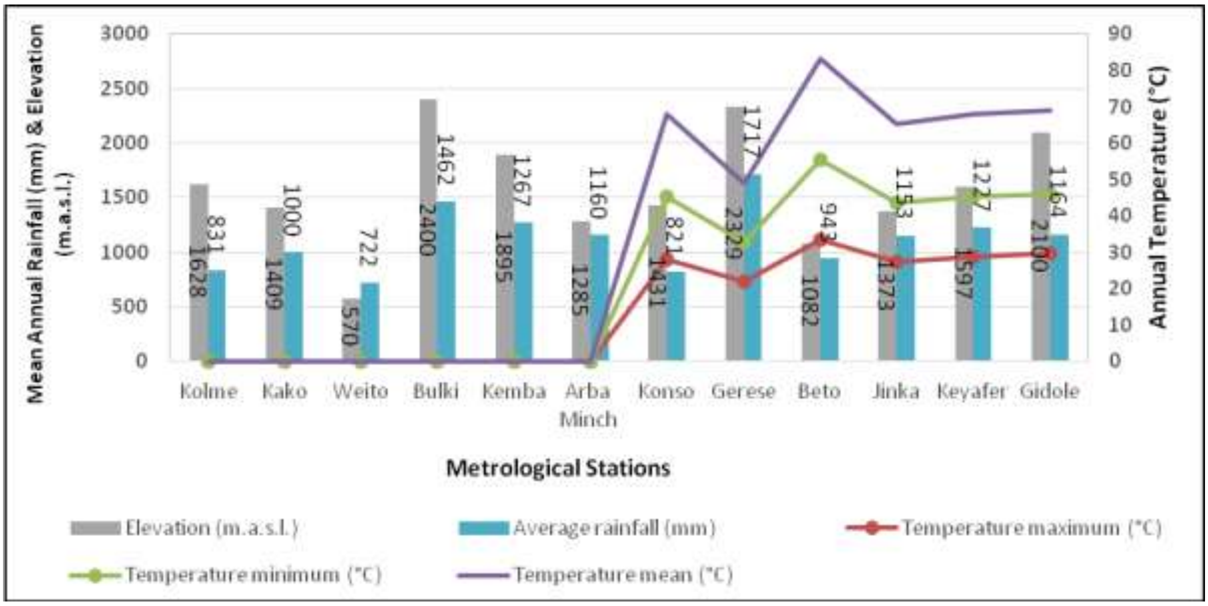

Figure 2. Annual rainfall and temperature records by meteorological stations in and around Weyto sub-basin.

Subsistence aagriculture is the main economy activityof the local people. The majority (70%) of people depend on mixed crop and livestock production (sedentary farming agriculturalists) and the remaining (30%) were agro-pastoralists and pastoralists. The sedentary farming agriculturalist communities inhabited the highland and midland areas. Crop production is diversified and includes a variety of crops: cereals, fruits, vegetables, root crops, *Enset* (*Ensete ventricosum*), cash crops, particularly spices (e.g., black cardamom, ginger) and coffee. The lowland areas are predominantly occupied by pastoralist and agro-pastoralist communities.

The watersheds have different land use/cover characteristics. Most watersheds in the highland and mountainous areas are characterized by agro-forestry based crop cultivation. In these areas, farmers mostly plant perennial crops, particularly *Enset*, integrated with cereals (like barley, wheat), legumes, root crops and vegetable-based farming, even on the steep landscapes. These watersheds also have patchy grasslands, scattered and small grove of trees are found on farmlands at the homesteads, along the river courses and on very steep landscapes (Figure. 3a & b). The trees along the river sides, steep landscapes, patches of grasslands and *Enset* altogether have been reducing runoff velocity and soil erosion rate.

The watersheds in the south-eastern parts particularly in *Konso* areas (e.g., Keseba and Keselte watersheds) are degraded as they have low vegetation cover and are heavily cultivated. However, farmers of the areas are actively engaged in terrace construction to protect the farmlands from soil erosion. Watersheds in the lowland areas and valley plains (upper and lower Weyto) are characterized by flat slope and covered by dense bush, woodlands and forests. Thorny, deciduous lowland trees (mainly Acacia species) are dominant vegetation with some broad-leaved trees (like Ficus and Palm trees) as riparian vegetation along the Weyto River and its major tributaries. The lowlands have very sparse population who depend on pastoralist and agro-pastoralist livelihood systems, mainly producing grazing and browsing animals (Figure. 3c & d). The indigenous pastoralist communities to some extent are also involved in hunting of wild pigs. In these areas, some settlers who come from neighbouring districts are found to be practicing crop production through shifting cultivation by clearing the natural vegetation.

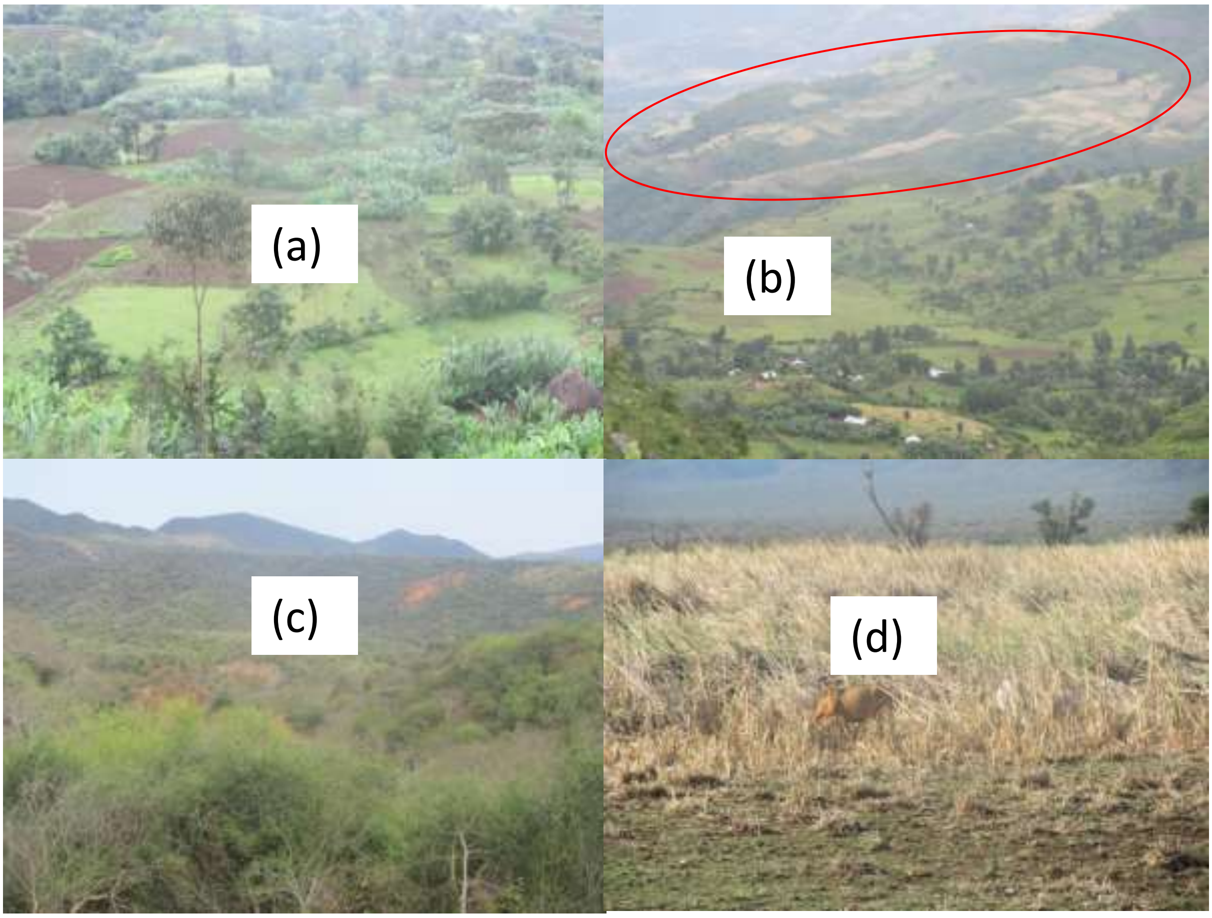

Figure 3. Major land use: *Enset* (a) and cereal (b) based farming systems in the highlands and land covers: forests (c), papyrus grass stripe (d) in Weyto sub-basin.

Methods

Application of GIS for soil erosion estimation

The RUSLE has now been one of the widely used soil erosion model to predict soil erosion by water. However, the model has been questioned for its accuracy, as it has various limitations in output quality which is determined by input data and where some of the input data involve expert judgment and hence are subject to personal bias and error. The model has less sensitivity to rainfall than land cover (Nearing, 1997). Also, it does not consider the effects of gully erosion and redistribution of eroded soil within small land units. Hence, the model is mainly used to estimate annual soil loss over long periods for smaller areas, as it lacks runoff factors and mostly gives exaggerated estimation (Kinnell, 2005). Moreover, it disregards ground conditions like plant litter, which are important in monitoring water infiltration and thereby soil erosion (Nearing, et al., 2005), and also does not estimate sediment pathway along hill slopes (Cohen et al., 2005). On the whole, the uncertainties associated with the RUSLE, and arguably soil erosion modelling in general, stem from several factors, including: the inability of models to capture the complex interactions involved in the soil loss, the low availability of long-term reliable data for modelling, and the lack of soil erosion observational data for model validation, especially in data-scarce environments (Benavidez et al., 2018). Therefore, in order to enhance the model erosion prediction power our analysis combined RUSLE with Geographic Information System (GIS) techniques and Remote Sensing (RS) data. Moreover, we also applied Hurni (1985) indexes for the different soil erosion factors to fit the RUSLE model with Ethiopian condition. . Therefore, in our analysis, we have used RUSLE model together with Hurni (1985)'s erosion factor indices by integrating with the GIS techniques and RS data, mainly the Digital Elevation Model (DEM with 30 and 200 m resolution) as part of the input data. GIS technique has been applied to generate and transform erosion factors, and perform the modelling.

In the process of analysis, the different input parameters of RUSLE: Rainfall erosivity (R), soil erodibility (K), slope gradient (S) and length (L) treated as topographic (LS) factor, land cover (C) and management (P) factors were generated. In order to simplify the analysis, land cover and management factors were merged into one before use in the model. As some of land cover practices are part of land management factors, we combined both while generating raster data using the tow maps (land cover and management). Application of the GIS techniques involved assigning the erosion factor by inserting index value for spatial feature data. Then, the feature data (shape files) containing the index values were converted into raster data while also performing the vis-à-vis process as detailed in the subsequent sub-sections below. Finally, all erosion factors data transformed into raster formats were used to model the erosion risk using the RUSLE model (Eq.1) in the raster calculator tool of ArcMap 10.3.1.

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

Eq. 1

where:

A = Total soil loss (t/ha/yr)
R = Rainfall erosivity factor
K = Soil erodibility factor
LS = Topographic (L= Slope length and S= Slope gradient) factor
C = Land cover factor
P = management factor

Data source and process of determining erosion factors

Data sources

The modelling was done using 1:250,000 scale maps of soil erodibility, rainfall ersosivity, land cover and management factors. On the other hand, slope length (L) and gradient (S) factors aggregated as topographic (LS) factor were generated from 200 m and 30 m resolutions of the Digital Elevation Model (DEM) data. The erosion factors data such as soil survey, land use/cover were obtained from Halcrow and GIRD (2007), soil and water conservation data were compiled from the records of district agriculture offices while the interpretation of satellite data was assisted by high resolution [60 cm] Google earth data and field observation. DEM data of Shuttle Radar Topography Mission (SRTM) was accessed from: https://earthexplorer. usgs.gov. Rainfall data of ten meteorological stations obtained from the Ethiopian Meteorological Agency (EMA) were used to generate rainfall erosivity factor map. These data were then used to generate different erosion factors. The details of the estimation methods are discussed below.

Determining rainfall erosivity (R)

Rainfall erosivity, R (MJ mm ha^{-1} h^{-1} yr^{-1}) is the product of the kinetic energy of rainfall (E) and the maximum intensity of rain in 30 minutes in cm $hour^{-1}$ (I_{30}). Rainfall intensity records are not available in most rain gauge stations of Ethiopia. Hence regression equation (Eq.2) developed by Hurni (1985) for Ethiopian condition was used to determine R values for mean annual rainfalls instead of I_{30}. Therefore, 34 years (1980 to 2014) annual rainfall data of 10 stations (found in and around the sub-basin) combined with agro-ecological map (Hurni 1998) developed from DEM were used to generate rainfall and erosivity map of the sub-basin. In this process the data analysis was performed using Excel and the final result transferred into raster map. After preparation of the erosivity map, the shape file (feature data) was converted into raster data format so as to make it ready as input data for RUSLE modelling.

$$\boldsymbol{R = (P * 0.562) - 8.12} \qquad \text{Eq. 2}$$

where, R is rainfall erosivity factor and P is mean annual precipitation (mm)

Soil erodibility factor (K)

Soil erodibility (K) factor is a measure of the susceptibility of soil particles to detachment and transport by rain drop and runoff (USDA, 2011). According to the models used in Wischmeier and Smith, (1965, 1978) and Renard et al. (1997), K factor depends on various physicochemical properties of soils such as the organic matter content, texture, permeability and structure that can range from 0.7 for the most fragile soils to 0.01 for the most stable soils. Zhang et al. (2008a) estimated K values on 13 runoff plots of soils in eastern China that ranged from 0.007 to 0.02 MJ mm ha^{-1} h^{-1} yr^{-1}. Nevertheless, there is as such no standard K index to be used under different soils and settings so far. Based on Wischmeier and Smith (1965; 1978) method, Hurni (1985) developed a simplified K factor index based on soils colour, assuming that soil colour has intrinsic relation with the above soil properties for Ethiopian case. Hence the soil map of the sub-basin adopted from Halcrow and GIRD (2007) was used to produce soil colour map and assigned with K values as per Hurni (1985) i.e. K value of 0.15, 0.20, 0.25 and 0.30 for black, brown, red and yellow colour soils respectively. The K values were assigned on the feature data (shape file) and then transformed into raster data to make it ready for RUSLE based modelling.

Land cover (C) and management practice (P) factors

The land cover factor is based on clean tilled and continuous fallow conditions as C represents the effects of plants, soil cover, soil biomass, and soil disturbing activities on erosion. The P factor represents the ratio of soil loss from lands treated with soil conservation practices (such as contouring and/or strip-cropping) to that with straight row farming up-and-down slope (1.00). In this analysis, the C and P factors were modified to Ethiopian condition as per the recommendation of Hurni (1985). Therefore, land use/cover (LULC) map developed by Halcrow and GIRD (2007) was used to generate C and P factor data which were mapped in one. Accordingly, 5 LULCs were identified and provided with C values as adopted from Hurni (1985) i.e. forestland (0.001), woodlands (0.005), bushland (0.01), grassland with fragmented farmlands/woodlands (0.05) and farmlands (0.0975 to 0.135 depending on the management type). The land management practices and corresponding P values for farmlands include: terracing and agro-forestry supported smallholder farmlands (0.0975), agro-forestry based smallholder's farmlands (0.105), *enset* based smallholder's farmlands (0.12), smallholder's farmlands mixed with patchy wood/bush lands (0.12) and counter cultivation based smallholder farmlands (0.135). Finally, after C and P index values were assigned to each mapping unit in the feature dataset (shape file) in ArcMap 10.3.1, the map was converted into raster data and made ready for RUSLE based calculation.

Topographic (LS) factor

Slope length (L) and gradient (S) are among the factors that affect soil erosion, which together are referred to as topographic (LS) factors (Krusekopf, 1943; Hurni 1985). In soil loss estimation, slope length determination is often a complicated process and hence combined form specifically single value estimated by Hurni (1985) for slope length and gradient is used (Bagegnehu Bekele and Yenealem Gemi, 2021). To overcome the challenge, unlike USLE, the RUSLE takes a number of considerations. For example, the RUSLE considers runoff differences over catchment such as runoff channelled into rills and gullies (as rill erosion is a major component in the RUSLE), soil saturation resulting from long duration rainfall that carries more runoff and creates greater erosion, soil deposition at concave slope landform and also takes into account of converging and diverging terrain (Renard et al., 1997). Therefore, Hurni (1985) recommended the combined LS (topographic) factor, based on which this study also used the combined LS factor for various slope gradients (%). In this exercise, two resolutions (200 m and 30 m) DEM data were used to determine the LS factor. The DEM data were transformed into feature data (shape file) so as to assign erosion index values for ranges of slope gradients as given in Table 1 and reclassified into new class as per Hurni (1985) recommendation. Then, LS feature data (shape file) carrying erosion index values were transformed back into raster format to make it ready for the RUSLE model-based calculation in ArcMap 10.3.1.

Table 1. Slope gradient (%) and LS factor index.

Slope gradient (%)	<2	4	6	8	13	25	40	55	100	>100
LS factor index	0.19	0.38	0.66	1.14	1.90	3.80	6.08	7.98	10.45	19.00

Sources: Hurni (1985) developed erosion factor indexes under Ethiopian condition; adapted from Wischmeier and Smith (1965; 1978)

Field data collection and map verification

Following interpretation and map production using the different remote sensing data, *in situ* field visit and data collection were carried out in two rounds of wet and dry seasons. The field data collection involved observation and cross-checking of interpreted information (polygon) from maps, images and DEM data to ascertain the actual ground condition on biophysical and socio-economic situation, erosion extents and degree of severityy. The assessment was done throughout the delineated watershed areas. Transect walks were made to check polygons with unique characters/tones, erosion hotspots, unique land uses/land covers, in different agronomic, conservation (soil and water) and land management practices. Geographical Positioning System (GPS) was used to locate the polygons and features of the base map on the ground and vice versa.

Moreover, focus group discussions (FGDs) were held with selected community members (at 15 localities) along the transect walk and key informant interviews (KIIs) were also carried out with selected districts agriculture offices. In order to collect relevant secondary data, structured formats were developed and distributed to districts and zones agriculture offices in 2015. The primary and secondary field data as well as very high (0.6 m) resolution Google Earth map were used to verify the produced maps and to assign erosion factor values of the various polygons of the input maps used in RUSLE-based erosion modelling.

RESULTS AND DISCUSSION

Erosion factors analysis results

Rainfall erosivity factor (R):

Rainfall erosivity values were estimated from mean annual rainfall data of 10 meteorological stations found in and around the sub-basin and agro-ecological map. As discussed earlier, the modelling used mean annual total precipitation. Our analysis revealed that erosivity ranged from 373 to 1176 MJmm/ha/h/yr (Figure 4a). The study sub-basin rainfall is expected to cause very high to moderate erosivity in the mountainous areas. In convers, the lowlands and midlands which are located in the central parts of the sub-basin receive relatively low rainfall and thus have low erosivity index and are characterized by flat and gently undulating landscapes. Therefore, the calculation considered this fact supported by ground (rainfall) data while inputting index values for R.

Soil erodibility factor (K):

In general, as shown in Figure 4b, the major soil types of the sub-basin are: Cambisols (63.2%), Nitisols (17.4%), Luvisols (11.1%), and Vertisols (8.3%). Thus, nearly three fourth (71.5%) of the sub-basin soils possess slight (8.3%) to moderate (8.3%) erodibility and the remaining parts are characterized by relatively high (0.18 to 0.2) to very high erodibility index (Panagos et al., 2015a). Soils with high to very high erodibility are Luvisols and Nitisols, which are located in the central north and northeast parts of the sub-basin. In contrast, areas with slight to moderate erodibility are covered by Cambisols and Vertisols. In this regard, literatures suggest that loam and fine sand textured soils are the most erodible that have fine clay and loam particles, which can easily be transported even under low runoff velocity and soils coarser than fine sand settle at short distance from the venue of detachment (Wischmeier and Smith, 1965; 1978; Hurni 1985; Duiker et al., 2001; Zhang et al., 2008a).

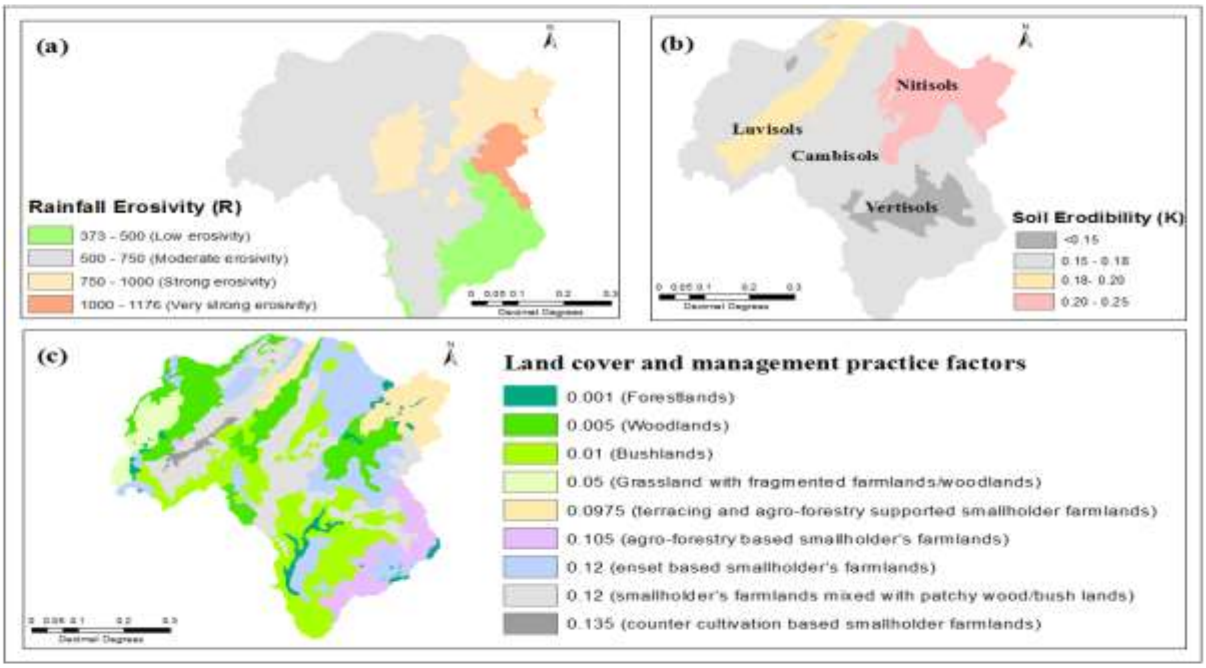

Figure 4. Maps of rainfall erosivity (a), soil erodibility (b) and land cover and management practice factors (c) for the Weyto sub-basin.

Land cover (C) and management practice (P) factors:

As shown in Figure. 4c, about 43.9% of the sub-basin is covered by forestlands (2.7%), woodlands (15.8%), bushlands (21.2%) and grasslands with fragmented farmlands/ woodlands (4.1%). Hence, these land units have minimal soil erosion risk due to good land cover. On the other hand, farmlands that cover about 56.1% of the sub-basin have high soil erosion risk, which are located in the northeast and northwest parts. Studies in highland of Ethiopia showed that most farmlands are severely affected by water erosion, (e.g., Hurni, 1993; Bojö and Cassells, 1995; Shimeles Damene et al., 2012; Balabathina et al., 2019; Atoma et al., 2020; Yared Mesfin et al., 2020). However, the erosion risk under different land management practices of the farmland has considerable variation. Accordingly, as our FGDs, KIIs and field assessment revealed, farmers in the highlands have been practicing different land management activities to enhance sustainable land use and crop production. From the farmlands of the sub-basin, nearly half (46%) are characterized by *Enset* (*Ensete ventricosum*, Musaceae) and agro-forestry based farming mixed with homestead tree and fruit planting. The agro-forestry based farming have a considerable role to reduce soil erosion, thus these land units have low erosion risk compared to farmlands without such management practice. In this regard, Young (1989) underlined that agro-forestry system reduces soil erosion through maintaining soil organic matter, improving soil chemical, biological and physical properties thereby enhancing efficient nutrient recycling within pedological system even from the substrata. On the other hand, runoff generated from fragmented farmlands located within forest, wood- and bush-lands might not continue with erosive velocity and the runoff will not have cumulated effect to cause significant erosion risk on the farmlands located at the down slope position. The field visits and satellite images also depict that the farmlands in the south eastern parts mainly in *Konso* areas have well developed terraces to minimize soil erosion (Figure 5). Here, it is worthy to mention that the *Konso* people are known traditionally for well-developed terraces. The United Nations Educational, Scientific and Cultural Organization (UNESCO) have registered the traditional terracing practice of *Konso* as a world heritage, which is estimated to be older than 400 years (Watson and Currey 2009).

Figure 5. Terracing practice in *Konso* area.

Topographic (LS) factor:

The LS factor analysis output under the two scenarios, using 30 m and 200 m resolution DEM data is given in Figure 6 and Table 2. The analysis shows that the sub-basin has a very complex landscape and topography. About 7% of the sub-basin have <2% slope gradients, whereas considerable parts (about 20%) of the sub-basin are characterized by steep (>25%) slope gradients that can facilitate high erosion risk or significantly higher LS values. As shown in Figure 6, parts of the sub-basin are characterized by depositional or very low soil erosion hazard areas, which are located along the valley plain following the Weyto River and its major tributaries. This is in accordance with the findings of Habtamu Sewnet and Amare Sewnet, (2016). (2016) who reported that the LS factor has a significant influence on soil loss at the upper-slope as opposed to lands at the lower landscape in the watershed. The soils in the low lying areas are dominated by Vertisols and Cambisols, which are characterized by poor internal and surfaces drainage; thus they are depositional than being exposed to erosion (Nyssen et al., 2019).

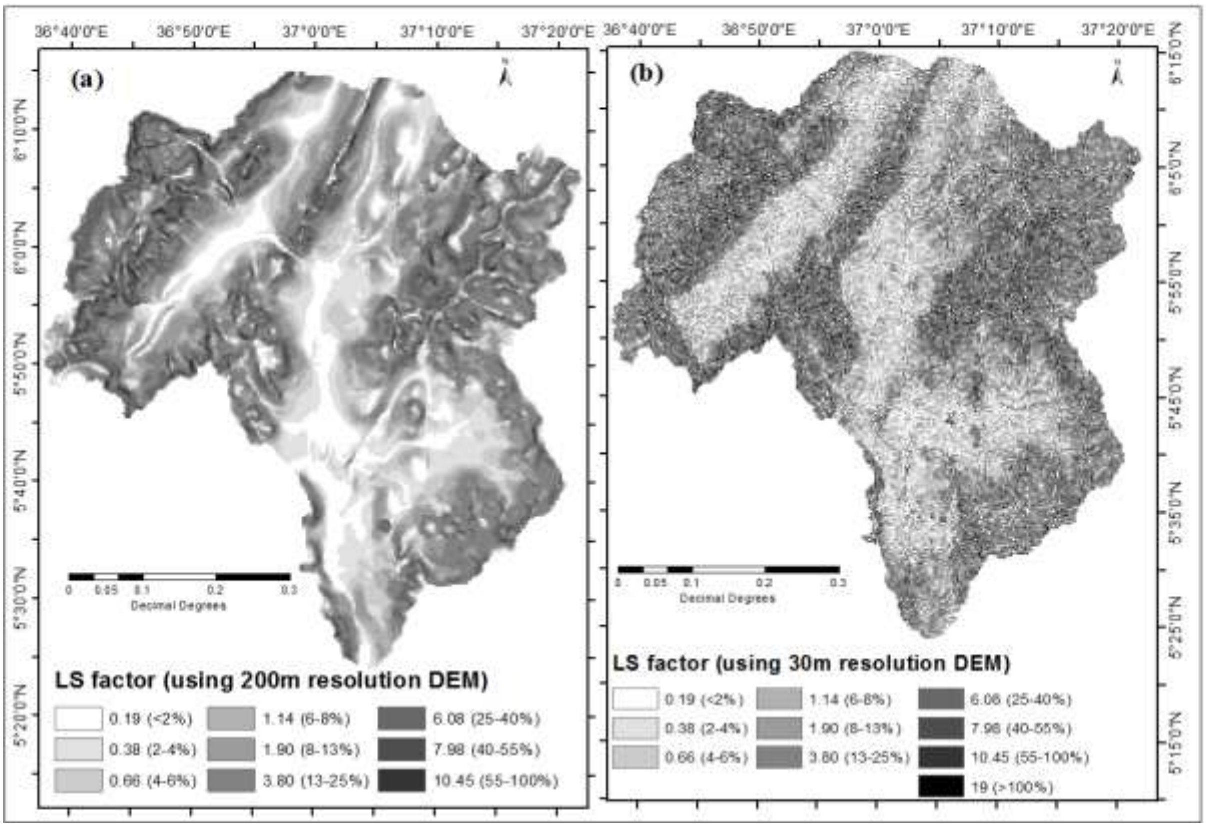

Figure 6. Weyto sub-basin topographic (LS) factor map calculated using 200 m (a) and 30 m (b) resolutions DEM data.

As indicated in Table 2 and Figure 6, the low resolution (small scale, i.e., 200 m) DEM data exaggerate the slope values in level to sloping (<25% slope) landforms compared to high resolution (large scale, i.e., 30 m resolution) DEM data. Analysis of 200 m resolution DEM data revealed that the coverage area of land with <25% slope gradient is 5.7% greater than area generated from 30 m resolution DEM data. In contrast, low resolution (200 m) DEM data underestimate slope values at steep terrains (>25% slope) compared to high (30 m) resolution DEM data. Thus, the area covered by steep slope (>25%) landform generated from 200 m resolution DEM data is 5.7% lower than that of 30 m resolution DEM data. This is in accordance with the findings of Zhang et al. (2008b) who stated that a coarse resolution DEM generates more generalized terrain by maintaining only the major relief features. These results in the vanishing of steep slopes and micro-relief features that tends to lengthen the flow path, and hence increasing the catchment areas (Wilson and Allant, 2000). According to the FAO (2006) classification, steep lands have over 30% slope that include high gradient escarpment, hills, mountains and valley landforms. This highlights that the estimation of LS factor values is influenced by the resolution of DEM data under use. Clinometers based slope measurement applied to verify slope data (generated using 200 and 30 m resolutions DEM data) showed considerable generalization and aggregation at lower slope percentage in low than high resolution DEM data. Therefore, LS estimation using high resolution data might be more realistic to the natural slope condition. Hence, we suggest that a better estimation of erosion risk can be done using the high resolution DEM data.

Table 2. Weyto watershed topographic (LS) factor and area covered by units of factors.

No	Slope range (%)	Combined LS factor*	Area covered under					
			200 m resolution DEM data (A)		30 m resolution DEM data (B)		Difference (A-B)	
			Hectare	%	Hectare	%	Hectare	%
1	< 2%	0.19	41,822	9.5	21,871.5	5.0	19,951	4.6
2	2 – 4%	0.38	58,665	13.4	48,696.2	11.1	9,968	2.3
3	4 – 6%	0.66	49,467	11.3	48,867.8	11.1	599	0.1
4	6 – 8%	1.14	39,574	9.0	41,995.4	9.6	-2,422	-0.6
5	8 – 13%	1.90	69,661	15.9	73,719.8	16.8	-4,059	-0.9
6	13 – 25%	3.80	106,536	24.3	105,583.5	24.1	953	0.2
7	25 – 40%	6.08	59,232	13.5	60,007.2	13.7	-775	-0.2
8	40 – 55%	7.98	11,157	2.5	22,868.6	5.2	-11,712	-2.7
9	55 – 100%	10.45	2,270	0.5	13,766.2	3.1	-11,496	-2.6
10	>100%	19.00	-	-	1,007.8	0.2	-1,008	-0.2
	Total		438,384	100	438,384	100.0		

**Adopted from Hurni (1985)*

Erosion hazard analysis

The sub-basin soil loss rate through water erosion was calculated using the RUSLE by integrating it with the GIS technique using two different resolutions DEM data. As discussed earlier, the different factors were mapped and converted into raster data. Raster data output of the soil erosion factors (R, K, LS, C and P) were imported into ArcMap 10.3.1 and the erosion rate was estimated using the raster calculator. In this analysis, the 200 and 30 m resolution DEM data yielded slightly different two soil erosion risks. In general, the soil erosion estimate using the higher resolution (30 m) was higher than low resolution (200 m) DEM data. The maximum erosion estimate using 30 and 200 m resolution DEM data were 36t/ha/yr and 21t/ha/yr, respectively (Figure 7). As shown in Table 3, area mapped using 200 m and 30 m resolution DEM data as natural to very slight erosion risk account for about 89.3% and 78%, respectively. Nearly 11.3% area was generalized in low slope range in case of low resolution (200 m) DEM data compared to 30 m resolution data. In converse, the low resolution DEM data underestimated erosion risk of steeper slope areas due to relatively low level of generalization by the higher resolution DEM data. Total area estimated to have moderate to very high soil erosion risk using 200 m and 30m resolution DEM data account for about 1.9% (8,330 ha) and 7.6% (33,407 ha), respectively. In general, the erosion risk analysis using the two different resolutions DEM data revealed that over 90% of the sub-basin does not have concerning soil erosion rate, which was estimated within tolerable soil loss limit, i.e., below 10 t/ha/yr. This study is in harmony with the findings of various studies focused on GIS and RS-based RUSLE model prediction (e.g., Fu et al., 2005; Kouli et al., 2009; Demirci and Karaburun 2012; Habtamu Sewnet and Amare Sewnet, 2016; Gaubi et al., 2017; Bouhadeb et al., 2018; Ayele Desalegn et al., 2018; Balabathina et al., 2019; Phinzi and Ngetar, 2019; Atoma et al., 2020) that reported low soil erosion losses at steep slope land under good vegetation cover and land management practices.

Table 3. Weyto sub-basin soil loss (A) in t/ha/y using 200 m and 30 m resolution DEM data.

No	Soil loss ranges (t/ha/yr)	Erosion class	Area covered under					
			200 m resolution DEM data (A)		30 m resolution DEM data (B)		Difference (A-B)	
			Hectare	%	Hectare	%	hectare	%
1	0-5	Natural - very slight	391,459	89.3	342,124	78.0	49,335	11.3
2	5 – 10	Slight	38,595	8.8	62,853	14.3	-24,258	-5.5
3	10 – 15	Moderate	7,736	1.8	25,182	5.7	-17,446	-3.9
4	15 – 20	High	583	0.1	7,286	1.7	-6,703	-1.6
5	20 – 36	Very high	11	0.0	939	0.2	-928	-0.2
	Total		**438,384**	**100**	**438,384**	**100**		

Note: The soil erosion class is adopted from Asnake Yimam andAmare Bantider, (2019) and contextualized to local condition.

In total, the average annual soil loss from Weyto sub-basin through water erosion using 200 m resolution DEM data was estimated 1.38 million tons, while the estimate using 30 m resolution DEM data was 1.86 million tons under the current land use/land cover (LULC) and land management practice. Generally, the analysis revealed more generalization and underestimation of erosion risk using low resolution DEM data. This implies that the accuracy of soil loss estimation decreases owing to the coarse (low) resolution of DEM (Mondal et al., 2017).

The landmasses having low erosion risk either have good vegetation cover (bush-, wood-lands, and forests) or receive relatively low rainfall or have level topography. Areas mapped under moderate to very high soil erosion rate are mainly farmlands. On the other hand, farmlands mapped under slight erosion risk are protected from erosion hazards with different management practices like terracing, agro-forestry and *Enset* based farming practices, where the factors are captured in the model. The current RUSLE, GIS technique and RS data based modelling of erosion risk results show similarity with earlier studies (e.g. Habtamu Sewnet and Amare Sewnet, 2016; Gezahegn Weldu et al., 2018; Yared Mesfin et al., 2020).

Erosion hazard hotspots and implication for watershed development

As our GIS based modelling revealed, there were significant differences in spatial soil loss across the sub-basin. Although the sub-basin has considerably large (over 80%) undulating to steep landform, soil erosion rate is not as such a severe problem over large area owing to the land use/cover and management practices. The model predicted moderate to severe soil erosion risk in the northwest, northeast and southeast watersheds, while the rest parts are likely prone to low risk (Figure 7). The low soil loss rate is mainly associated to good vegetation cover over large area. Agro-forestry and SWC practices in some areas also contributed to lesser estimate of the model on farmlands. Out of 17 identified major (sub) watersheds, Dencha and Bera watersheds have very high soil erosion hazards, followed by Upper Bezo, Konte and also part of Lomate, Keselte, Keseba and Zororo watersheds. Any change in LULC and land management practices would potentially alter the soil loss rate. LULC shift to crop production, particularly on lands over 3% slope should be accompanied by appropriate SWC and other land management practices, otherwise soil degradation through erosion can be significantly increased (Shimeles Damene et al., 2012). In converse, good land management practices like terracing, agro-forestry practices and shift from annual to perennial crops in sloppy area could reduce accelerated soil erosion via water or runoff (Young, 1989; USDA, 2011). In light of these findings, we recommend that land use governance needs to be improved through strict enforcement of Ethiopia's existing policies such as the rural land use and management rules (Negarit Gazeta No. 456/2005) and Community-Based Participatory Watershed Development Guideline (MoARD, 2005) so as to minimize potential danger on land resources.

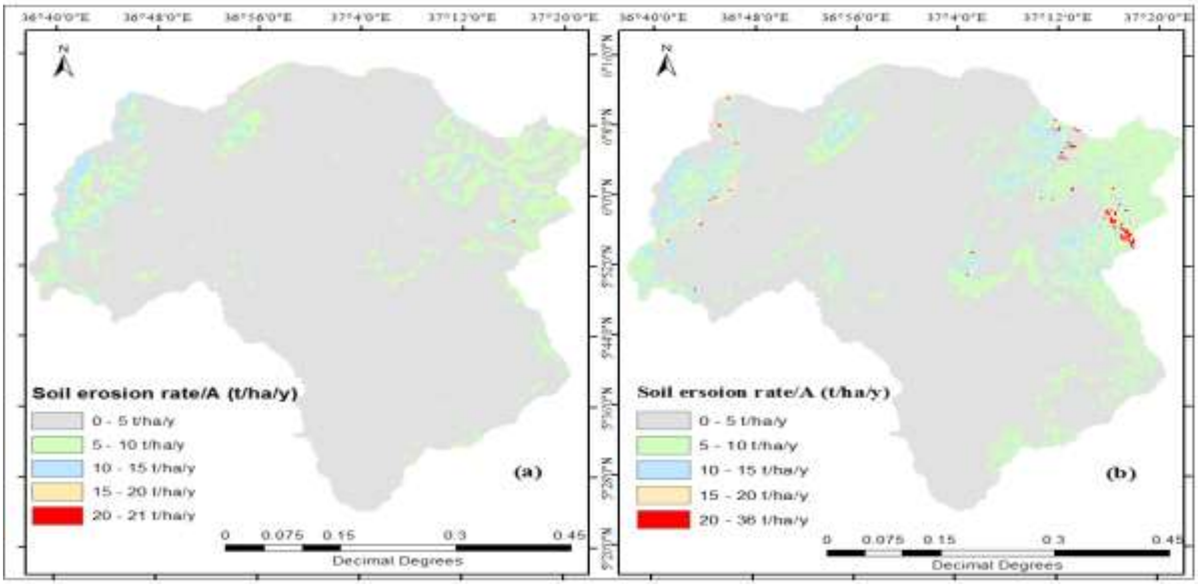

Figure 7. Weyto sub-basin soil erosion (t/ha/y) calculated using 200 m (a) and (b) 30 m resolution DEM data.

CONCLUSION

The results from our analysis demonstrates the usefulness of combining the GIS technique with RS data such as the DEM for RUSLE based soil loss estimation and in identifying water erosion hotspot areas. The findings from the study can provide some useful insights to a range of relevant actors, particularly the land use planners, development actors; policy and decision makers so as to conduct regular erosion risk monitoring and devise appropriate actions. However, as our analysis shows, the quality of erosion risk estimation depends on scale and/or resolution of input data, i.e., erosion factor data such as the DEM. The analysis reveals that erosion estimation using higher (30 m) resolution DEM data is more realistic as the slope generated is more in line with ground reality and allows lesser generalization. Based on our findings from the case of Weyto sub-basin, we thus conclude that the GIS technique and RS oriented RUSLE model can be used for soil erosion risk prediction in large areas even at basin, sub-basin and macro watershed level. However, the accuracy of the prediction can be enhanced using very detailed input data, i.e., high resolution RS (DEM and satellite data) or large-scale maps of other erosion factors data.

Our field survey reveals that areas identified as high erosion risk hotspot areas have very high water erosion, including severe gully formation and land slide. Moreover, number of pocket areas with very high erosion evidence has been mapped as slight and moderate erosion risk areas. The generalization and underestimation of erosion prediction is mainly emanated from generalized input data that have very low scale (resolution), making it difficult to disaggregate the data for necessary details. In light of these findings, we suggest that the application of more detailed soil, LULC, land management (such as SWC practices and topographic or LS factors) might help to yield better erosion risk estimation. As topography (particularly the slope of the land) plays an important role in soil erosion, use of high resolution DEM data might also improve the model estimation capacity. Therefore, erosion risk analysis result of high resolution (scale) input data might help planers and researchers to give practical and accurate advices for practitioners and policy makers.

REFERENCES

1. Asnake Yimam Yesuph, Amare Bantider Dagnew, (2019). Soil erosion mapping and severity analysis based on RUSLE model and local perception in the Beshillo Catchment of the Blue Nile Basin, Ethiopia. Environmental Systems Research **8(17).** https://doi.org/ 10.1186/s40068-019-0145-1
2. Atoma, H., Suryabhagavan, K.V., Balakrishnan, M. (2020). Soil erosion assessment using RUSLE model and GIS in Huluka watershed, Central Ethiopia. Sustainable Water Resources Management **6(12**). https://doi.org/ 10.1007/s40899-020-00365-z
3. Bagherzadeh, A. (2014). Estimation of soil losses by USLE model using GIS at Mashhad plain, Northeast of Iran, Arab. Journal of Geosciences **7**: 211–220. https://doi.org /10.1007/s12517-012-0730-3
4. Balabathina, V., Raju, R.P., Mulualem, W. (2019). Integrated Remote sensing and GIS-based Universal Soil Loss Equation for Soil Erosion Estimation in the Megech River Catchment, Tana Lake Sub-basin, Northwestern Ethiopia. American Journal of Geographic Information System **8(4):**141-157. https://doi.org /10.5923/j.ajgis.20190804.01
5. Bagegnehu Bekele, Yenealem Gemi, Y. (2021). Soil erosion risk and sediment yield assessment with universal soil loss equation and GIS: in Dijo watershed, Rift valley Basin of Ethiopia. Modelling Earth Systems and Environment **7**:273–291. https://doi.org/10.1007/s40808-020-01017-z
6. Benavidez, R., Jackson, B., Maxwell, D., Norton, K. (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 Science **22(11**): 6059–608. https://doi.org/10.5194/hess-22-6059-2018
7. Bojö, J., Cassells, D. (1995). Land degradation and rehabilitation in Ethiopia: A reassessment. AFTES, Working Paper 17, World Bank. https://documents1.worldbank.org/curated /en/381421468744300592/pdf/multi-page.pdf Accessed 30 April 2021.
8. Bouhadeb, C.E., Menani, M.R., Bouguerra, H., Derdous, O. (2018). Assessing soil loss using GIS based RUSLE methodology. Case of the Bou Namoussa watershed – North-East of Algeria. Water and land development **36(1-3):** 27–35. https://doi.org/10.2478/jwld-2018-0003
9. Cohen, M.J., Shepherd, K.D., Walsh, M.G. (2005). Empirical reformulation of the universal soil loss equation for erosion risk assessment in a tropical watershed. Geoderma **124 (3-4):**235–252. https://doi.org/10.1016/j.geoderma. 2004.05.003

10. Shimeles Damene, Asmamaw Bahir A, Villamor GB (2020) The Role of Chomo grass (Brachiaria humidicola) and exclosures in restoring soil organic matter, total nitrogen and associated functions in degraded lands in Ethiopia. Regional Environmental Change **20**:92. https://doi.org/10.1007/s10113-020-01680-z

11. Shimeles Damene, Lulseged Tamene, Vlek, P.L.G. (2012). Performance of farmland terraces in maintaining soil fertility: A case of Lake Maybar watershed in Wello, northern highlands of Ethiopian. Journal of Life Science **6(55):**2151-2161. https://doi.org/10.17265/1934-7391/2012.11.010

12. Shimeles Damene, Lulseged Tamene, Vlek, P.L.G. (2013). Performance of exclosure in restoring soil fertility: A case of Gubalafto district in North Wello Zone, northern highlands of Ethiopia. CATENA **101**:136-142. https://doi.org/10.1016/j.catena.2012.10.010

13. Demirci, A., Karaburun, A. (2012). Estimation of soil erosion using RUSLE in a GIS framework: a case study in the Buyukcekmece Lake watershed, northwest Turkey. Environmental Earth Sciences **66**:903–913. https://doi.org/10.1007/s12665-011-1300-9

14. Ayele Desalegn, Abrham Tezera Gessesse, Fikrey Tesfay, F. (2018). Developing GIS-Based Soil Erosion Map Using RUSLE of Andit Tid Watershed, Central Highlands of Ethiopia. Journal of Scientific Research & Reports **19(1**):1-13. https://doi.org/10.9734/JSRR/2018/40841

15. Duiker, S.W., Flanagan, D.C., Lal, R. (2001). Erodibility and infiltration characteristics of five major soils of southwest Spain. Catena **45**:103–121. https://doi.org/10.1016/S0341-8162(01)00145-X

16. FAO (2004) Methodological framework for land degradation assessment in dry-lands. ftp://ftp.fao.org/agl/agll/lada/LADA-Methframwk-simple.pdf Accessed 25 July 2021.

17. FAO (2006) Guidelines for soil description, Fourth edition. Italy, Rome. https://www.fao.org/3/a0541e/a0541e.pdf Accessed 20 May 2021.

18. Almaw Fenta, Tsuneka, A., Nigussie Haregeweyn, N., Poesen, J., Tsubo, M., Borrelli, P., Panagos, P., Vanmaercke, M., Broeckx, J., Yasuda, H., Kawai, T., Kurosaki, K. (2020). Land susceptibility to water and wind erosion risks in the East Africa region. Science of The Total Environment **703**:135016 https://doi.org/10.1016/j.scitotenv.2019.135016

19. Fu, B.J., Zhao, W.W., Chen, L.D., Zhang, Q.J., Lu, Y.H., Gulinck, H., Poesen, J. (2005). Assessment of soil erosion at large watershed scale using RUSLE and GIS: A case study in the loess plateau of china. Land Degradation & Development **16**:73–85. https://doi.org/10.1002/ldr.646

20. Ganasri, B.P., Ramesh, H. (2016). Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin. Geoscience Frontiers 7(6):953-961. https://doi.org/10.1016/j.gsf.2015.10.007

21. Gaubi, I., Chaabani, A., Ben Mammou, A., Hamza, M.H. (2017). A GIS-based soil erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) (Lebna watershed, Cap Bon, Tunisia). Natural Hazards 86:219–239. https://doi.org/10.1007/s11069-016-2684-3

22. Habtamu Sewnet Gelagaya, Amare Sewnet Minale, (2016). Soil loss estimation using GIS and Remote sensing techniques: A case of Koga watershed, Northwestern Ethiopia. International Soil and Water Conservation Research **4(2):**126-136. https://doi.org/10.1016/j.iswcr.2016.01.002

23. Halcrow Group Limited and Generation Integrated Rural Development (GIRD) Consultants, 2007. Rift Valley Lakes Basin Integrated Resources Development Master Plan Study Project, Part II Sector Assessments, Volume 2:– Natural Resources. Annex A: Geology and Seismology; Annex C: Soils and Land Evaluation, Annex D: Land Use and Land Cover and Annex F: Livestock and Rangeland. Addis Ababa, Ethiopia

24. Hurni, H. (1998). Agro-ecological belts of Ethiopia: Explanatory notes on three maps at a scale of 1:1,000,000. Soil Conservation Research Program Research report. https://edepot.wur.nl/484855. Accessed 20 May 2021

25. Hurni, H. (1993). Land degradation, famines and resource scenarios in Ethiopia. In: Pimentel (ed.) World soil erosion and conservation. Cambridge University Press, Cambridge, 27-62.http://dx.doi.org/10.1017/CBO9780511735394.004

26. Hurni, H. (1985). Erosion-Productivity-Conservation Systems in Ethiopia. Proceedings of 4th International Conference on Soil Conservation, Maracay, Venezuela, **3** (**9**):654-674

27. Hurni, H., Berhe, W.A., Chadhokar, P., Daniel, D., Gete, Z., Grunder, M., Kassaye, G. (2016). Soil and Water Conservation in Ethiopia: Guidelines for Development Agents, Second revised edition. Bern, Switzerland: Centre for Development and Environment (CDE), University of Bern, with Bern Open Publishing (BOP).

28. Hurni, H., Herweg, K., Portner, B., Liniger, H. (2008). Soil Erosion and Conservation in Global Agriculture. *In:* Braimoh, A.K. and.

Vlek, P.L.G (Eds.), Land Use and Soil Resources 41-71. https://doi.org/10.1007/978-1-4020-6778-5_4

29. Kinnell, P.I.A. (2005). Why the universal soil loss equation and the revised version of it do not predict event erosion well. Hydrological Process **19(3):**851–854. http://dx.doi.org/10.1002/hyp.5816
30. Kouli, M., Soupios, P., Vallianatos, F. (2009). Soil erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. Environmental Geology **57**:483–497. https://doi.org/10.1007/s00254-008-1318-9
31. Krusekopf, H.H. (1943). The Effect of Slope on Soil Erosion. University of Missouri College 'of agriculture agricultural experiment station, Research bulletin 363. https://core.ac.uk/download/pdf/62789983.pdf Accessed 10 January 2021
32. Kumar, S., Kushwaha, S.P.S. (2013). Modelling soil erosion risk based on RUSLE-3D using GIS in a Shivalik Sub-watershed. Journal of Earth System Science **122(2):** 389-398. https://doi.org/10.1007/s12040-013-0276-0
33. López-García, E.M., Torres-Trejo, E., López-Reyes, L., Flores-Domínguez, Á.D., Peña-Moreno, R.D., López-Olguín, J.F. (2020). Estimation of soil erosion using USLE and GIS in the locality of Tzicatlacoyan, Puebla, México. Soil and Water Research, **15 (1):**9–17. https://doi.org/10.17221/165/2018-SWR
34. Mondal, A., Khare, D., Kundu, S., Mukherjee, S., Mukhopadhyay, A., Mondal, S. (2017). Uncertainty of soil erosion modelling using open source high resolution and aggregated DEMs. Geoscience Frontiers **8(3):**425-436. https://doi.org/10.1016/j.gsf.2016.03.004
35. Nana-Sinkam, S.C. (1995). Land and environmental degradation and desertification in Africa, ECA/FAO. http://www.fao.org/docrep/X5318E/x5318e02.htm.
36. Nearing, M. (1997). A Single, Continuous Function for Slope Steepness Influence on Soil Loss. Soil Science Society of America Journal , **61(3).** https://doi.org/10.2136/sssaj1997.03615995006100030029x
37. Nearing, M.A., Jetten, V., Baffaut, C., Cerdan, O., Couturier, A., Hernandez, M,, Le Bissonnais, Y., Nichols, M.H., Nunes, J.P., Renschler, C.S., Souche`re, V,, van Oost, K. (2005). Modeling response of soil erosion and runoff to changes in precipitation and cover. Catena **61**:131–154. https://doi.org/10.1016/j.catena.2005.03.007
38. Negarit Gazeta, 2005. Federal Democratic Republic of Ethiopia rural land administration and use proclamation. Negarit Gazeta, No 456/2005, Addis Ababa.
39. Nyssen, J., Tielens, S., Tesfamichael Gebreyohannes, Tigist Araya, Kassa Teka, Van de Wauw, J., Degeyndt, K., Descheemaeker, K., Kassa Amare, Mitiku Haile, Amanuel Zenebe, Munro, N., Walraevens, K., Kindeya Gebrehiwot, K., Poesen, J., Frankl, A., Alemtsehay Tsegay, Deckers, J. (2019). Understanding spatial patterns of soils for sustainable agriculture in northern Ethiopia's tropical mountains. PLoS ONE **14(10):** e0224041. https://doi.org/10.1371/journal.pone.0224041
40. Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., Alewell, C. (2015a). The new assessment of soil loss by water erosion in Europe. Environ. Sci. Policy, **54**:438–447. https://doi.org/10.1016/j.envsci.2015.08.012
41. Panagos, P., Ballabio, C., Borrelli, P., Meusburger, K., Klik, A., Rousseva. S., Tadić, M.P., Michaelides, S., Hrabalíková, M., Olsen, P., Aalto, J., Lakatos, M., Rymszewicz, A., Dumitrescu, A., Beguería, S., Alewell, C. (2015b). Rainfall erosivity in Europe. Science of The Total Environment **511(1**): 801-814. https://doi.org/10.1016/j.scitotenv.2015.01.008
42. Panditharathne, D.L.D., Abeysingha, N.S., Nirmanee, K.G.S., Mallawatantri, A. (2019). Application of Revised Universal Soil Loss Equation (RUSLE) Model to Assess Soil Erosion in "Kalu Ganga" River Basin in Sri Lanka. Applied and Environmental Soil Science 2019:4037379. https://doi.org/10.1155/2019/4037379.
43. Phinzi, K., Ngetar, N.S. (2019). The assessment of water-borne erosion at catchment level using GIS-based RUSLE and remote sensing: A review. International Soil and Water Conservation Research, **7(1):**27–46. https://doi.org/10.1016/j.iswcr.2018.12.002
44. Renard, K.G., Foster, G.R., Weesies, D.K., McCool, Yoder, D.C. (1997). Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). Agricultural Handbook, Number 703, Washington DC. https://www.ars.usda.gov/arsuserfiles/64080530/rusle/ah_703.pdf Accessed 18 May 2021
45. Scherr, S.J. (1999). Soil degradation, a threat to developing-country food security by 2020? Food, agriculture and the environment discussion paper 27. International Food Policy Research Institute 2033 K Street, N.W. Washington DC 20006-1002 USA. https://acervo.socioambiental.org/sites/default/files/documents/T1D00022.pdf. Accessed 5 January 2021
46. Bekele Shiferaw, Holden, S.T. (1998). Resource degradation and adoption of land

conservation technologies in the Ethiopian highlands: A case study in Andit Tid, North Shewa. Agricultural Economics **18**:233-247. https://doi.org/10.1111/j.1574-862.1998. tb0050

47. Lulseged Tamene., Vlek, P.L.G., Park, S.J., Dikau, R. (2006). Analysis of factors determining sediment yield variability in the highlands of northern Ethiopia. Geomorphology, **76(1**):76-91. https://doi.org/10.1016/j.geomorph. 2005.10.007
48. Kebrom Tekle, (1999). Land degradation problems and their implications for food shortage in south Wello, Ethiopia. Environmental Management, **23(4):**419-427. https://doi.org /10.1007/s002679900197
49. Yared Mesfin Tessema, Jasi´nska, J., Lemma Tiki Yadeta, Switoniak, M., Puchalka, R., Eyob Gebrehiwot Gebregeorgis, (2020). Soil Loss Estimation for Conservation Planning in the Welmel Watershed of the Genale Dawa Basin, Ethiopia. Agronomy **10(6):**777. https://doi.org/10.3390/agronomy10060777
50. USDA (2011). National Soil Survey Handbook, 430-VI, Department of Agriculture, Natural Resources Conservation Service. http://soils.usda.gov/technical/handbook/ Accessed 17 October 2020.
51. Vlek, P.L.G., Le, B.Q., Lulseged Tamene, (2008). Land decline in land-rich Africa. A creeping disaster in the making. Center for development research (ZEF) University of Bonn, Science Council and CGIAR. https://www.fao.org/3/i0056e/i0056e00.htm. Accessed 10 February 2021
52. Watson, E.E., Currey, J. (2009). Living terraces in Ethiopia: Konso landscape, culture and development, University of Cambridge.
53. Wilson, J.P., Gallant, J.C. (2000). Terrain Analysis: Principles and Applications, New York.
54. Wischmeier, W.H., Smith, D.D. (1978). Predicting Rainfall Erosion Losses. A Guide to Conservation Planning. The USDA Agricultural Handbook No. 537, Maryland.
55. Wischmeier, W.H., Smith, D.D. (1965). Prediction Rainfall Erosion Losses from Cropland East of the Rocky Mountains: A Guide for Selection of Practices for Soil and Water Conservation. Agricultural Handbook, No. 282.
56. Gezahegn Weldu Woldemariam, Anteneh Derribew Iguala, Solomon Tekalign, Reddy R.U. (2018). Spatial Modeling of Soil Erosion Risk and Its Implication for Conservation Planning: the Case of the Gobele Watershed, East Hararghe Zone, Ethiopia. Land 7(25). https://doi.org/10.3390/land7010025
57. Young, A. (1989). Agroforestry for soil conservation; CAB International, International Council for Research in Agroforestry.http://apps.worldagroforestry.org/downloads/Publications/PDFS/03_Agroforestry_for_soil_conservation.pdf. Accessed 05 February 2021
58. Zhang, K.L., Shu, A.P., Xu, X.L., Yang, Q.K., Yue, B. (2008a). Soil erodibility and its estimation for agricultural soils in China. Journal of Arid Environments **72(6):**1002-1011. https://doi.org/10.1016/j.jaridenv.2007.11.018
59. Zhang, J.X., Chang, K., Wu, J.Q. (2008b). Effects of DEM resolution and source on soil erosion modelling: a case study using the WEPP model. International Journal of Geographical Information Science **22(8**):925-942. https://doi.org/10.1080/13658810701776817