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Potential soil erosion estimation and area prioritization for better conservation planning in Gumara watershed using RUSLE and GIS techniques'

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Abstract

Background: Water induced soil erosion has been continued to threaten the land resources in sub humid north-western highlands of Ethiopia. Soil and water conservation measures have been implemented without site-specific scientifically quantified soil erosion data and priority bases. In this regard, quantitative analysis of soil erosion and its spatial variation plays a decisive role for better evidence and priority based implementation. Thus, this study aimed to estimate potential soil loss, identify hotspot areas, and prioritize for conservation measures in Gumara watershed using RUSLE, GIS and remote sensing techniques'.

Result: The study result showed that soil loss due to water erosion was found to be a critical problem in the watershed. It ranges from nearly zero in gentle slope of forest lands to 442.92 t ha^{-1} $year^{-1}$ on very steep slope cultivated lands. A total of 9.683456 million t of gross surface soil has been lost annually, with an average soil erosion rate of 42.67 t ha^{-1} $year^{-1}$. Of which 62.1% was generated from cultivated land. The model result indicated a high spatial variability of soil erosion within the watershed. High intensity of soil erosion has been principally attributed to slope and land use/covers. The study further estimated that about 63.1% of the total soil loss was generated from only 29.3% of the area delineated as very severe soil erosion severity class. Soil erosion rate for 71.7% of the watershed area was beyond the maximum tolerable soil erosion limit estimated for Ethiopian highlands (> 18 t ha^{-1} $year^{-1}$). The sub-watershed severity class map revealed that 3814 ha of the sub-watershed area was evaluated as very severe level of soil erosion severity class.

Conclusion: Soil erosion in the watershed has been a threatening problem for agricultural production to day, its sustainability and to be worsening in the future unless remedial measures were taken, mainly due to human intervention. Therefore, Gumara watershed needs immediate intervention for better conservation planning by considering identified priority classes and hotspot areas.

Keywords: Potential soil loss, Erosion severity class, Erosion hotspots, Sub-watershed prioritization, RUSLE, Gumara watershed

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Background

Soil erosion caused by water is the loss of top fertile surface soil as a result of erosive rainfall and consequent runoff (Ganasri and Ramesh 2016). It is considered to be the most risky form of soil degradation (Alexandridis et al. 2015). Soil erosion is a worldwide environmental problem that affects the productivity of all natural ecosystems and agriculture, which threaten the lives of most smallholder farmers (Haregeweyn et al. 2012; Keno and Suryabhagavan 2014; Gessesse et al. 2015).

It can be facilitated by different natural and anthropogenic factors (Alexandridis et al. 2015). The fast growing population and associated consequences further exacerbated the problem and exerts negative influence on soil resources. Population growth in conjunction with other processes is leading to much more rapid deterioration of natural resources in developing nations (Repetto and Holmes 1983). Since, the main causes of soil erosion such as land cover degradation (Adimassu et al. 2014; Ganasri and Ramesh 2016), steep slope cultivation (Hurni et al. 2015a; Nyssen et al. 2004), agricultural intensification (Adimassu et al. 2014; Nyssen et al. 2004) has high relation with population pressure and is the main cause for soil erosion (Haregeweyn et al. 2017; Nyssen et al. 2008). As a result, the problem is more serious in areas related with agricultural intensification, land degradation and other man's activities on earth (Ganasri and Ramesh 2016).

Soil erosion led to a considerable economic costs and painful environmental impacts through soil nutrient losses (Shiferaw et al. 2009), water quality decline and effects on agricultural activities (Pimentel et al. 1995). It affect the seedlings through rill formation in the short-term and led to reduction of soil depth, water-holding capacity and soil fertility in the long-term, which, in turn, leads to limited vegetation growth and reduction of crop production (Hurni et al. 2010). Soil erosion and associated nutrient losses contributed significantly to low agricultural productivity in many parts of developing countries (Shiferaw et al. 2009). Its economic effect is more serious in underdeveloped nations, which are economically poor and low level in technology and unable to easily control as well as replenish soil nutrients (Tamene and Vlek 2008).

Soil erosion is main environmental and economic problem in Ethiopia (Fazzini et al. 2015). The problem is more severe in the country related with steep topography, overgrazing and long cultivation history with outdated technology (Nyssen et al. 2004). It is considered to be the main treat to the national economy (Fazzini et al. 2015; Hurni 1993), national food supply (Mekuriaw et al. 2018) and sustainability of agricultural production in the country (Hurni et al. 2010; Molla and Sisheber 2017).

In Ethiopia, the highlands[1] account for 43% of the area and 95% of the cultivated land and considered to have high soil fertility potential in the country (Desalegn et al. 2018). This high potential area has been densely populated (Haregeweyn et al. 2017; Nyssen et al. 2009), and the problem of soil erosion is worst due to intensive agricultural practices, slope steepness (Nyssen et al. 2004) and high rainfall erosivity (Fazzini et al. 2015).The rain feed agricultural areas of Ethiopian highlands are estimated to lose 940,893,165 t of net soil annually (Hurni et al. 2015b) and two-third of the country's population is affected (Hurni et al. 2015a). Due to this, 50% of the highlands are significantly eroded and causes a land productivity loss by a rate of 2.2% per year (Greenland and Nabhan 2001). As a result serious environmental degradation has been occurred and the livelihood of many households critically affected (Sultan et al. 2017).

Currently, the highest soil erosion rate is being observed in the western part of the country (Hurni et al. 2015b). As a typical northwestern Ethiopian highland, Gumara watershed is among area with highest rainfall erosivity (Fazzini et al. 2015) and severely affected by soil erosion. It has been identified as severe soil erosion risk (Haregeweyn et al. 2017) and high mean runoff area (Haregeweyn et al. 2015). The soil resources has been degraded and consequently affected the productivity of the land. Currently the area is characterized by high soil acidity, recurrent landslide (Gedif et al. 2016) and high environmental degradation. Nevertheless, the problem of soil erosion in the watershed is still not addressed. Soil and water conservation has been practiced in the watershed for about two decades; however, its implementation has been led without site-specific scientifically estimated soil erosion data and priority bases.

Several researches have been done so far in estimating soil erosion in the Ethiopia highlands (e.g. Gelagay and Minale 2016; Gashaw et al. 2017; Haregeweyn et al. 2017; Miheretu and Yimer 2018; Woldemariam et al. 2018; Zerihun et al. 2018). However, the problem of soil erosion has been prevalent and even increasing (Environment for Development (EfD) 2010) and it could be worsen in the future (Niang et al. 2014), especially on Ethiopian highlands, in which the livelihoods of the population is merely dependent on agriculture and the natural environment. In addition, soil erosion can be influenced by local climate, topography, population, soil susceptibility, agricultural practices and agro-ecology (Tebebu et al. 2010). This indicates that the problem of soil erosion is

[1] Highland: is equivalent to "Ethiopian highlands" in this study context and defined as an area of elevation extending from about 1000 m above sea level up to the highest peak of 4533 m in Ethiopia (Hurni et al. 2010).

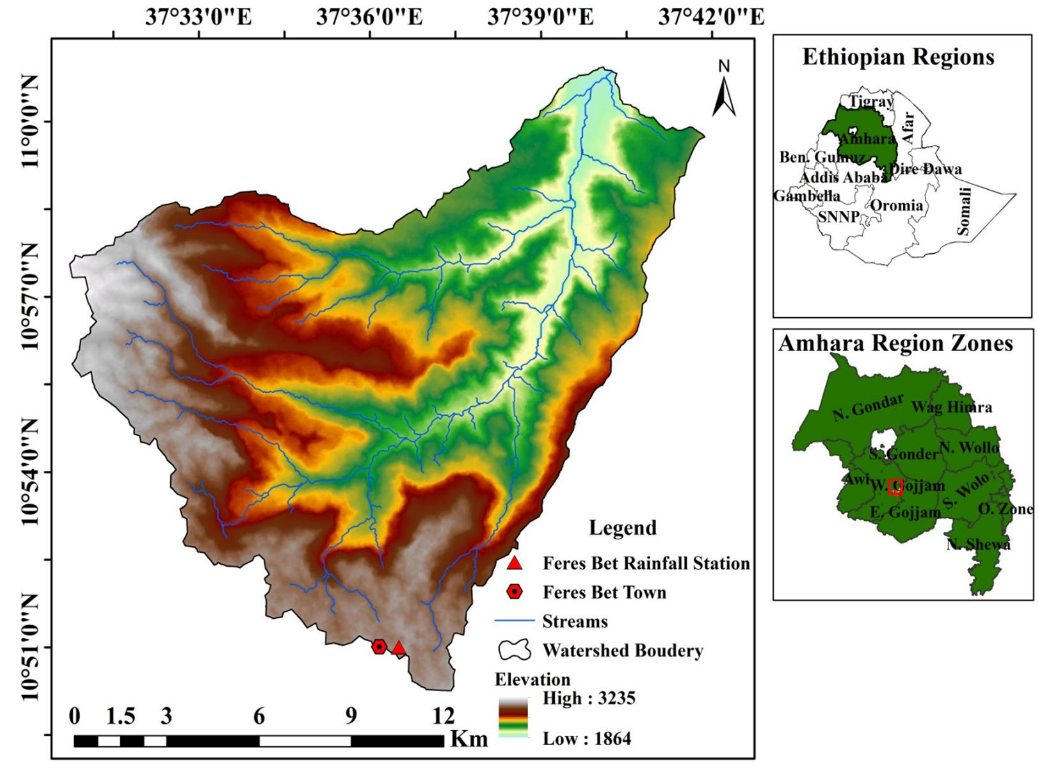

Fig. 1 Location map of Gumara watershed

still an important issue to be tackled trough scholarly site-specific researches and valuable recommendations.

Controlling such threatening problem requires understanding the rate of soil loss and its spatial variation. The assessment of the current erosion rates must be the first step in caring out a conservation programme (Hurni 1985). In this regard, quantitative assessment of soil erosion is a key to infer the extent and magnitude of the problem and identification of more vulnerable sites. Different model based methods has been developed for soil erosion spatial assessment and quantification (Kim et al. 2012; Zhang et al. 2009). The revised universal soil loss equation (RUSLE) (Renard et al. 1997) with its integration to geographic information system (GIS) is among widely applied empirical models for assessment of sheet, inter-rill and rill erosion. GIS based soil erosion models are important means for erosion assessment and prioritization to initiate possible land management measures (Bewket and Teferi 2009; Silva et al. 2012; Khadse et al. 2015; Ganasri and Ramesh 2016; Markose and Jayappa 2016). Therefore, this study used RUSLE model in which most of the parameters were calibrated in Ethiopian highland conditions (Hurni 1985), and applicable with the limited available data.

In this regard, the objectives of the study was (1) to estimate potential average annual soil loss (t ha^{-1} $year^{-1}$) in the watershed (2) to assess the spatial variability of soil erosion rate (3) to prioritize hotspot areas and sub-watersheds for conservation measures in the sub-humid Gumara watershed, northwestern highland of Ethiopia.

Materials and methods

Study area

Gumara watershed (Fig. 1) is located in Dega Damot district,[2] Amhara National Regional State, Northwestern Ethiopia. It is among the head quarter streams of Upper Blue Nile Basin. It lies within 10°50′15″ to 11°0′40″N and 37°30′40″ to 37°41′22″E, covers an area of 204.4 km^2. Gumara watershed is part of the northern highland. It is dominated by the Oligo-miocene volcanic trap basalt rock underlying by early tertiary volcanoes and part of the late Paleozoic to early tertiary sediment as well as Cenozoic volcanic and sedimentary rock formations (Abbate et al. 2015). The watershed is part of

[2] District: locally referred and roughly equivalent to "woreda", is the next lower level of administration in the current Ethiopian administration system.

Table 1 The types, sources and quality of RUSLE input data used in this study

Data type	Data source	Data quality
Landsat 8 satellite image	Downloaded from USGS (http://earthexplorer.usgs.gov)	30*30 m
ASTER GDEM	Downloaded from USGS (http://earthexplorer.usgs.gov)	1 arc–second
Soil map	Collected from ministry of water, irrigation and energy of Ethiopia	1:250,000
Rainfall data	Collected from national meteorology agency of Ethiopia	20 years monthly data
Topo-sheet map	Collected from Ethiopian geospatial information agency	1:50,000
GPS points	Field data collected using GARMIN VISTA HCx GPS	–

the northwestern highlands of Ethiopia, characterized by diverse topographic conditions. The elevation ranges from 1864 to 3235 m above sea level.

The digital soil map of the watershed collected from Ministry of Water, Irrigation and Energy indicated that, the soil of the watershed is characterized by haplic luvisols, haplic nitisols and haplic alisoils (Table 3). Haplic alisols is the dominant soil type in the watershed, covering an area of 90.67 km^2 (43.76%). The study watershed received 2078.1 mm mean annual rainfall in a unimodal pattern. The mean annual temperature in the area is 16.6 °C, where 71% of the watershed has highland tropical climate. Land use/covers in the watershed are dominated by cultivated land (58.09%) (Table 5; Fig. 3a). Subsistence agriculture, in the form of mixed crop and livestock system is the main source of livelihood for nearly 90% of the households in the watershed. The population density of the watershed was 158, 184 and 216 in 1994, 2007 (Central Statistical Agency of Ethiopia (CSA) 1994, 2007) and 2017 (estimated by Dega Damot District Administration office in 2017) respectively.

Method of soil loss estimation (The RUSLE Model)

Potential soil loss[3] estimation was carried out using widely used and evaluated soil erosion model, which was first developed as USLE (Wischmeier and Smith 1978) and modified into RUSLE (Renard et al. 1997). It was also adapted and most of the variables calibrated by Hurni (1985) in the Ethiopian highland condition. RUSLE was selected for our study by considering its advantages of simplicity, compatibility, applicability in limited data conditions and its adoption in Ethiopian highland conditions. In data scarce areas for validation of models, it is suggested to be cost effective soil erosion estimation method for effective conservation planning (Haile and Fetene 2012; Prasannakumar et al. 2012). The RUSLE model quantifies soil erosion by taking climate, soil property, topographic, cover management, and conservation practices into consideration. The RUSLE soil loss estimation model equation is given below (Eq. 1):

$$A = R * K * LS * C * P \quad (1)$$

where A is estimated annual soil loss (t ha^{-1} $year^{-1}$), R is rainfall erosivity factor (MJ mm ha^{-1} h^{-1} $year^{-1}$), K is soil erodability factor (t ha^{-1} MJ^{-1} mm^{-1}), L is slope length and S is slope steepness factor (dimensionless), C is land use/cover factor (dimensionless) and P is conservation support practice factor (dimensionless).

The input data for aforementioned five major erosion determining factors were collected from different primary and secondary sources. The types, sources, collection methods and quality of RUSLE input data has been presented in Table 1.

RUSLE parameters estimation

Rainfall erosivity factor (R) estimation

Rainfall erosivity represents the erosive force of specific rainfall (Prasannakumar et al. 2012) or the energy of rainfall as the driving force behind soil erosion. R-factor can be explained by the interaction between rainfall kinetic energy and with the soil surface (Wischmeier and Smith 1978). Rainfall erosivity is a multifaceted process in which the amount, intensity, energy, duration, pattern, size of raindrop of rainfall and associated runoff exerts influence (Farhan and Nawaiseh 2015). In RUSLE model rainfall erosivity parameter estimation was based on the multiplication of total storm energy by 30 min rainfall intensity; expressed as $R = EI_{30}$ (Renard et al. 1997). However, it is difficult to apply this equation directly in data poor areas like Ethiopia. Instead it was modified in the real situations of Ethiopia by Hurni (1985) to be applicable using easily available mean annual rainfall data. Thus, our study employed Hurni (1985) empirical equation; expressed as (Eq. 2):

$$R = -8.12 + (0.562 * P) \quad (2)$$

where R is rainfall erosivity (MJ mm ha^{-1} h^{-1} $years^{-1}$) and P is mean annual rainfall (mm).

In this regard, 20 years (1997–2016) monthly rainfall data of four surrounding (with in 16 km buffer zone of

[3] Potential soil loss: refers to the amount of predicted or estimated (not measured/not actual) soil loss through water induced soil erosion.

Table 2 Mean annual rainfall and R-value (computed from 20 years monthly data)

Soil type	Latitude	Longitude	Elevation (m a.s.l)	Mean annual rainfall	R_factor value
Dengay Ber	37.55	10.72	2800	2091.08	1167.07
Feres Bet	37.61	10.85	3000	2078.1	1159.77
Genet Abo	37.43	10.82	1931	1961.7	1094.36
Motta	37.89	11.07	2417	1260.85	700.48

the watershed) rainfall stations (*Dengay Ber, Feres Bet, Genet Abo and Motta*) were collected from Ethiopian National Meteorology Agency (Table 2). Some missed rainfall data were found in the collected data but it was filled using arithmetic average and normal ratio methods. Since, the normal average rainfall of *Feres Bet, Dengay Ber* and *Genet Abo* stations are within 10% of normal annual rainfall in each station arithmetic average method were used (Radi et al. 2015). Whereas, normal ratio method was applied for *Motta* rainfall station due to the fact that the normal average annual rainfall was greater than 10% of other surrounding stations (Radi et al. 2015).

The mean monthly data was averaged per year and rainfall station to find 20 years yearly rainfall data. The average of yearly rainfall data was computed for 20 years to find the long term mean annual rainfall for each rainfall station. The erosivity value of each station -was computed using Eq. 2 and a point map developed using erosivity value of stations. Inverse distance weighted (IDW) interpolation method was used to generate erosivity map for the watershed surface area using ArcGIS 10.3 (Fig. 2a). IDW gives the most representative interpolation result for annual rainfall with a minimum of errors (Keblouti et al. 2012). Then, 30×30 m cell size rainfall erosivity factor raster map was created.

The R-factor map revealed that the erosivity of rainfall in the watershed ranged from 1013.45 to 1157.77 MJ mm ha^{-1} h^{-1} with a mean value of 1120.46 MJ mm ha^{-1} h^{-1} (Fig. 2a).

Soil erodibility factor (K) estimation

The soil erodibility value refers to the influence of soil properties on soil loss during storm events on highland areas (Wischmeier and Smith 1978). It is the sensitivity of the soil to erosion, easy removal of the silt, and the amount of runoff assumed in an individual rainfall contribution (Kayet et al. 2018). Is the K-factor implies the properties of the soil and vulnerability of soil particles to be detached and transported by rainfall-runoff (Haile and Fetene 2012). Some of the most important soil properties that affect soil erodibility are soil texture, drainage condition, soil depth, structure and organic matter content (Prasannakumar et al. 2012). Different methods of soil erodibility estimations were suggested and this study used soil type and color method adapted in Ethiopian case (Hurni 1985).

The soil map of Abay river basin was collected from Ministry of Water, Irrigation and Energy, prepared for the purpose of developing Abay basin master plan by the then Ministry of Water Resources (MoWR 1998). It was developed in 1:250,000 scale as a multipurpose digital map following food and agricultural organization (FAO) soil classification standard. The soil map of the watershed was extracted from Abay Basin soil map and three types of soil (Fig. 2b) have been identified. Further, 24 soil samples were taken and its color was identified using Munsell color chart for validation of the color of the soil in the map. The K-value for each soil type was assigned depending on the type of soil and its color as suggested (Hurni 1985) (Table 3). The vector map was converted into 30×30 m raster map using its K-value in ArcGIS 10.3 conversion tools.

The erodibility value of soils in the watershed varies from .2 t ha^{-1} MJ^{-1} mm^{-1} in haplic luvisols to .25 t ha^{-1} MJ^{-1} mm^{-1} in haplic nitosols and haplic alisols (Table 3; Fig. 2c).

Slope steepness and length factor (LS) estimation

LS factor is a combined factor which affect the velocity and volume of runoff (Prasannakumar et al. 2012). The steepness and length of slope affects the rate of water induced soil erosion considerably (Gashaw et al. 2017), through greater accumulation of runoff (Wischmeier and Smith 1978). It can increase the erosivity of runoff through increased velocity of runoff water. As a result the water travels in a higher speed in steeper slopes and consequently increases its shear stress on the surface and transportation of greater sediment (Wischmeier and Smith 1978; Haile and Fetene 2012). The determination of LS value was initially proposed through direct measurements of slope (Renard et al. 1997), but not applicable for watershed level studies.

In this study L and S values were calculated using Eqs. 3, 4, 5 and 6 (Renard et al. 2011). For the estimation of LS-value, one arc-second pixel size (30.73×30.73 m) ASTER global digital elevation model (GDEM) version 2 was downloaded from United States Geological Survey (USGS) website (http://earthexplorer.usgs.gov). It was geometrically corrected and extracted based on the study watershed shape file using. Following this necessary analysis/inputs for LS-value estimation/such as slope analysis, filling sinks, flow direction and flow accumulation

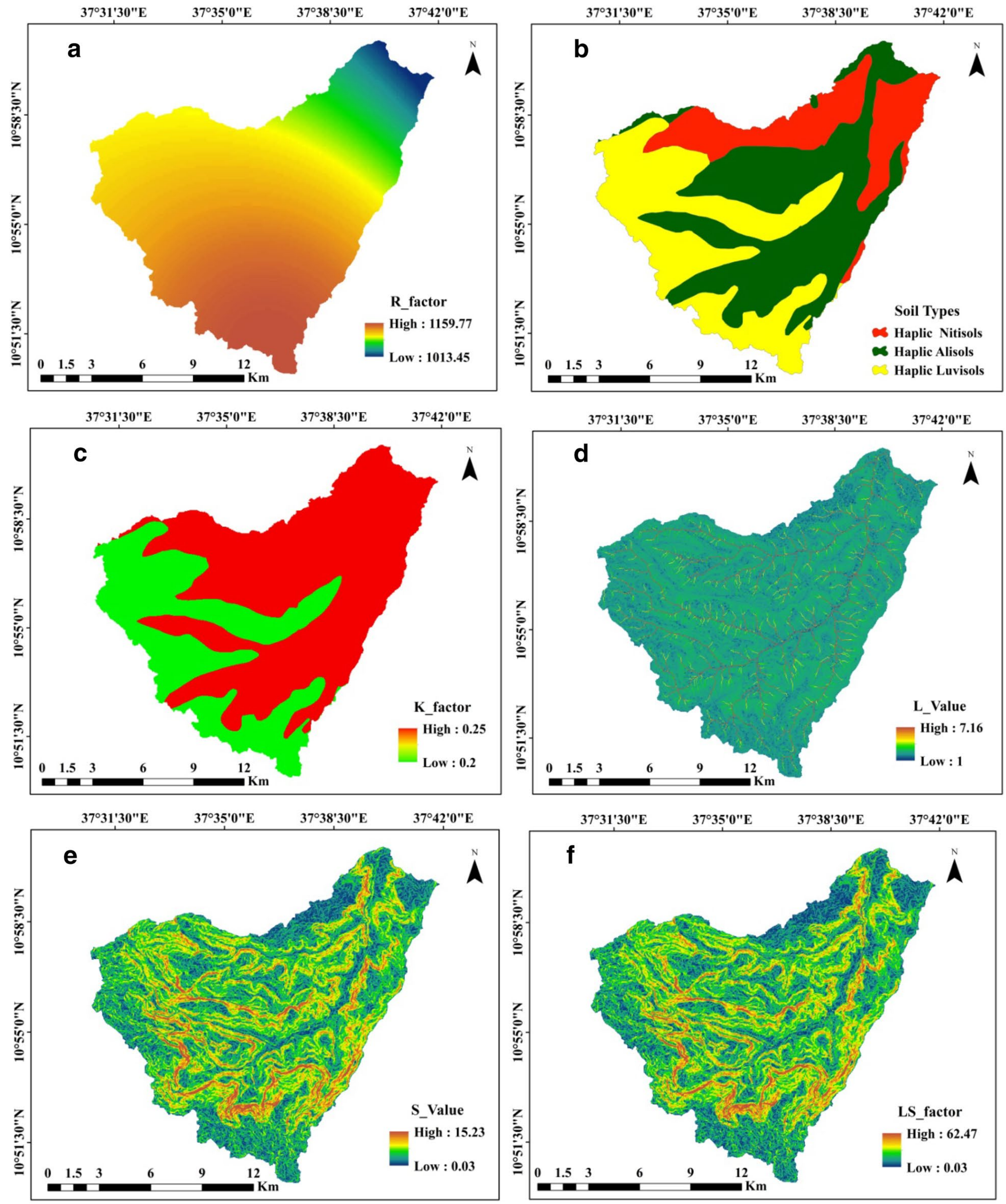

Fig. 2 Map of Gumara watershed showing **a** R-factor, **b** soil types, **c** K-factor, **d** slope length value, **e** slope steepness value and **f** LS-factor value

Table 3 Soil type, color and erodibility value of Gumara watershed

Soil type	Soil color	Area (%)	K-value (Hurni 1985)
Haplic Luvisols	Brown (Gashaw et al. 2017; Moges and Bhat 2017	35.04	.2
Haplic nitisols	Red (Gelagay and Minale 2016)	21.21	.25
Haplic Alisols	Red (Gelagay and Minale 2016; Moges and Bhat 2017)	43.76	.25

were performed. After the estimation of L and S-values using equations expressed; the LS-value was computed by multiplying the value of L and S in pixel-by-pixel basis using raster calculator of ArcGIS 10.3 (Fig. 2d–f).

According to FAO/UNISCO (2006) slope classification system 74.4% of the watershed area was classified as moderately steep to very steep land (Table 4). The LS-value rages from 0.03 in low flow concentration level slope land to 62.45 in very steep slope areas (Fig. 2f).

$$L = (\lambda/22.13)^{m} \quad (3)$$

$$m = \left(\beta/(1+\beta)\right) \quad (4)$$

$$\beta = (\sin\theta/0.0896) \Big/ \left[3.0(\sin\theta)^{0.8} + 0.56\right] \quad (5)$$

where L is slope length factor, λ is the horizontal projection (m) or (flow accumulation × cell size), m is variable slope length exponent, β is computed for conditions when the soils is moderately susceptible to both rill and inter-rill erosion and sin θ is slope angle in degree (GDEM generated slope in degree × 0.01745).

$$\begin{aligned} S &= 10.8 * \sin\theta + 0.03 \quad \delta \le 9\% \\ S &= 16.8 * \sin\theta - 0.5 \quad \delta \ge 9\% \end{aligned} \quad (6)$$

where S is slope steepness factor, sin θ is slope angle and δ is slope gradient in percent.

Cover management factor (C) estimation

It indicates how the cover of the land, crops land uses and crop management systems determines soil loss instead of losses from bare fallow areas (Haregeweyn et al. 2017). It is the effect of vegetation canopy and ground cover in reduction of soil erosion (Renard et al. 1997). Land use/cover classification map and normalized difference vegetation index (NDVI) are most commonly used methods for C-value estimation. We selected land use/cover classification map approach, since it gives comparatively precise C-value than normalized difference vegetation index (NDVI) (Lin et al. 2017).

Land use/cover map of the watershed was classified using 30*30 m cloud free landsat 8 satellite image taken in March 2017 downloaded from USGS website (http://earthexplorer.usgs.gov). March has been selected due to the fact that the C-value varies seasonally depending on vegetation cover variation per seasons and March is the optimum month for single image estimation (Alexandridis et al. 2015). Prior to classification image rectification, layer stacking, image enhancement and extraction have been made as image pre-processing. 1:50, 000 toposheet map was used for rectification of the satellite image.

Six main LUC types were identified based on the researchers' knowledge of the area and reconnaissance survey (Table 5; Fig. 3a). LUC classes were forest land (area covered by dense and tall trees both natural and plantations), shrub land (land covered by short trees, shrubs, and scattered trees), cultivated land (a land covered by annual and perennial crops, fallow lands), grass land (an area covered by grasses), bare land (stony or rocky areas and soil exposed without any cover) and built-up area (urban areas, schools and health centers and rural homesteads). Due to two basic reasons; different crop land uses has been classified as cultivated land uses in our LUC classification. Firstly, crop rotation in yearly and seasonal basis is a common practice, so crop land use in this year may not represent the next year. Secondly, it is difficult to detect different crop land uses from 30 m resolution image. It is a procedure used most commonly in Ethiopia (Bewket and Teferi 2009;

Table 4 Slope classes (modified from FAO 2006) and area coverage in Gumara watershed

Slope class		Area (ha)	Area ratio (%)
Description	Slope (%)		
Level slope	< 1	31.07	.15
Very gentle sloping	1–2	83.85	.41
Gently sloping	2–5	621.3	3.04
Sloping	5–10	1935	9.48
Strongly sloping	10–15	2583	12.6
Moderately steep	15–30	6995	34.3
Steep	30–45	4152	20.3
Very steep	>45	4037	19.8

Table 5 Land use/cover, area coverage and published C-values

LUC type	Area (ha)	Area (%)	C-value	Source
Forest land	854.46	4.18	.001	Hurni (1985); Zerihun et al. (2018)
Shrub land	4476.87	21.9	.014	Hurni (1985); Gessesse et al. (2015); Moges and Bhat (2017)
Cultivated land (Ethiopian tef)	11,873.43	58.1	.25	Hurni (1985); Haile and Fetene (2012)
Grass land	1326.24	6.49	.05	Hurni (1985); Haile and Fetene (2012)
Built-up area	578.97	2.83	.05	Moges and Bhat (2017)
Bare land	1327.5	6.5	.05	Moges and Bhat (2017); Haile and Fetene (2012)

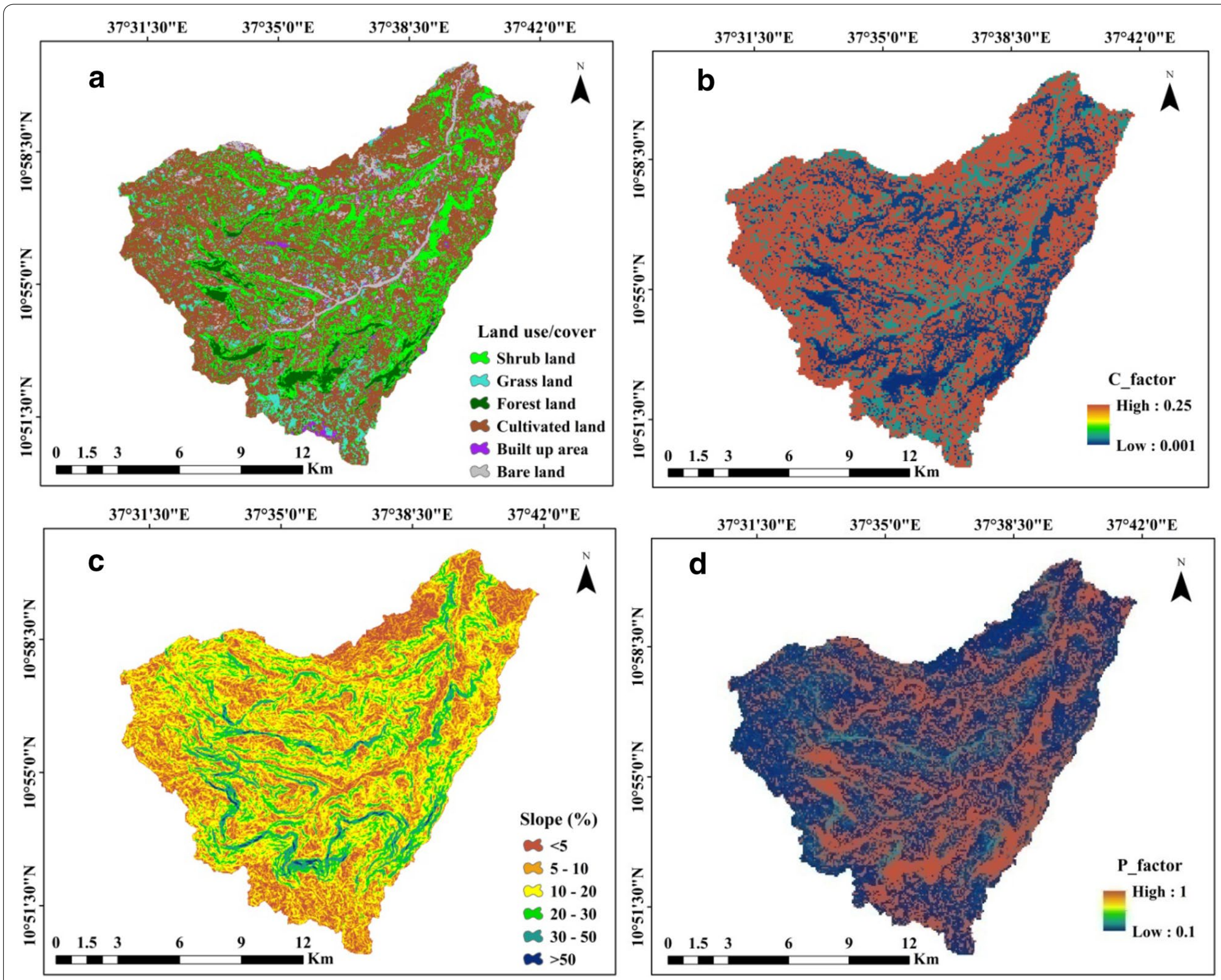

Fig. 3 Map showing **a** land use/cover, **b** C-factor, **c** slope in percent, **d** P-factor for Gumara watershed

Gelagay and Minale 2016; Haregeweyn et al. 2017; Setegn et al. 2010; Zerihun et al. 2018).

The image was classified using supervised classification in maximum likelihood algorithm procedure. The classification was performed using 350 reference data (ground truth data) (50 reference points per LUC type) collected from the field using global positioning system (GPS) as recommended by Congalton and Green (2009). The accuracy assessment was done using 150 (30 per LUC type) reference data from the field using GPS. Ground control points were collected using stratified random sampling method, which is appropriate method for reference data (Congalton and Green 2009) and accuracy assessment (Van Genderen and Lock 1977). Error (confusion) matrix and kapa coefficient were used to evaluate the overall classification accuracy of the classified image and the agreement between classified image and the reference data respectively. Kappa coefficient is appropriate to use for accuracy assessment if stratified random sampling method has been used for collection of training points used for accuracy assessment (Senseman et al. 1995). Thus, the overall classification accuracy was 90.56%, implies accurate classification (Congalton and Green 2009) and kappa coefficient result indicates (.89) showed a good agreement between the classified image and reference data (Landis and Koch 1977). The image analysis was performed using ERDAS IMAGIN 2014 software.

The classified land use/cover raster map was converted to vector format to assign the suggested C-values for each land use/cover types using ArcGIS10.3 software. C-values suggested by Hurni (1985) for forest land, shrub land, cultivated land and grassland and Moges and Bhat (2017) for bare land and built-up area were used (Table 5). The soil map in a vector form with C-values was converted to 30*30 m raster map to make it compatible with other parameters for cell-by-cell multiplication. The cover management factor value ranges from .001 in forest covers to .25 in cultivated lands.

Conservation practice factor (P) estimation

It refers to the effects of land conservation practices in minimizing the quantity and rate of rainfall-runoff and soil erosion Wischmeier and Smith (1978). Conservation practice factor signifies the ratio of soil erosion from a land treated with a specific conservation measure to its equivalent soil loss from up and down slope tillage (Markose and Jayappa 2016). *P* value can be determined by the type of conservation measure implemented.

In the study area terracing is a typically implemented conservation method, but it was difficult to estimate the P-value from it due to absence of data. Indeed, terrace structures were constructed through mass-community mobilization and we identified in our on-site observation, most of them are poor design due to lack of assistance, irregularities in implementation and fully or partially demolished due to low level of maintenance. This study employed an alternative method using a combination of slope and land use/covers for estimation of the P-value as proposed by Wischmeier and Smith (1978) (Table 6). The method was also used by other similar studies (Gelagay and Minale 2016; Haregeweyn et al. 2017; Moges and Bhat 2017).

Table 6 Conservation practices factor value (Wischmeier and Smith 1978)

Land use type	Slope (%)	P-value
Agricultural land use	0–5	.1
Agricultural land use	5–10	.12
Agricultural land use	10–20	.14
Agricultural land use	20–30	.19
Agricultural land use	30–50	.25
Agricultural land use	50–100	.33
Non agricultural land use	0–100	1.00

Therefore, the land use/cover map classified for C-factor estimation and slope map developed from GDEM were used for P-factor estimation (see details in C-factor for LUC classification). Both maps were converted into vector file to make them union or to find an attribute having both slope and LUC values. Using union analysis in ArcGIS 10.3; the slope and LUC map of the watershed was combined and values were assigned accordingly. Then, it was converted to 30 × 30 m raster map using the assigned P-value (Fig. 3d). The estimated conservation practice factor values ranges from .1 in cultivated land with a slope < 5 to 1 in other land use/covers except agricultural land uses (Table 6; Fig. 3d).

Finally, all the parameter layers were resampled to 30 × 30 m cell size raster map and projected with UTM Zone 37N, WGS 1984 datum. The five RUSLE factors were multiplied in raster calculator of ArcGIS10.3 in a cell-by-cell basis to estimate the potential annual average soil loss and its spatial variability in the watershed. Sub-watershed vulnerability map was also generated from the soil loss map by using sub-watersheds delineated. The schematic presentation of the soil erosion analysis has been presented (Fig. 4).

Besides, simple descriptive statistics such as percentage, maximum, minimum mean and standard deviation were used to present the model estimated result in a meaningful manner. It was used to summarize and present the overall mean soil loss in the watershed, the mean and percentage of soil loss under erosion severity classes, slope categories, land uses/cover and soil types using soil loss map of the model estimate in ArcGIS 10.3 environment, spatial analyst tools, zonal statistics extension.

Results and discussion

Consistency and validation of the model estimate

Validation of the model estimates was challenging in this study, due to poorly available data to weigh against the model estimates with the actual soil loss. However, as an option hydrological scientific model validation method

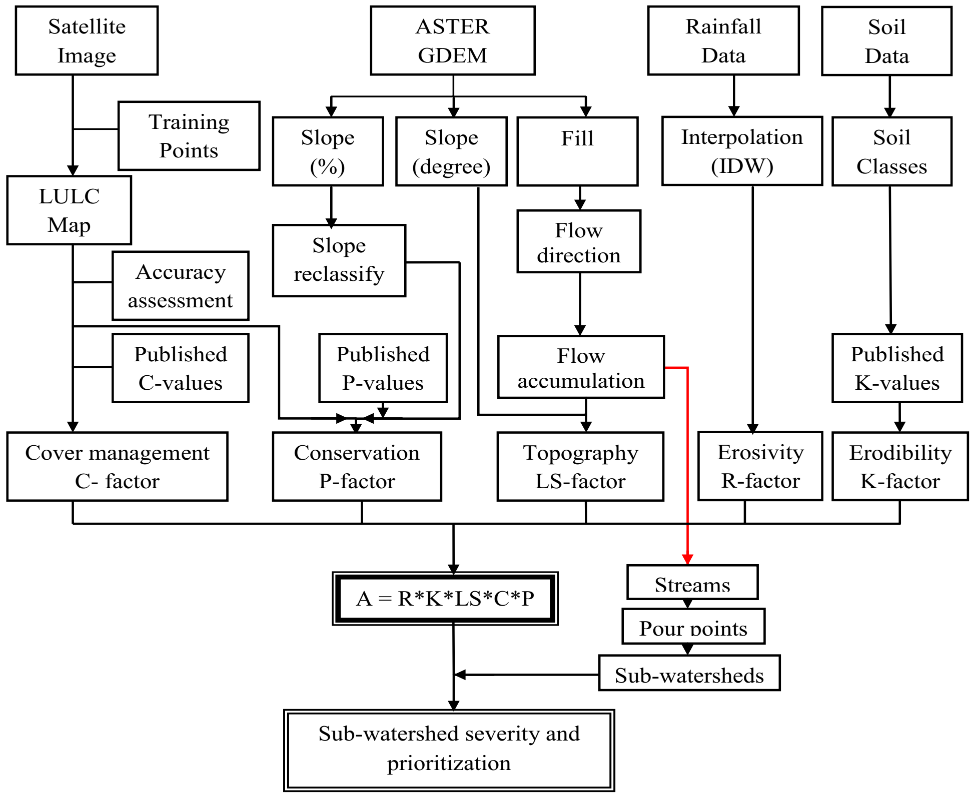

Fig. 4 Methodological flow of soil loss estimation using RUSLE model and watershed prioritization

proposed by Biondi et al. (2012) was used for this study to cheek the validity and consistency of the model estimation by comparing it with that of previously published results (Haregeweyn et al. 2017; Zerihun et al. 2018). The result was compared against studies conducted in the nearby areas mainly Northwestern highlands with both observed (Setegn et al. 2010; Subhatu et al. 2017) and estimated results (Bewket and Teferi 2009; Gelagay and Minale 2016; Haregeweyn et al. 2017; Zerihun et al. 2018) (Table 7). Some variations on previously reported results with this study estimates could be related to their respective site-specific variations in parameters.

Potential soil loss in the Gumara watershed

A quantitative expression of soil erosion is a fundamental phase for any watershed management (Prasannakumar et al. 2012; Khadse et al. 2015). This study tried to quantify and map soil erosion in Gumara watershed (Fig. 5a). The average annual soil loss in sub-humid Gumara watershed was estimated to be 42.67 t ha^{-1} year^{-1}. A total of 9.683456 million t of soil has been lost annually. Our estimate was consistent with the results reported by Subhatu et al. (2017) for terraced Anjeni watershed (31–37 t ha^{-1} year^{-1}) and Molla and Sisheber (2017) (42 t ha^{-1} year^{-1}) for Lake Koga watershed, Upper Blue Nile Basin. Amsalu and Mengaw (2014) reported a relatively comparable estimate for Jabi Tehinan District (30.6 t ha^{-1} year^{-1}). A recent comprehensive study by Haregeweyn et al. (2017) in the upper Blue Nile basin also found a comparable result ranging from zero to 200 t ha^{-1} year^{-1} with an average soil loss rate of 27.5 t ha^{-1} year^{-1}.

The result in this study is somehow lower than the estimates for Chemoga watershed with 93 t ha^{-1} year^{-1}

Table 7 Consistency of model estimate with previously published results in the Upper Blue Nile Basin, Northwestern highland

Study site	Mean annual soil loss (t ha^{-1} year^{-1})	References
Gumara watershed	42.67	This study
Anjeni watershed	24.6	Setegn et al. (2010)
Chemoga watershed	93	Bewket and Teferi (2009)
Dembecha district	49	Zerihun et al. (2018)
Koga watershed	47	Gelagay and Minale (2016)
Upper Blue Nile Basin	27.5	Haregeweyn et al. (2017)
Geleda watershed	23.7	Gashaw et al. (2017)

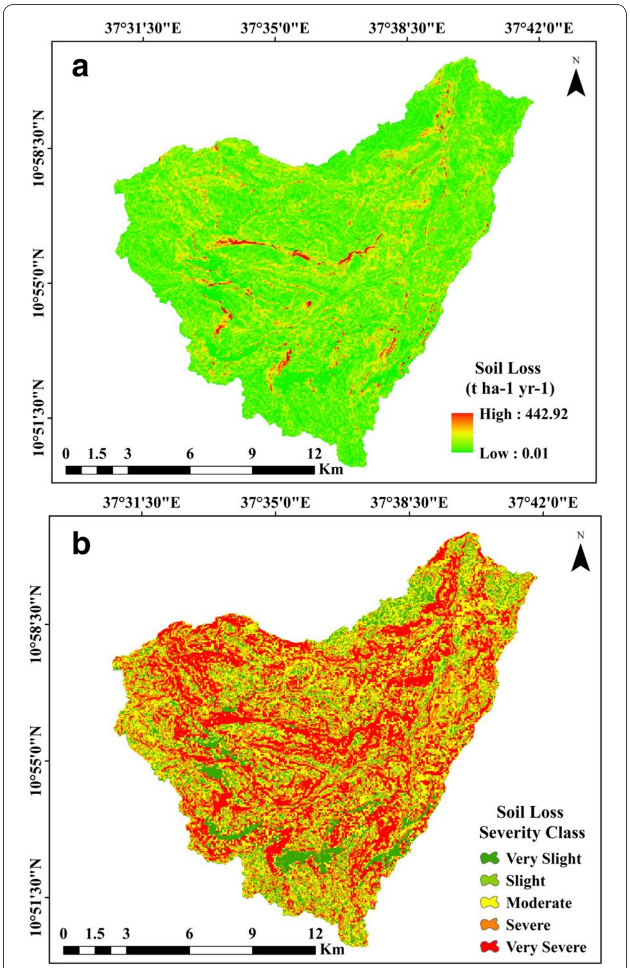

Fig. 5 Soil erosion map of Gumara watershed **a** potential soil loss (t ha^{-1} year^{-1}), soil loss spatial variation and hotspot areas, **b** severity classes

(Bewket and Teferi 2009), Dembecha district 49 t ha^{-1} year^{-1} (Zerihun et al. 2018), Koga watersheds with 47 t ha^{-1} year^{-1} (Gelagay and Minale 2016) and 68 t ha^{-1} year^{-1} Rib watershed (Moges and Bhat 2017). The variation observed might be mainly due to high topographic factor values observed in their estimated LS-values. On the contrary relatively lower soil loss results were reported by Gashaw et al. (2017) 23.7 t ha^{-1} year^{-1} for Geleda watershed and Miheretu and Yimer (2018) 24.3 t ha^{-1} year^{-1} for Gelana sub-watershed. This could be attributed to highland mountainous and steep slope conditions to gather with relatively higher rainfall in Gumara watershed.

In the Ethiopian highland case erosion rate ranging between 2 and 18 ha^{-1} year^{-1} is believed to be tolerable (Hurni 1985). In this case the soil erosion rate for 71.71% of the watershed area was beyond the maximum tolerable limit (> 18 t ha^{-1} year^{-1}) with 56 t ha^{-1} year^{-1} average rate of soil loss. The mean annual soil loss (42.67 t ha^{-1} year^{-1}) was greater than fourfold of the mean soil erosion tolerance (10 t ha^{-1} year^{-1}). Since it is predominantly an agricultural watershed, characterized by dense human and animal population, and population density has strong relationship with soil erosion risk (Haregeweyn et al. 2017), it is speculated that soil erosion problem is more likely to be challenging in the future. As a result, it needs immediate better and priority based conservation intervention to rehabilitate affected areas and sustaining the land resource.

Soil loss spatial variation and its relation with slope, LUC and soil types in the Watershed

Potential annual soil loss ranges from 0.01 to 442.92 t ha^{-1} year^{-1} (Fig. 5b), with an average soil loss rate of 42.67 t ha^{-1} year^{-1} and standard deviation of 41.32 t ha^{-1} year^{-1}. The range of soil loss has been much smaller than the estimates for Koga watershed 0–716 t ha^{-1} year^{-1} (Molla and Sisheber 2017) and Rib watershed 0–807 t ha^{-1} year^{-1} (Moges and Bhat 2017) in the northwestern Ethiopian highlands. The erosion risk map was developed depending on the severity classes adopted from Haregeweyn et al. (2017). The map revealed 26.4%, 20.9% and 29.3% of the watershed area was experienced moderate, severe and very severe soil erosion rate respectively (Table 8). Their respective average soil loss was 22.5, 38.7 and 92 t ha^{-1} year^{-1}, which is very high as compared to soil erosion tolerance in Ethiopia. Of the total,

Table 8 Severity classes adopted from Haregeweyn et al. (2017), its area coverage, soil loss and priority levels

Area (hectare)			Soil loss (t ha^{-1} year^{-1})			Priority level
Severity class (t ha^{-1} year^{-1})	Area (ha)	Area (%)	Mean soil loss (t ha^{-1} year^{-1})	Total soil loss (t/year^{-1})	Soil loss ratio (%)	
Very slight (< 5)	1789.02	8.76	2.9	56,988.14	.59	V
Slight (5–15)	2987.73	14.6	9.84	326,517.6	3.37	IV
Moderate (15–30)	5396.22	26.4	22.5	1,351,680	14	III
Severe (30–50)	4271.31	20.9	38.7	1,836,689	19	II
Very severe (> 50)	5981.31	29.3	92	6,111,582	63.1	I

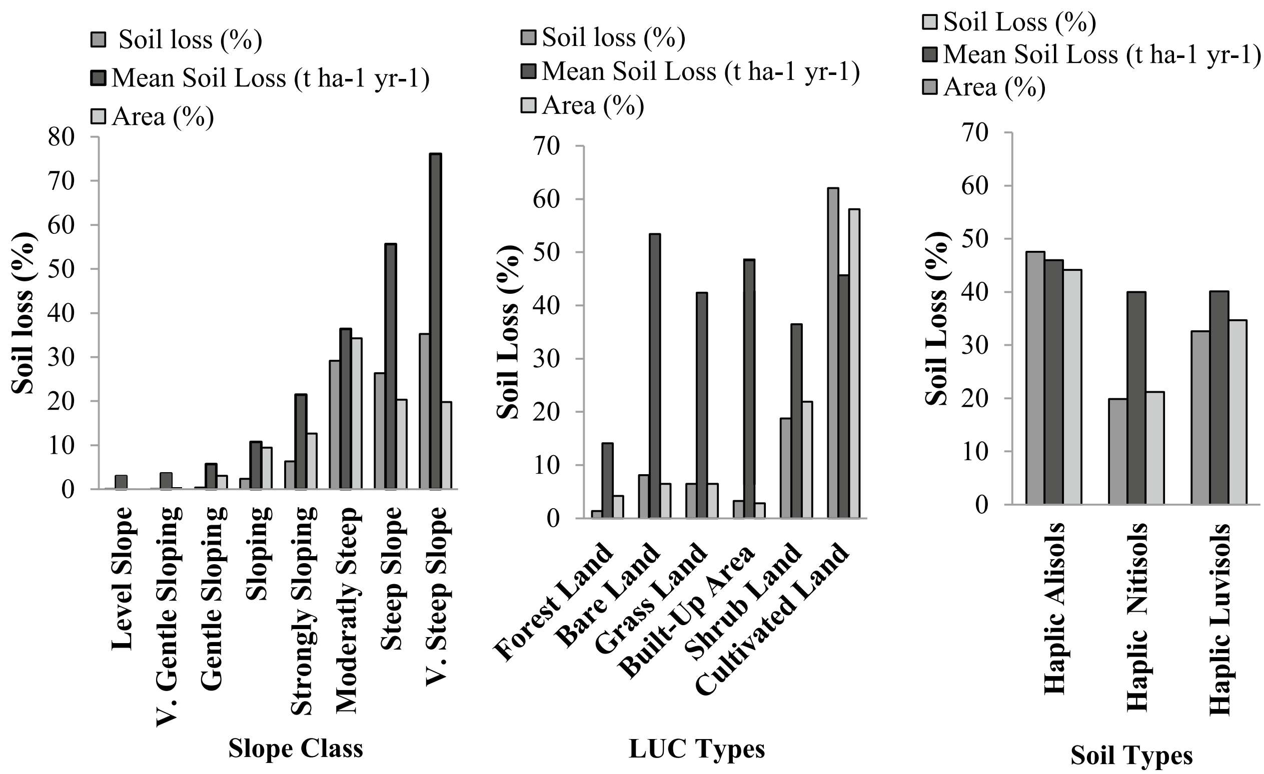

Fig. 6 Soil loss with respect to slope, land use/cover and soil types in Gumara watershed

9.299951 million t (96.4%) of soil has been lost each year from these classes and most of them are the cultivated land. Such occasions threatens the agricultural sector, which is the main means of livelihood for more than 90% of the watershed community. Areas classified as severe and very sever classes representing 50.19% of the watershed (Table 8) is the priori-focus area and basically need immediate attention for better conservation measures.

Our estimates was in agreement with the finding of Haregeweyn et al. (2017) in the Upper Blue Nile basin, reported nearly similar result that 77.3% of the basin area experienced moderate to very severe erosion. Our estimates of soil loss contradicted with a study result for Geleda watershed reported that 78.75% of the watershed area classifies under low level of soil erosion (Gashaw et al. 2017). Large proportion of the area in Geleda watershed may be attributed to the low steepness of area, which is indicated by the low slope steepness value (.07 to 2.46).

The estimated result confirmed the existence of greater soil erosion spatial variability in the watershed. This is basically attributed to the characteristics of the area in terms of slope and land use/covers. The majority (61.6%) of soil loss in the watershed is coming from steep and very steep slope lands (16.5°–65.5°) constituting 40.1% spatial share of the watershed area (Fig. 6). Our estimates were in agreement with previous studies such as Gashaw et al. (2017), Kayet et al. (2018), Markose and Jayappa (2016) and Woldemariam et al. (2018). Similarly, Ferreira and Panagopoulos (2014) observed high relationship of greater soil erosion with steepest gradient and low land cover in Alequa reservoir watershed, Portugal.

High soil erosion and hotspot areas were dominantly observed in the mid-portions of the watershed followed by the upper portion while the lower part is experienced relatively low erosion rates. Similarities result was reported by Bewket and Teferi (2009) for Chemoga watershed, Ethiopia. Our result was inconsistent with the study results Markose and Jayappa (2016) reported excessive soil erosion in the downstream part of Kali River basin, India. Such disparities may arise depending on existence of undulating surface in the watershed portions, as confirmed by estimates for Gumara watershed and Kali River basin. This also implies a strong association of soil erosion with topography.

The cultivated land show signs of very severe soil erosion hot spot areas. It accounts 62.06% of the total soil loss in the watershed with a mean erosion rate of 45.68 t ha^{-1} year^{-1}. Whereas forest land covers were less vulnerable and generates 14.09 t ha^{-1} year^{-1} average rate of soil erosion (Fig. 6). Higher soil loss in the agricultural land uses could probably be caused by continuous cultivation of steep slope areas without proper land management systems. In Gumara watershed, 36.7% and 13.5% of the cultivated land has been under strongly sloping and moderate to very steep slope gradient respectively according to FAO slope classification system. It assured a report by Hurni et al. 2015a stated the cultivation of very steep terrain is a prime threatening factor for soil resources than anything else in Ethiopia. Similarly a study result by Ganasri and Ramesh (2016) in Nethravathi Basin, reported high soil erosion rate in agricultural land. Our finding was not in agreement with the study result by Markose and Jayappa (2016) for Kali river basin, reported less soil erosion agricultural areas than forest land. Our study clearly indicated that forest and shrub land has estimated to have low level of mean soil loss rate whereas barren land and cultivated lands constitutes the highest (Fig. 6).

Following its high erodibility and its existence in the steepest gradient of the watershed, haplic alisols are more vulnerable with a mean soil loss of 45.95 t ha^{-1} year^{-1} (Fig. 6). In contrast, with similar erodibility value haplic nitisols has the lowest mean soil loss (35.8 t ha^{-1} year^{-1}), mainly because most of its area is dominated by relatively lower slope steepness. This indicates that the effect of topography was significant in predicting the soil loss effect of soil types.

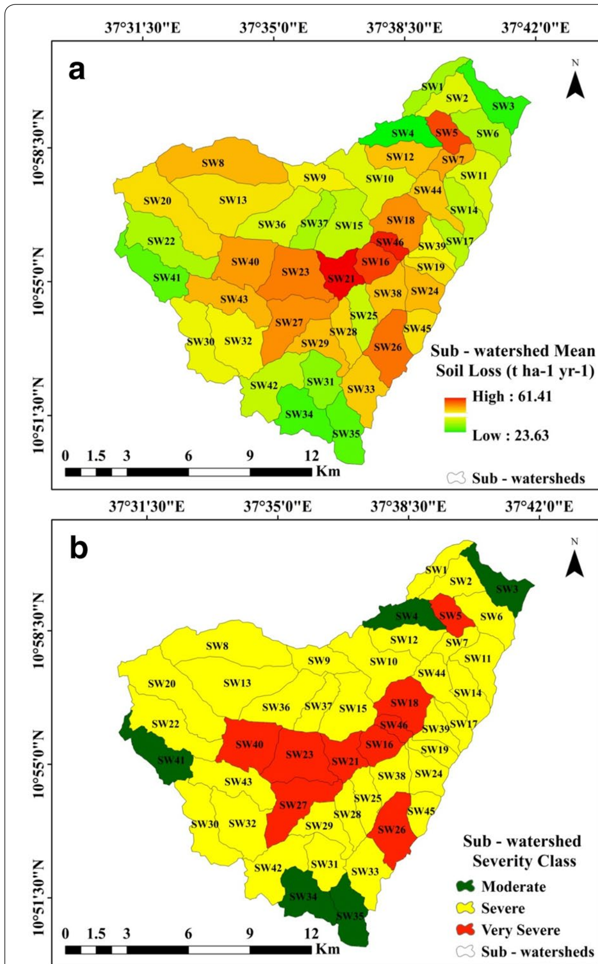

Fig. 7 Map of sub-watersheds in Gumara watershed showing **a** average soil loss (t ha^{-1} year^{-1}), **b** severity class

Sub-watershed vulnerability and prioritization

Gumara watershed was classified in to 46 sub-watersheds and their vulnerability classes were identified (Fig. 7). The erosion severity class map of sub-watersheds revealed nearly the entire watershed needs the implementation of different types of conservation measures. However, implementation of conservation measures in all sub-watersheds may not be possible and effective. Identification of more risky sub-watersheds was basic for selection of prior-focus areas for conservation planning (Gashaw et al. 2017; Silva et al. 2012; Woldemariam et al. 2018). In this regard, prioritization was done using the annual soil loss estimated for the watershed by RUSLE. Several studies successfully implemented this method for sub-watershed prioritization (Bewket and Teferi 2009; Kayet et al. 2018; Khadse et al. 2015; Markose and Jayappa 2016; Silva et al. 2012).

In this case the variation among sub-watersheds is considered to be the attributed by individual model parameter characteristics and their interaction. As per the model estimates sub-watersheds experienced a potential average soil erosion rate ranging from 23.63 to 61.41 t ha^{-1} annually (Table 9; Fig. 7a). Highest estimate was found to be at SW21 (61.41 t ha^{-1} year^{-1}) followed by SW46 (60.65 t ha^{-1} year^{-1}) and the lowest mean soil loss was generated from SW4 (23.63 t ha^{-1} year^{-1}). The result showed that there was greater variability of soil erosion not only in pixel basis but also among sub-watersheds.

The sub-watershed vulnerability class map revealed four, thirty-one and eleven sub-watersheds were identified as very severe, severe and moderate level of vulnerability respectively (Table 9; Fig. 7b). The minimum average soil loss of sub-watersheds was 23.63 t ha^{-1} year^{-1}, which is beyond the maximum tolerable limit. It indicates that Gumara watershed is found to be more vulnerable for soil erosion. However, sub-watersheds identified as very severe and severe erosion classes constitute 69.81 and 23.7% of soil loss in the watershed. As a result, it is better to give priority for more vulnerable sub-watersheds for conservation planning. Most of the top priority sub-watersheds are found in the mid stream

Table 9 Sub-watersheds, their total and mean annual soil loss and priority level

SW_ID	Area (ha)	MSL (t ha^{-1} $year^{-1}$)	TSL ($t/year^{-1}$)	SLR (%)	Priority level	SW _ID	Area (ha)	MSL (t ha^{-1} $year^{-1}$)	TSL ($t/year^{-1}$)	SLR (%)	Priority level
1	250.64	34.42	97,685.06	1.01	Severe	24	321.66	48.07	171,163.7	1.77	Severe
2	354.78	40.74	160,578.5	1.66	Severe	25	298.35	38.05	126,140.3	1.3	Severe
3	394.19	24.75	109,135.2	1.13	Moderate	26	510.3	54.47	307,227.3	3.17	Very severe
4	372.78	23.63	96,891.3	1	Moderate	27	623.07	51.54	356,765.6	3.68	Very severe
5	228.95	57.94	153,423	1.58	Very severe	28	263.25	45.42	132,841	1.37	Severe
6	430.83	35.16	167,367.8	1.73	Severe	29	365.31	47.44	192,560.9	1.99	Severe
7	187.65	49.69	103,411.1	1.07	Severe	30	581.39	41.6	268,142	2.77	Severe
8	963.81	48.33	513,573	5.3	Severe	31	391.59	32.04	139,415	1.44	Severe
9	333.54	43.35	159,538.2	1.65	Severe	32	661.41	42.53	312,437.2	3.23	Severe
10	667.7	40.62	305,215.6	3.15	Severe	33	446.3	46.14	231,780.1	2.39	Severe
11	408.5	40	184,252.8	1.9	Severe	34	484.2	26.11	138,681.4	1.43	Moderate
12	411.39	47.29	216,140.3	2.23	Severe	35	414.44	27.7	128,536.9	1.33	Moderate
13	994.5	44.08	487,076.4	5.03	Severe	36	584.37	39.61	257,172.4	2.66	Severe
14	343.8	37.23	141,367.4	1.46	Severe	37	290.34	35.06	113,093.3	1.17	Severe
15	610.47	37.32	253,168.9	2.61	Severe	38	344.43	47.31	181,036.8	1.87	Severe
16	281.7	58.6	183,432.4	1.89	Very severe	39	246.24	42.29	115,565.7	1.19	Severe
17	199.62	36.75	80,657.29	.83	Severe	40	596.34	50.62	335,420.9	3.46	Very severe
18	455.76	51.54	260,993.8	2.7	Very severe	41	487.52	28.45	154,786.6	1.6	Moderate
19	182.43	44.41	89,314.3	.92	Severe	42	607.76	37.22	253,889.6	2.62	Severe
20	903.06	44.89	449,013.4	4.64	Severe	43	551.34	48.35	296,222.4	3.06	Severe
21	326.97	61.41	223,112.7	2.3	Very severe	44	343.44	46.74	178,343.2	1.84	Severe
22	685.98	35.23	267,772.3	2.77	Severe	45	232.38	45.01	114,544.9	1.18	Severe
23	648.9	53.16	383,295.1	3.96	Very severe	46	135.45	60.65	91,273.74	.94	Very severe

MSL, mean soil loss; TSL, total soil loss; SLR, soil loss ratio; SW_ID, sub-Watershed identification number (SW1, SW2, SW3, … SW46)

part of the watershed, where as less priority areas were concentrated more on the downstream part unlike the findings of Markose and Jayappa (2016).

Conclusion and policy implications

Estimation of soil erosion is required to make conservation planning evidence (priority) based to be more effective with the available limited resources. The RUSLE potential soil loss estimation model gives a good implication of soil erosion intensity and variability in Gumara watershed. The watershed experienced a serious problem related to water induced soil erosion. An estimated 9.683456 million t of top fertile soil has been lost from the watershed annually with an average soil erosion rate of 42.67 t ha^{-1} $year^{-1}$. Estimated areas of 82.08% were evaluated to be experienced severe and very severe soil erosion rate in the watershed. This is far beyond the soil erosion rate tolerable limit.

The cultivation of steep slope areas has been identified as prior causes for occurrence of severe soil erosion and hotspot areas. Thus, cultivated land was found to be the most vulnerable, which is a pillar of livelihoods for most of the watershed population. As a result immediate attention is needed for conservation measures especially in steep continuously cultivated mid-portion of the watershed. The sub-watershed vulnerability map showed that most of the watershed area was endangered with soil erosion, in which 3814 ha (9 sub-watersheds) were categorized under the first priority levels of soil erosion. Such sub-watersheds need immediate attention for better watershed management depending on priority classes. As a result, well planned and evidence based watershed management interventions are very essential to rehabilitate degraded areas and minimize future soil erosion in the watershed.

An integrated approach of RUSLE, GIS and remote sensing found to be important tool for soil mapping and quantification of soil erosion, its spatial variation and prioritization of sub-watersheds especially in data poor areas. This is vital for giving first hand information that may assist planning for conservation measures. Land resource related sectors: especially local governmental and non governmental institutions and land management expertise may use this information for better conservation measures implementation in the watershed.

Abbreviations

GDEM: global digital elevation model; GPS: global positioning system; ha: hectare; LUC: land use/cover; RUSLE: revised universal soil loss equation; GIS: geographic information system; RS: remote sensing; SW: sub-watershed; t: ton; USGS: United States Geological Survey.

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Authors' contributions

MB has made considerable contributions in designing the study, data acquisition, data collection, analysis, and interpretation; TY and DT have made significant contribution in designing and analysis of data in the study and editing, commenting and suggesting ideas in the manuscript preparation process. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

All authors agreed and approved the manuscript for publication in Environmental Systems Research.

Competing interests

The authors declare that they have no computing interests.

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