Prioritization of sub-watersheds for conservation measures based on soil loss rate in Tikur Wuha watershed, Ethiopia

Abiot Ketema[1] · Gowdagere Siddaramaiah Dwarakish[1]

Abstract

Soil erosion is unquestionably the trickiest land degradation that adversely agricultural productivity. Since resources are scarce, in developing countries like Ethiopia, implementing soil and water conservation practice at a time on the entire watershed is not feasible. Therefore, recognizing erosion-prone areas (the priority watersheds) based on the magnitude of soil loss rate is indispensable. The purpose of this study is to delineate priority sub-watersheds of the Tikur Wuha watershed in Ethiopia based upon the soil loss rate. A universal soil loss equation under the geographic information system environment was employed to estimate the soil loss rate. The result revealed that the average soil loss rate from the watershed is 14.13. It is resulting in a gross soil loss of 962,083 from the entire watershed. A small portion of the watershed (9.22%) is suffering from severe and very severe soil loss rate (> 25). A total of 14.41% of the watershed have soil loss rates above the maximum soil loss tolerance of the area (> 12). Among the seven sub-watersheds in the watershed, four sub-watersheds (SW_3, SW_1, SW_2, and SW_4) are falling under the top priority zone. Soil and water conservation measures should be executed rapidly in the Tikur Wuha watershed, consistent with the rank of the priority watersheds.

Keywords Ethiopia · Prioritization · Soil and water conservation · Soil loss rate · Sub-watersheds

Abbreviations

DEM	digital elevation model
GIS	geographic information system
LU/LC	land use/ land cover
MLC	Maximum Likelihood Classification
MoWR	Ministry of Water Resource
NMSA	National Meteorological Service Agency
SLR	soil loss rate
SLT	soil loss tolerance
SRTM	Shuttle Radar Topography Mission
SW	sub-watershed
SWC	Soil and Water Conservation Engineering
TWW	Tikur Wuha watershed
USA	United States of America
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System
WWDSE	Water Works Design and Supervision Enterprise

✉ Abiot Ketema
ketemaabiot80@gmail.com

Gowdagere Siddaramaiah Dwarakish
dwaraki.gs@gmail.com

[1] Department of Applied Mechanics and Hydraulics, National Institute of Technology Karnataka, Surathkal, Mangalore, Karnataka 575 025, India

Introduction

Soil erosion is unquestionably the trickiest land degradation in the globe (Bridges and Oldeman 1999). Soil erosion influences about one billion people across the world, of which about 50% of the community under the influence is concerted in Africa (Lal and Humberto 2008). In Ethiopia, water erosion is the most critical environmental threat that adversely affects agricultural productivity, economic growth, and food security (Hurni 1985; Taddese 2001; Molla and Sisheber 2017; Gashaw et al. 2017). The consequence of soil erosion in Ethiopian reservoirs is serious (Wolancho 2012). Reports from different parts of Ethiopia show that many reservoirs have already lost their storage capacity and intended service as a consequence of heavy sedimentation (Setegn et al. 2010;

Haregeweyn et al. 2012; Berhane et al. 2016; Gelagay 2016). As Tamene et al. (2006) stated, the majority of micro-irrigation dams in the Tigray region of northern Ethiopia will be closed due to siltation in less than half of the design period. Lake Haramaya (Senti et al. 2014) in eastern Ethiopia and Lake Cheleleka (Water Works Design and Supervision Enterprise [WWDSE] 2001) in southern Ethiopia were filled with sediment and vanished in response to soil erosion.

The issue of soil erosion is severe in the Tikur Wuha watershed (TWW). The Lake Cheleleka (11.3 km^2) in 1973 in TWW is changed first to the swampy area and subsequently dried up and changed to grassland in 2011 (WWDSE 2001; Dadi 2013; Wondyrade 2014) as a result of soil erosion and sedimentation. After Lake Cheleleka was filled with silt, the sediment is now directly entering the Lake Hawassa and consequences a rise of the lake level and expansion of the surface area of the lake. Also, grasses are growing in the lake and expand its area year to year due to the deposition of nitrogen and phosphorus from agricultural fields as a consequence of soil erosion. The implication is that the problem of soil erosion is severe in the study area (TWW). It needs to be quantified by using available data and methods to provide valuable information for decision-makers in planning and implementing site-specific watershed management strategies.

Planning for soil and water conservation (SWC) measures involves an adequate understanding of the spatial variation of erosion risk in the areas, the extent of areas affected, and their magnitude in the watershed. However, the spatial variation of soil loss rate (SLR) in TWW and sediment delivery to the Lake Hawassa from the TWW is not understood well. This is a current challenge for planners and policymakers to develop long-term SWC strategies. Therefore, the comprehensive study is highly needed, and the issue has to be addressed at a scale relevant to practice watershed management. Thus, this study aims to deepen the understanding of SLR at the watershed level.

It may not be feasible to cope with the whole area of the watershed with SWC measures at a time. Since resources are scarce, in developing countries like Ethiopia, implementing SWC practice at a time on the entire watershed is not practical. Thus, the whole watershed is divided into several smaller units, as sub-watersheds since a watershed is an excellent unit for planning and execution of the SWC practices. Therefore, recognizing erosion-prone areas for prioritizing sub-watershed in reference to the magnitude of SLR is indispensable for planning and implementing sustainable watershed management and wise use of resources. Prioritization of a sub-watershed for the execution of SWC practices involves the ranking of different sub-watershed based on the magnitude of SLR (Adinarayana 2003). Most of the soil erosion assessment studies for watershed prioritization in Ethiopia are not presented at the sub-watershed level. They are given the finding at the watershed level. It may not help to identify hot spot areas for implementing soil and water conservation activities in the top priority area. This article presented the soil loss rate at the sub-watershed level and prioritized the sub-watersheds based on the magnitude of soil loss rate for the execution of SWC activities.

The present study carried out to predict the spatial variation of SLR and prioritize the sub-watersheds of TWW using universal soil loss equation (USLE) and geographic information system (GIS) techniques. The USLE is widespread in water erosion assessment for predicting a long time average soil loss from the area dominated by rill and inter rill water erosion. Moreover, USLE is more suitable for agricultural land and low slope gradients. The USLE was employed to predict the SLR in the study watershed. The details of the USLE is given in the methodology part.

The international application of the USLE needs adaptation to local conditions and the changing of USA units to the SI metric system. However, users of the USLE are unaware of the considerations necessary to develop metric conversion factors. K-factor values in the SI units will be about 0.1317 times those of US customary units (Foster et al. 1981). The maximum K-factor value will be comparable to 0.10 (Foster et al. 1981). Panagos et al. (2012) assessed the soil erodibility factor (K-factor) for Europe, relying on 22,000 soil samples collected within Europe. They found that the K-factor of USLE ranges from 0.013 to 0.087, with a mean of 0.041 in the SI unit. The K-factor values in China concentrated in the ranges between 0.0229 and 0.0457, with a mean of 0.0321 in the SI unit (Wang et al. 2016). Studies in Ethiopia for prediction of soil erosion using USLE misused K-factor values (Bewket and Teferi 2009; Brhane and Mekonen 2009; Amsalu and Mengaw 2014; Ayalew 2015). They used the K-factor values without converting them into the metric system. These are relatively high values and seriously affect the result and may mislead the decision-makers. Corrected K-factor values were used in this study.

This paper is segregated into four sections. The "Introduction" section has briefly presented the background of the study, and the impacts of the soil erosion in Ethiopia in general and TWW in particular. Also, it describes the necessity and the intention of the study. The "Materials and methods" section provides a detailed description of the study area, data products used in the study, and comprehensive methodology framed to complete the research work. The "Results and discussion" section of the article provides the result and discussion. In this section, the USLE factors are determined, and the corresponding raster maps were developed. The average soil loss rate was estimated, and SLR reclassified. Besides, the priority watersheds were recognized for SWC activities on the bases of the magnitude of SLR. The "Conclusions" section summarizes and concludes the finding of the research work. Limitations of the study and future scope are presented.

Material and methods

Description of the study area

The Tikur Wuha watershed is found between latitude 6° 48′ N to 7° 10′ N and longitude 38° 28′ E to 38° 43′ E in southern Ethiopia at a distance of 275 km south from Addis Ababa. It falls into two administrative boundaries of the Sidama regional state in the South and Oromia regional state in the northern alignments. The watershed has a catchment area of 681 km^2 (Fig. 1). The topography ranges from 1668 to 2976 m above the mean sea level. The major part of the study area (57.83%) is level to the gentle slope (0–8%) but bounded by steep mountains with hillier regions to the eastern part of the watershed. Only a small portion of the watershed is classified under steep to very steep (> 30%) slope classes. TWW is a sub-humid watershed in Ethiopian highlands with an average annual rainfall of 1071 mm. Most of the watershed area is rainfed agricultural land (mostly mixed perennial and annual cropping). Besides, other important land use/land covers in the watershed are grassland, shrubland, urban, and swampy area. In general, four major soil types have been identified in the watershed; these are Andosols, Fluvisols, Luvisols, and Vertisols (MoWR 2008). Several streams characterize the drainage network of the watershed. All streams drain into the Cheleleka wetlands, which subsequently flow into Lake Hawassa through the Tikur Wuha River (the sole permanent river feeding Lake Hawassa (Fig. 1)).

Data set

Various temporal and spatial data, including rainfall, (LU/LC) land use/ land cover, topography, and soil characteristics, are needed to attain the purpose of the study. The topographic information was derived from the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) 30-m resolution, which is downloaded from https://earthexplorer.usgs.gov. The LU/LC map was generated from a cloud-free Landsat-8 image of 2017 (30-m resolution) satellite image downloaded from https://earthexplorer.usgs.gov. The soil map was clipped from the Rift Valley Lake Basin soil map (1:50,000 scale) generated by the Ministry of Water Resource (MoWR 2008). Besides, observed precipitation data for the period of 1978 to 2017 were collected from the (NMSA) National Meteorology Service Agency, Ethiopia.

Methodology

The USLE (Wischmeier and Smith 1978) and its revised version (RUSLE) (Renard et al. 1997) are widely used models for assessment of SLR (Ashiagbor et al. 2013; Maryam and Biswajeet 2014; Ganasri and Ramesh 2016; Markose and
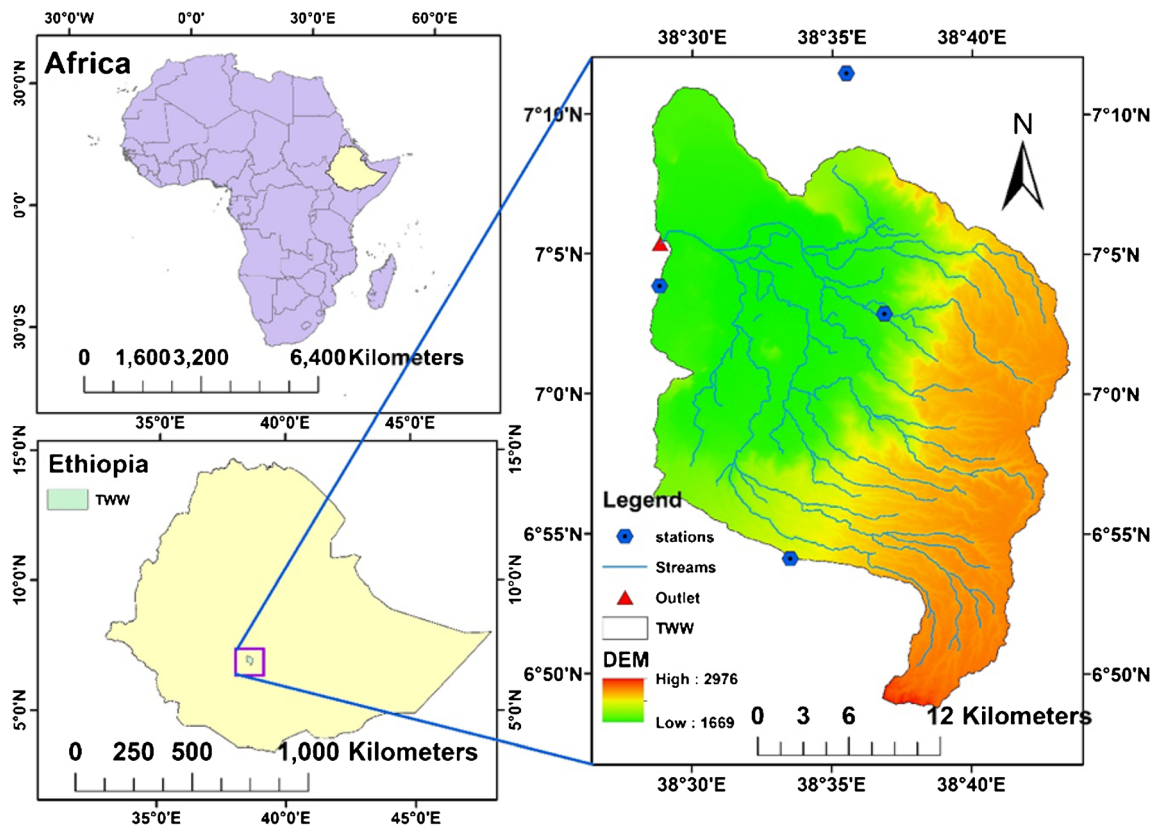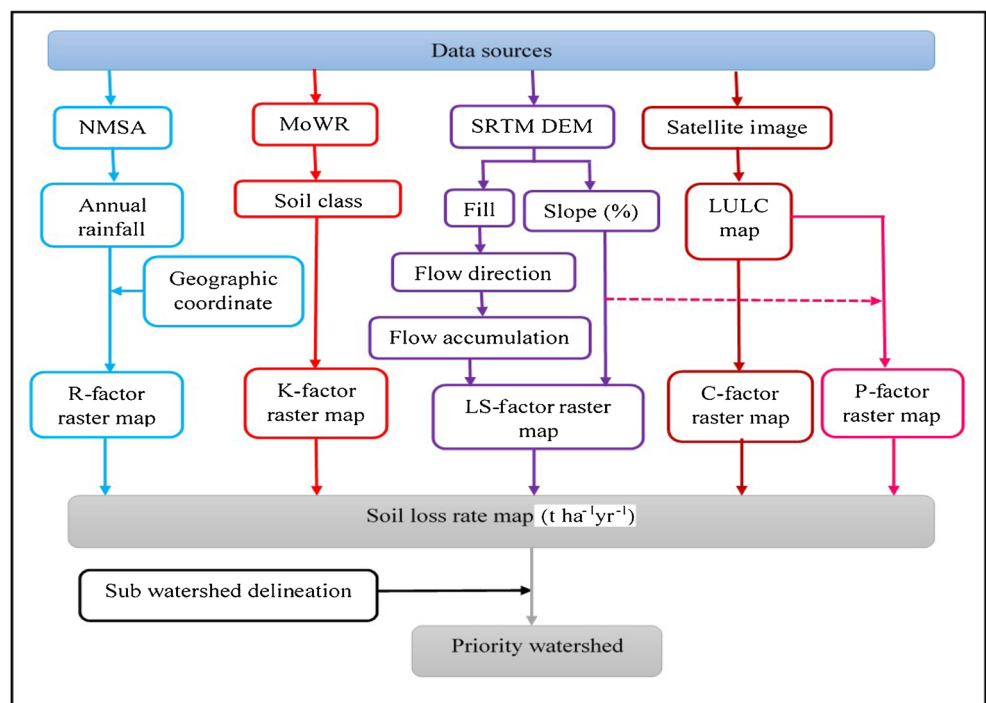

Fig. 1 Location map of Tikur Wuha watershed

Fig. 2 The framework for the modeling of SLR and prioritization of watersheds using the USLE and GIS

Jayappa 2016; Rejani et al. 2016; Uddin et al. 2016; Yuan et al. 2016). USLE was mainly developed for conditions in the United States of America (USA). The use of USLE in other areas requires adaptation to the local situation. Thus, Hurni (1985) simplified the USLE by adapting the factors to conditions in Ethiopia based on long-term measurements and experimental data from a large number of test plots in five Soil Conservation Research Project (SCRP) stations, namely Anjeni, Andit Tid, Gununo, Hunide Lafito, and Mayabir, in various slopes, soils, land uses, crops, and under several SWC treatments in different agro-climatic zones of Ethiopia and one additional station in Eritrea (Afdeyu). In various agro-climatic regions of Ethiopia USLE coupled with GIS has been successfully and extensively applied for the estimation of the spatial variation of soil loss and it has been provided a good result (Bewket and Teferi 2009; Brhane and Mekonen 2009; Sisay et al. 2014; Adugna et al. 2015; Ayalew 2015; Wolka et al. 2015; Fenta et al. 2016; Gelagay and Minale 2016; Gashaw et al. 2017). Therefore, the present study employed USLE (Eq. 1) adopted for the Ethiopian condition (Hurni 1985) and coupled with a GIS tool to quantify the SLR of TWW. Mathematically, the equation is denoted as follows:

$$A = R \times K \times LS \times C \times P \qquad (1)$$

where A is the mean annual SLR (t ha^{-1} year^{-1}), R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} year^{-1}), K is the soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1}), LS is the slope length and steepness factor, C is the land cover and management factor, and P is the support practice factor. The details of the USLE factors are found in (Wischmeier and Smith 1978) and briefly described underneath.

The following three steps were developed for the estimation of the SLR, and recognition of priority watershed and summarized in Fig. 2.

(i)   It is generating the raster map of the necessary input parameters of USLE.
(ii)   The soil loss rate map of the watershed was developed and classified into severity categories based on different criteria (based on soil erosion severity class, soil loss tolerance of the area, and average soil loss rate of the country).
(iii) Prioritization of sub-watersheds for SWC practices based on the relative erosion status of the sub-watersheds

Table 1   *P*-factor values

Land-use class	Slope class in percent	P-factor
Agricultural land	0 to 5	0.10
	5 to 10	0.12
	10 to 20	0.14
	20 to 30	0.19
	30 to 50	0.25
	50 to hundred	0.33
Non-agricultural land (built up, shrubland, grassland, marshy, and water body)	All	1.00

Table 2 Annual rainfall and the R-factor of TWW

Station name	Altitude (m)	Latitude	Longitude	Area (km²)	Area (%)	Yearly average rainfall (mm)	R-factor
Hawassa	1701	7° 3′	38° 28′	136.28	20.02	962.33	530.78
Haisawita	2249	6° 54′	38° 33′	209.94	30.83	1146.37	633.85
Shashemene	1943	7° 11′	38° 35′	32.28	4.74	894.58	492.84
Wondogenet	1770	7° 20′	38° 36′	302.38	44.41	1087.29	600.76
Average						1071.35	591.84

Rainfall erosivity factor

Rainfall erosivity factor (R-factor) is determined by the rainfall erosion index (EI$_{30}$). It is a measure of rainfall events (Wischmeier and Smith 1978). But measured data like intensity and kinetic energy are not commonly obtainable in every area for precise determination of R-factor (Lal and Humberto 2008). Researchers developed various equations for the computation of R-factor on the bases of average annual, monthly, and daily precipitations. However, those equations cannot be applied to Ethiopia due to the fact that they are valid for the areas they were elaborated for. Also, extrapolating them to another place beyond the database from which they have been derived is not convincing. Due to the difficulty of direct determination of R-factor, as the intensity of the precipitation does not exist at the meteorological stations in the TWW, indirect methods developed by Hurni (1985) for Ethiopia on the bases of average annual rainfall (Eq. 2) are applied.

$$R = 0.56P - 8.12 \qquad (2)$$

where R is in MJ mm ha^{-1} h^{-1} year^{-1}, and P is the average yearly precipitation in mm.

A similar method was employed by (Bewket and Teferi 2009; Amsalu and Mengaw 2014; Adugna et al. 2015; Ayalew 2015) in Ethiopia to determine the R-factor.

The daily rainfall data for four stations in and near the watershed were collected from a national meteorological service agency, South Nation Nationality and People Regional State, Hawassa branch office. In developing countries like Ethiopia, meteorological stations are sparsely available. All the stations in and near the watershed that satisfy the criteria (the data availability, period of observation of data in the study area, and gaps in data records are the criteria applied for the choice of used stations) were included. Nearest neighbor values filled the missing data. The databases of the rainfall from four stations are for the duration of 40 years (1978 to 2017). The data were first aggregated into average annual rainfall amounts in the attribute table. The yearly average rainfall amounts for the four stations were entered as point values with respect to the geo-referenced locations culminating into a point map. The point map was rasterized using the functions in ArcGIS 10.3 software. The rasterized rainfall point map was then used to develop a Thiessen map (rainfall map), which is a map with continuous surface annual rainfall values depicting various rainfall regimes in the study area. The yearly rainfall map shows the spatial

Fig. 3 Rainfall erosivity map of Tikur Wuha watershed
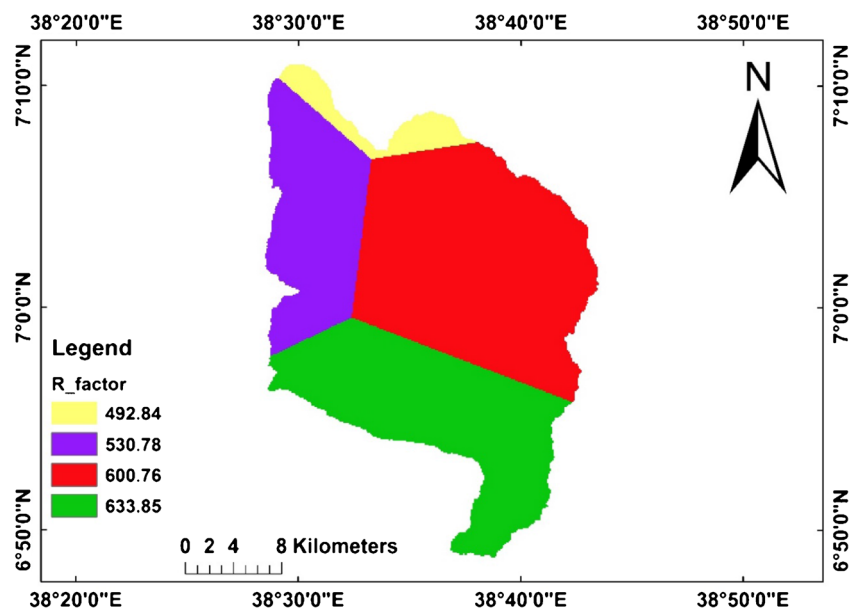
Table 3 K-factor values in SI unit and the corresponding area

Soil type	Area (km²)	Area (%)	K-factor (US unit)	K-factor (SI metric unit)
Hablic Luvisols	233.54	34.30	0.09	0.012
Xeroic Luvisols	135.25	19.86	0.11	0.015
Eutric Vertisols	18.99	2.79	0.15	0.020
Eutric Fluvisols	203.64	29.91	0.18	0.024
Molic Andosols	10.47	1.54	0.20	0.026

variation of annual rainfall in the watershed, and it was used to generate the R-factor raster map. R-factor map was developed by using GIS-based on the yearly rainfall map and Eq. 2.

Soil erodibility factor

Soils vary in their vulnerability to erosion. This variation, due to the soil type itself, is called the soil erodibility (Wischmeier and Smith 1978). Organic matter content, permeability, texture, and the soil structure is the critical soil characteristics that control the K-factor. Determination of K-factor values by direct measurement of the erodibility factor is expensive and requires considerable time and equipment to execute. In this study, to determine the K-factor value, Hurni (1985) adapted K-factor estimations for various soil types for Ethiopian condition were used. But this value is in the US unit. It needs to adjust the values multiplied by a conversion factor to get the K-factors in the SI unit.

Slope length and slope steepness

The slope length and slope steepness (LS-factor) reflects the impacts of topography on water erosion. Steeper slopes rise runoff velocities, and longer slopes allow for the accumulation of runoff. Both these results are increased erosion potential. The steeper and prolonged the hill, the higher is the risk of erosion (Hudson 1995). The two factors have been determined separately; however, in field applications, considering the two as a single topographic factor is more convenient. Since the altitude of each location defines topography within an area, altitude data stored in a DEM are the standard input for performing topographical operations in raster format. For this research, the LS-factor can be used in a single index, as shown in Eq. 3, defined by Wischmeier and Smith (1965), and derived from DEM.

$$LS = \left(\frac{x}{22.13}\right)^m \left(0.065 + 0.045s + 0.0065s^2\right) \qquad (3)$$

where x = the field slope length, can be determined by multiplying flow accumulation and the resolution of the DEM, s = slope gradient (%). The magnitude of m in Eq. 3 does not mean the same for all places or all conditions at a given site. m values vary from 0.2 to 0.5 subjects to the slope (Wischmeier and smith 1978): slope greater than five ($m = 0.5$), the slope between three and five ($m = 0.4$), the slope between one and three ($m = 0.3$), and a slope less than one ($m = 0.2$).
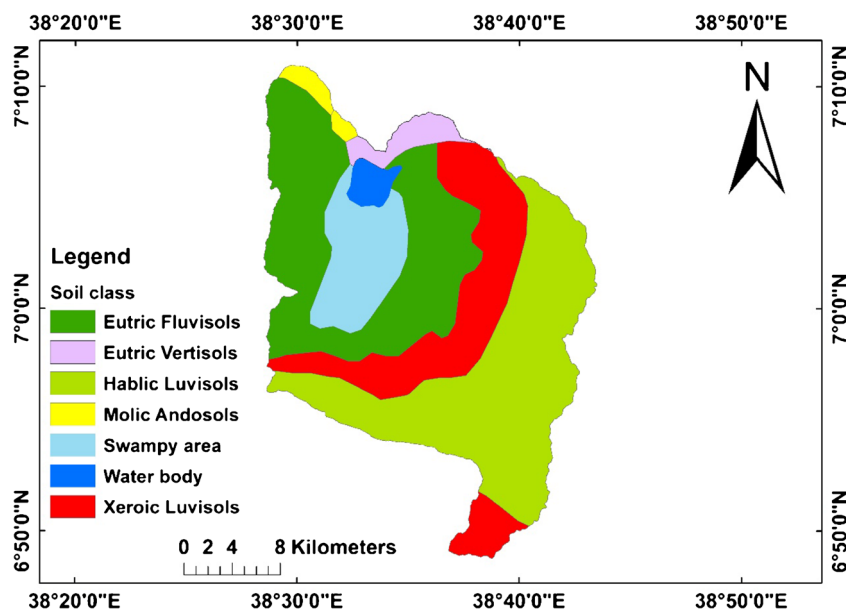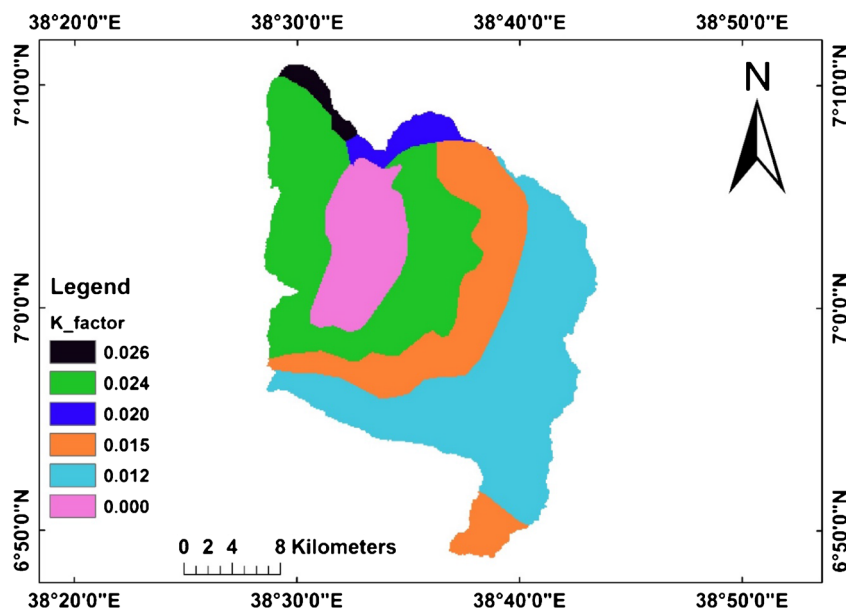
Fig. 4 The soil class raster map of Tikur Wuha watershed

**Fig. 5** The soil erodibility class map of Tikur Wuha watershed


Cover and management factor

In estimating the cover and management factor (*C*-factor), it is indispensable to know the LU/LC of the study area. The LU/LC map of the watershed was developed from the Landsat Operational Land Imager and Thermal Infrared Sensor (OLI_TIRS) image acquired on 12-December-2017 during the dry season. The images with 30-m resolution and cloud cover of less than 10% were collected from the USGS Centre for Earth Resources Observation and Science (https://earthexplorer.usgs.gov/). The image was projected to Universal Transverse Mercator (UTM) coordinate system (WGS 84 datum, UTM Zone 37 N). Supervised classifications

were implemented with the Maximum Likelihood Classification (MLC) algorithm. In classifying the images, 600 reference data from Google Earth images of the corresponding periods were used. Accuracy assessment was employed with reference to the corresponding Google Earth images to illustrate the representativeness of the classified images on the ground. The overall accuracy of the LU/LC map was 87.33%. ERDAS 2014 was employed for image classifications purpose and ArcGIS 10.3 for mapping purposes. For classification, seven LU/LC classes were established in the scheme as intensively cultivated, moderately cultivated, water, shrubland, built up, swampy, and grassland. The *C*-factor value was determined for each LU/LC class of the

Fig. 6 The DEM of Tikur Wuha watershed
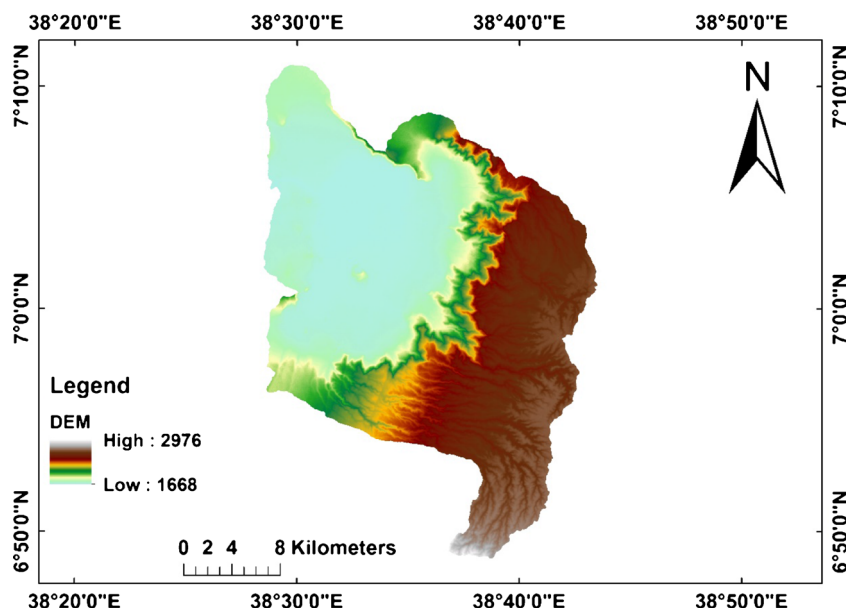
Fig. 7 The slope class map of Tikur Wuha watershed
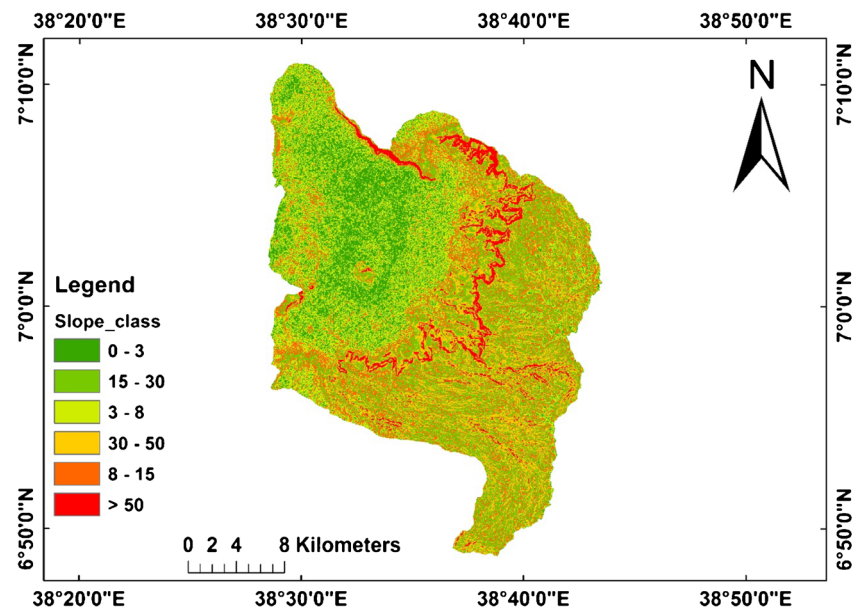
TWW on the bases of available literature recommendations in the Rift Valley Lake Basin in Ethiopia (MoWR 2008) in the Ethiopian highlands (Hurni 1985), and other published literature.

Support practice factor

The effects of supportive conservation methods such as terracing, contouring, tillage, cropping practices, in particular, and land management, in general, are significant in controlling SLR at a specific area. The magnitude of erosion declines with the installation of these methods (Morgan 2005). In the Tikur Wuha watershed, there is

an insignificant portion of the watershed has been cured with improved SWC intervention through the Safety Net Program and government. Previously constructed works were reported as destroyed in many places as a result of the free grazing of cattle and a lack of maintenance (MoWR 2008). Hence, support practice factor (P-factor) values from slope and land use classes were used in this study. Firstly, the LU/LC map was developed. The LU/LC map was reclassified into two categories that are agricultural land and non-agricultural land. At the same time, the slope in percent map was reclassified into six classes, as shown in Table 1. Then, using raster analysis in ArcGIS 10.3, the P-factor raster map was developed by using the reclassified LU/LC map, slope in percent map,
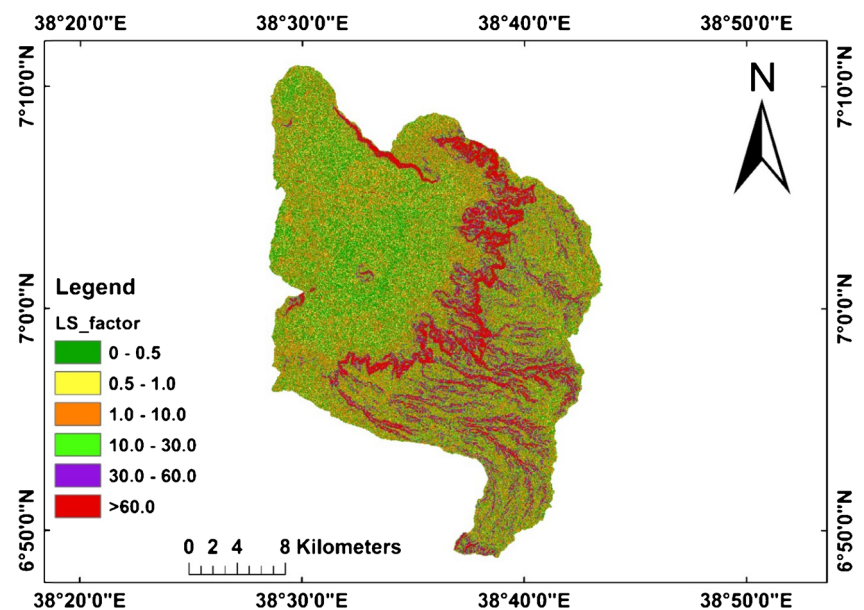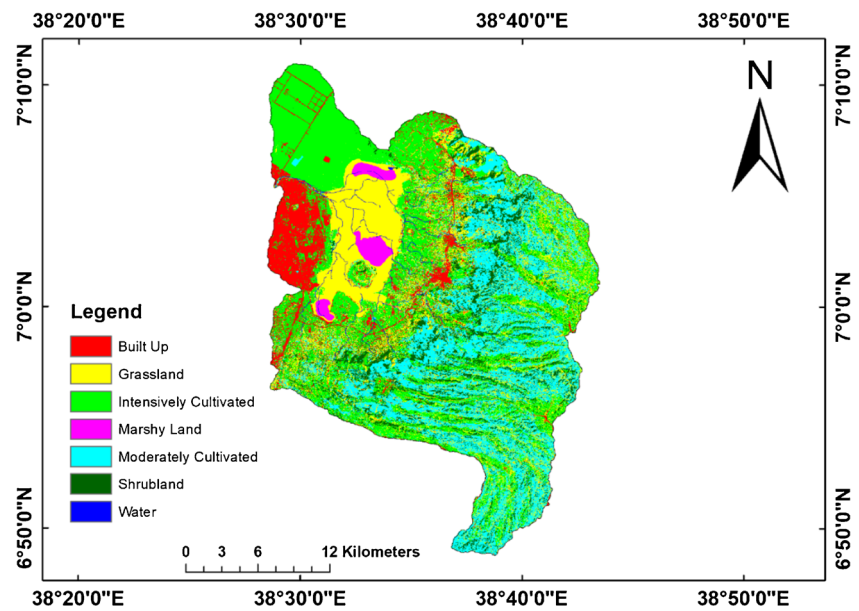
Fig. 8 LS-factor map of Tikur Wuha watershed

Fig. 9 Land use/land cover map of Tikur Wuha watershed

and Table 1. Similar methods of determining *P*-factor values have been employed in earlier studies from several nations (Bewket and Teferi 2009; Adediji et al. 2010; Shiferaw 2011; Mulu and Dwarakish 2016).

Results and discussion

USLE factors determined

R-factor

On the bases of the rainfall data from four meteorological stations in and near the watershed for a period of 40 years from 1978 to 2017, the areal yearly average rainfall was 1071.35 mm. The annual rainfall and rainfall erosivity with the area and the percentage contribution of each station to TWW are summarized in Table 2. Figure 3 displays the spatial variation of the *R*-factor of TWW. The *R*-factor ranges from 530.78 to 633.85 MJ mm ha^{-1} h^{-1} year^{-1} with an average value

of 591.84 MJ mm ha^{-1}h^{-1}year^{-1}. It is highest at Haisawita and relatively low at Shashemene. This value of *R*-factor is less compared to the report by Andriyanto et al. 2015. Andriyanto et al. 2015 reported *R*-factor from 980 to 1439 MJ mm ha^{-1} h^{-1} year^{-1} in the Kalikato watershed in Indonesia. This significant difference in *R*-factor arises from the high yearly average rainfall value up to 2509 mm in the area. The result is high compared to Brhane and Mekonen 2009. They reported *R*-factor 357 MJ mm ha^{-1} h^{-1} year^{-1} at Medego watershed, Northern Ethiopia.
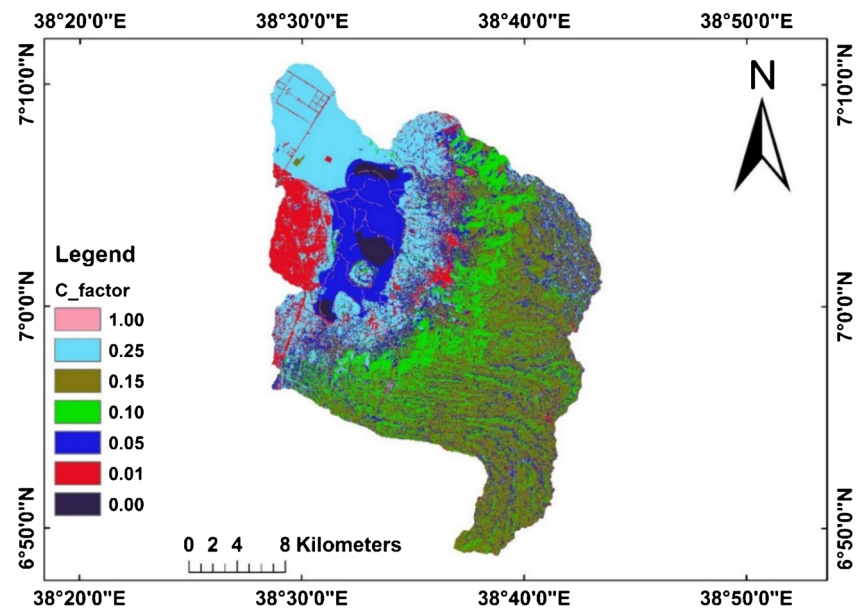
K-factor

Table 3 revealed the *K*-factors for each soil class with the corresponding soil type with a percentage of the area in TWW. Figure 4 and Fig. 5 display the soil class raster map and the value of the *K*-factor for each soil class and its spatial pattern in the TW, respectively. The *K*-factor of TWW ranges from 0.000 to 0.026. Panagos et al. (2012) assessed the *K*-factor for Europe, relying on 22,000 soil samples collected

Table 4 Adopted cover and management factor values for different LULC in the TWW

LULC	Area (km^2)	Area (%)	*C*-factor values	References
Intensively cultivated	146.75	21.55	0.25	Hurni (1985), MoWR (2008)
Moderately cultivated	205.20	30.14	0.15	Hurni (1985), MoWR (2008)
Built up	64.03	9.40	0.01	Haregeweyn et al. (2017)
Shrub land	105.85	15.55	0.10	MoWR (2008)
Grassland	144.29	21.19	0.05	MoWR (2008), Hurni (1985)
Marshy	10.14	1.49	0.00	MoWR (2008)
Water	4.62	0.68	1.00	Yesuph and Dagnew (2019)

Fig. 10 The cover and management factor map of the Tikur Wuha watershed


within Europe. They found that the *K*-factor of USLE ranges from 0.013 to 0.087, with a mean of 0.041 in the SI unit. The *K*-factor values in China concentrated in the ranges between 0.0229 and 0.0457, with an average of 0.0321 in the SI unit (Wang et al. 2016). The *K*-factor of TWW is in the range of other results elsewhere (Panagos et al. 2012; Wang et al. 2016). Compared to studies in Ethiopia (Bewket and Teferi 2009; Brhane and Mekonen 2009; Amsalu and Mengaw 2014), the value of *K*-factor is relatively less. Both Bewket and Teferi (2009) and Amsalu and Mengaw (2014) reported *K*-factors ranges from 0.15 to 0.25 in Ethiopia. Brhane and Mekonen (2009) revealed the *K*-factor ranges from 0.15 to 0.30 at Medego watershed, Northern Ethiopia. Ashiagbor et al. 2013 showed the *K*-factor values up to 0.351 in Guana,

Africa. This difference in values has resulted because of using the *K*-factor value without converting to the SI unit.

LS-factor

Figures 6 and 7 showed the DEM and slope class map of the watershed. The topography ranges from 1668 to 2976 m above the mean sea level. The major part of the study area (57.83%) is level to the gentle slope (0–8%) but bounded by steep mountains with hillier regions to the eastern part of the watershed. Only a small portion of the watershed is classified under steep to very steep (> 30%) slope classes. The LS-factor is displayed as a map (Fig. 8). It varies from zero to greater than 60. A significant part of the area (41.05%) have LS-factor less than 1, and almost half

Fig. 11 Supporting practice factor map of Tikur Wuha watershed
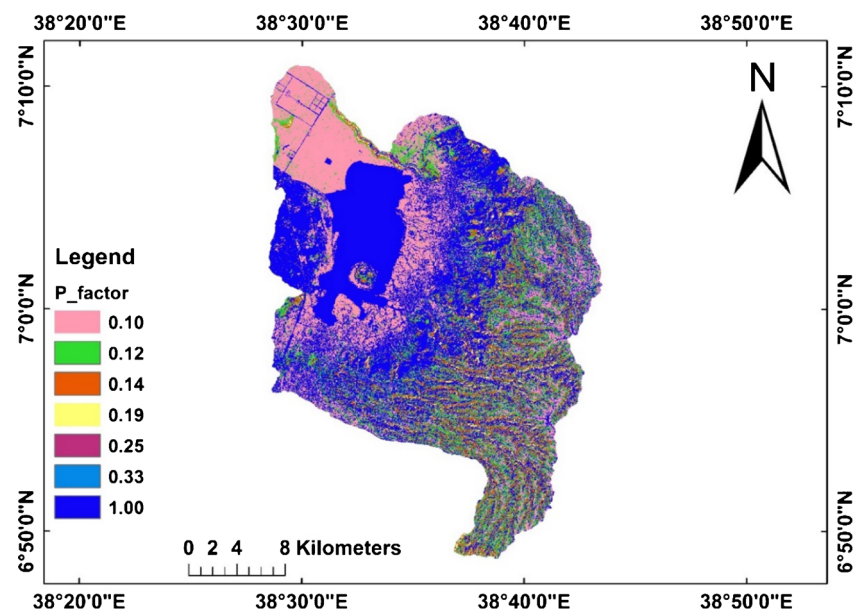
of the watershed (51.94%) have LS-factor between 1 and 60. A small portion of the watershed (7.01%) have an LS-factor value greater than 60. Bewket and Teferi 2009 also reported the LS-factor ranges from zero to greater than 100 in Chemoga watershed in the Ethiopian highlands. The LS-factor reflects the impacts of topography on water erosion. Steeper slopes rise runoff velocities, and longer slopes allow for the accumulation of runoff. Both these results are increased erosion potential. The steeper and prolonged the hill, the higher is the risk of erosion (Hudson 1995). The higher LS-factor is observed in the steeper slope area in the study watershed.

C-factor

The C-factor is the ratio of soil loss from land with specific vegetation to the corresponding soil loss from continuous fallow (Wischmeier and Smith 1978). The LU/LC class map was developed from the Landsat-8 satellite image for the year 2017. Most of the watershed area (51.69%) is cultivated land. Besides, other LU/LCs in the watershed are grassland, shrubland, urban, and swampy area (Fig. 9). Then, the C-factor values of each LU/LC class were allocated on the bases of literature recommendations in the Rift Valley Lake Basin in Ethiopia (MoWR 2008) and Ethiopian highlands (Table 4). The C-factor map was developed and depicted in Fig. 10. The C-factor of TWW ranges from 0 to 1, and it is in the range of studies elsewhere. Bewket and Teferi 2009 reported the C-factor ranges from 0.01 to 0.60 in Ethiopian highlands.

P-factor

The P-factor gives the ratio between the soil loss expected for a certain soil conservation practice to that with up- and down-

**Table 5** SLR class of TWW on the bases of severity class

SLR class (t/ha/year)	Area in km^2	Area in %	Severity class
0–5	534.43	78.49	Very slight
5–10	40.41	5.93	Slight
10–25	43.33	6.36	Moderate
25–45	23.17	3.41	Severe
> 45	39.54	5.81	Very severe

slope plowing (Wischmeier and Smith 1978). The P-factor raster map was developed on the bases of the LU/LC and slope of the watershed. The P-factor values are depicted in Fig. 11. The P-factor of the watershed ranges from 0.11 to 1.00 and it is in the range of studies elsewhere in Ethiopia (Bewket and Teferi 2009; Shiferaw 2011; Ayalew 2015; Mulu and Dwarakish 2016).

The soil loss rate of the Tikur Wuha watershed

The SLR of TWW was predicted by using USLE (Eq. 1). It is computed by map algebra under the raster calculation of ArcGIS 10.3. The predicted SLR was classified based on severity class (Table 5) and depicted in Fig. 12. Due to the absence of observed sediment data specific to the study area, approaches described by Ketema and Dwarakish (2019) were used to ensure the applicability of the USLE in TWW. The results were compared with outcomes of similar studies across Ethiopian highlands and in Rift valley lake basins. Also, the result of the model was discussed with respect to soil loss tolerance (SLT) of the country and the average SLR of Ethiopia.

Fig. 12 Soil loss rate class map of Tikur Wuha watershed based on severity class
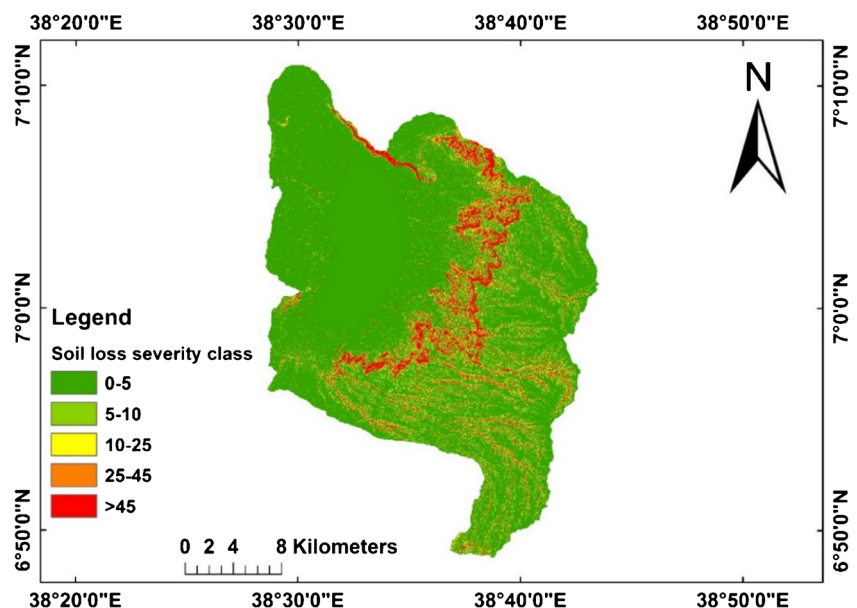
Table 6 Soil loss rate class based on soil loss tolerance (SLT) of the TWW

| SLR class (t/ha/year)	Area in km^2	Area in %	Severity class
0–6	545.14	80.06	Low
6–12	37.61	5.53	Medium
> 12	98.13	14.41	High

The SLR of TWW was ranged from 0.00 to greater than 45 t ha^{-1} year^{-1} with the mean value of 14.13 t ha^{-1} year^{-1}. It was resulting in the gross soil loss of 962,083 t year^{-1} in the entire watershed (from 68,088 ha). The average SLR of the watershed is found within the range of the SLR in areas having the same agro-climatic zone in Ethiopia (Bewket and Teferi 2009; Brhane and Mekonen 2009; Amsalu and Mengaw 2014; Senti et al. 2014; Sisay et al. 2014; Ayalew 2015; Gashaw et al. 2017; Belayneh et al. 2019). Report from these studies discovered that SLR ranged from 9.10 to 93 t ha^{-1} year^{-1}. Also, the average SLR of TWW is comparable with the annual mean SLR of Ethiopia (that is 12 t ha^{-1} year^{-1}) (Hurni 1987 as cited in Hurni 1988).

Although the result of the study is found to be in the range of results reported in Ethiopia, the estimated mean annual SLT is relatively somehow lower than the estimates in other watersheds (Bewket and Teferi 2009; Amsalu and Mengaw 2014; Senti et al. 2014; Sisay et al. 2014; Gashaw et al. 2017; Belayneh et al. 2019). This is because previous studies in Ethiopia used K-factor values in US units. It results in overestimating the SLR and mislead the decision-makers. The major problem in water erosion assessment in Ethiopia is the misuse of K-factor values. This study used corrected K-factor values in TWW in Ethiopia. Besides, the majority of the study watershed (57.83%) is flat to the gentle slope (0–8%).

The result of the study found that a small portion of the watershed (9.22% of the study area) is suffering from severe and very severe SLR (> 25 t ha^{-1} year^{-1}). The majority of the watershed (78.49% of the TWW) are classified under very slight (< 5 t ha^{-1} year^{-1}) potential erosion risk. The finding of this study is matching with the result carried out in Ethiopia and elsewhere in a different part of the world. Studies point out that, within the watershed, a small erosion hot spot areas are the source of a large amount of soil loss and sediment load (Setegn et al. 2009; Maryam and Biswajeet 2014; Andriyanton et al. 2015; Ayalew 2015; Gelagay and Minale 2016; Markose and Jayappa 2016; Rejani et al. 2016; Yuan et al. 2016; Gashaw et al. 2017). The spatial pattern of the classified SLR map shown areas with severe and very severe SLR are found in the east, northeast, and southeast portion of the watershed (Fig. 12). Managing this small portion of the watershed can significantly improve the productivity of the watershed.

Also, the SLR was classified based on the SLT of the country specific to the study watershed. The SLT of Ethiopia varies from 2 to 22 t ha^{-1} year^{-1} (Hurni 1998). The values of SLT depends on the agro-climatic zone. Based on annual rainfall and altitude, the agro-climatic region of the TWW is Weynadega and Dega. This implies that the SLT of the watershed varies from 6 to 12 t ha^{-1} year^{-1}. The average SLR of TWW (14.13 t ha^{-1} year^{-1}) is beyond the maximum SLT of the watershed. The implication is that there is a need to execute proper SWC measures so that to decline the extent of SLR from the watershed, below the minimum SLT value,

Fig. 13 Soil loss rate class based on SLT of the area
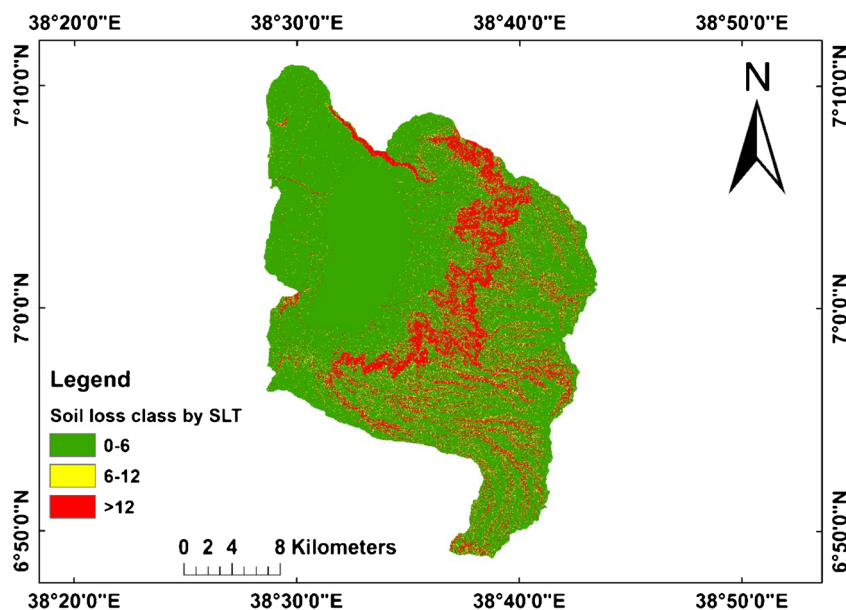
Fig. 14 The average SLR of sub-watersheds in Tikur Wuha watershed
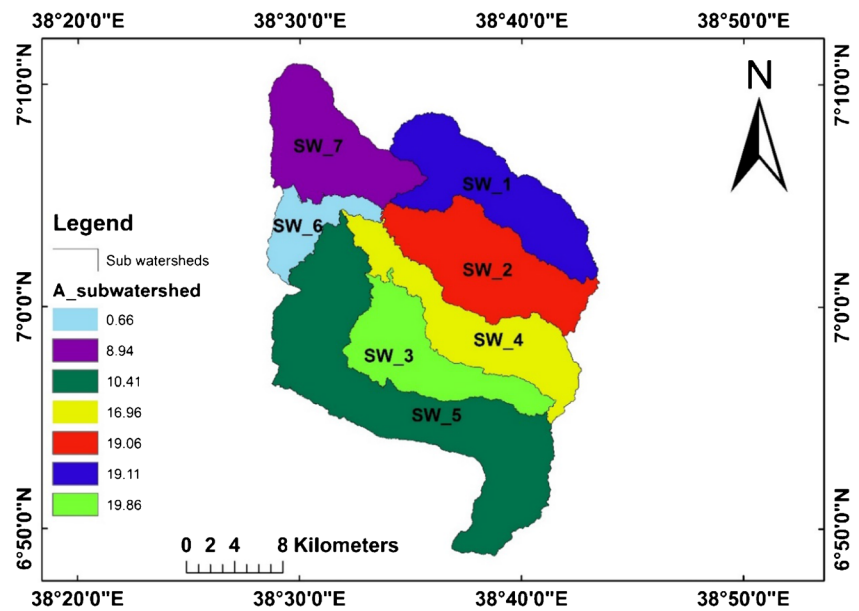
and to protect the Lake Hawassa from sedimentation and pollution; and to increase the agricultural productivity of the study area. Table 6 and Fig. 13 showed the portion of the area having SLR higher than the maximum SLT of the study watershed and the area having SLR less than the minimum SLT of the area. A total of 14.41% of the watershed have SLR higher than the maximum SLT of the area.

Moreover, the SLR of TWW was classified into two levels based on average soil erosion of Ethiopia. Reports from Ethiopia (Hurni 1988) show that the average SLR nationwide was estimated to be 12 t ha^{-1} year^{-1}. Even though the majority of the area (85.59) have SLR below the average SLR of the country, the average SLR of the watershed is higher than the average SLR of the country. This also uncovers that there is a need to implement SWC practices in the TWW.

Prioritization of sub-watersheds for SWC based on SLR

It is not practicable to take the whole watershed area at a time for its SWC practice. Thus, the entire watershed is divided into

several sub-watersheds. The purpose is to identify priority watersheds to plan and implement SWC practices. To prioritize the sub-watersheds, the TWW in Ethiopia has divided into seven sub-watersheds. The area of each sub-watershed is computed and ranges from 5.4 to 29.23 km^2, which is considered a practical working area for the execution of SWC practices. The average SLR was estimated for each watershed (Fig. 14). The ranking of the watersheds was done in decreasing order. That is, a watershed with the highest value of average yearly SLR was ranked first, and one with the lowest was ranked last (Table 7).

The result of the study revealed that all the sub-watersheds in TWW except SW_6 need implementation of SWC practices. Watershed SW_3 (19.86 t ha^{-1} year^{-1}) was ranked first, followed by SW_1, SW_2, and SW_4, respectively. These watersheds are found on the eastern side of TWW and having relatively steep slope sides (Fig. 14). The implication is that topography is the dominant factor affecting SLR in the study watershed (Fig. 8 and Fig. 14). The lowest average SLR was generated from SW_6 (0.66 t ha^{-1} year^{-1}).

The TWW were further categorized into three prioritization classes: high, medium, and low (Table 7). Figure 14 was

Table 7 Priority watersheds for SWC on the bases of the SLR

Sub-watersheds	Area (km^2)	Area (%)	Average SLR (t/ha/year)	Rank	Priority class
SW_1	96.26	14.14	19.11	2	High
SW_2	100.65	14.78	19.06	3	High
SW_3	75.18	11.04	19.86	1	High
SW_4	87.13	12.80	16.96	4	High
SW_5	199.03	29.23	10.41	5	Medium
SW_6	37.07	5.44	0.66	7	Low
SW_7	85.56	12.57	8.94	6	Medium

shown; SW_3, SW_1, SW_2, and SW_4 were categorized as a top priority (first priority) sub-watersheds in the TWW that need immediate SWC measures to reduce soil loss from the watershed. SW_6 at the downstream side was categorized as a low priority whereas SW_5 and SW_6 were classified as medium priority (second priority) watersheds. The sub-watershed with high priority subsidize more to SLR. Therefore, top priority (first priority) should be given to them during the planning and execution of SWC practices in TWW.

Conclusions

Planning and implementation of SWC measures are required to reverse the effect of soil loss and for sustainable agricultural production. Recognition of priority watersheds is very critical in identifying the sub-watersheds needing preferential SWC practices. This study quantitatively assessed and mapped SLR in TWW and identified the priority watersheds using USLE. The average SLR of the watershed (14.13 t ha^{-1} year^{-1}) is larger than the maximum SLT of the watershed and higher than the average SLR of the country. The implication is that there is a need to plan and execute proper SWC methods in the watershed so that to decline the extent of SLR from TWW watershed, below the minimum SLT value, and to protect the Lake Hawassa from sedimentation and pollution, and to increase the productivity of TWW. The result of the study found that the majority of the watershed (78.49% of the watershed) are classified under low (< 5 t ha^{-1} year^{-1}) SLR. A small portion of the watershed (9.22%) is suffering from severe and very severe SLR (> 25 t ha^{-1} year^{-1}). Managing this small portion of the watershed can significantly increase the productivity of the area. A large amount of SLR is originated from a small part of the watershed in the southeast, east, and northeast of the watershed. Severe and very severe SLR were detected in the steep slope portion of the TWW. The implication of this is the slope is the dominant factor affecting SLR in the study watershed. The findings of the study are comparable to those made by other studies at the same agro-climatic condition in Ethiopia at the watershed level. The generated SLR maps with respect to sub-watersheds are used to identify areas where corrective actions should be commenced. To prioritize the sub-watersheds, the TWW in Ethiopia was divided into seven sub-watersheds. SWC methods must be carried out, giving priority to four sub-watersheds (that is, SW_3, SW_1, SW_2, and SW_4), falling under the top priority zone in the watershed. The sub-watershed with high priority subsidize more to SLR. Therefore, top priority (first priority) should be given to them during the planning and execution of SWC practices in TWW. Lack of adequate and qualified data is a common problem in a developing country (Guiamel and Lee

2020). Due to the challenges of limited access to observed data in the study area, model validation based on comparing results from similar watershed was applied in this study. Therefore, these findings will be applicable only for prioritization of sub-watersheds for execution soil and water conservation activities in the study watershed.

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