Enset-Based land use land cover change detection and its impact on soil erosion in Meki river watershed, Western Lake Ziway Sub-Basin, Central Rift Valley of Ethiopia

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Research

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Abstract

Background

Water erosion, upland degradation and deforestation are key environmental problems in the Meki river watershed. The study assessed the land use land cover change (LULCC) for 30 years and it examined the contribution of indigenous Enset-Based land use system (EBLUS) to reduce soil erosion and prevent water bodies including Lake Ziway from sedimentation which was not considered in the former studies. GPS based data collected and satellite based LULC analysis using ERDAS Imagine 2014 performed to investigate existing farm management practices and land cover respectively. HEC-GEOHMS, Geo-statistical interpolation and RUSLE were applied to model watershed characteristics, spatial climate parameters and soil loss respectively.

Result

Meki river watershed (2110.4sq.km of area) is dominantly covered by cultivated LUS (41.5%), EBLUS (10.65%), Bush and Chat LUS (25.6%), Forest and plantations LUS (14.14%), built-up (7.4%) and water bodies (0.75%). Soil loss is increasing from 1987 to 2017 and a larger part of the watershed suffers a moderately severe to very severe risk (18 t $ha^{-1}yr^{-1}$ to >80 t $ha^{-1}yr^{-1}$) in all sub-watersheds irrespective of the land use systems which shows the watershed is facing sever degradation problem. The mean soil loss of 30.5 t $ha^{-1}yr^{-1}$ and 31.905 t $ha^{-1}yr^{-1}$ are verified from Enset growing zones and non-Enset growing zones of the watershed respectively.

Conclusion

EBLUS saves significant amount of soil despite the steepness of the slopes of the Enset growing zones of the watershed. Hence, expansion of EBLUS can contribute in sustaining water bodies, including Lake Ziway by reducing soil loss rate and sedimentation problem for the ecological sustainability of the watershed. Therefore, separate land use policy and awareness creation are mandatory for such EBLUS expansion, sustainable watershed management interventions and conservation of the natural environment in the watershed based on its suitability and severity of erosion risk mapping.

Key words: Enset, Soil-loss, geostatistics, RUSLE, Land use policy, Meki-river-watershed

1. Background

Enset is an indigenous and herbaceous monocot plant and widely grown as a food crop (Borrell JS *et al.*, 2020, Fetta, 2019; Westphal, 1975) and it is banana-like perennial plant that grows best at an altitude of 1600 to 3100 m.a.s.l., a temprature of 16° C to 20° C, a relative humidity of 60 to 80%, annual rainfall of 1100 mm to 1500 mm and its leaves reaches a height of 5 to 13 m (James S *et al.*, 2020; Uloro & Mengel, 2014). The enlarged pseudo-stem and underground corm (carbohydrates) of the plant is used for human consumption (Michael , 2002) and its products are used for everything from food wrapping to medicinal purposes throughout the southern highlands of Ethiopia including Meki river watershed (Uloro & Mengel, 2014).

The resistance to relatively prolonged soil moisture stress or drought, higher yield compared to other cultivated crops in the region and the minimum input required to produce it makes Enset attractive to farmers (Uloro & Mengel, 2014). According to Anita, *et al.*, (1996), the anti-famine, anti-drought, and food security enhancing nature of Enset-based farming systems which is constrained mainly by land degradation (Tilahun & Robert, 2006) and little attention has been paid by policymakers and researchers (Uloro & Mengel, 2014), points to the need for further consideration of Enset in terms of research, development and policy.

Most of the efforts of policymakers and researchers in Meki river watershed have been concentrated on cash crops or the more familiar grains than Enset and there is lack of appreciation of the number of people who depend on this root crop and the number of lives that have been saved during drought and the resulting famine (Uloro & Mengel, 2014).

Therefore, it is important to give emphasis to study the impact of change in Enset-Based land use systems (EBLUS) that may alter the hydrological processes (Elfert and Bormann, 2010) such as infiltration, groundwater recharge, base flow and runoff (Ermias Teferi *et al.*, 2013; Uhlenbrook, 2007; DeFries and Eshleman, 2004) by reducing the rain drop impact equivalent to the forest (Wolka *et al.*, 2015). It is also one of the most important factors influencing soil erosion and sediment yield (A. Kavian *et al.*, 2017) through its root fiber systems to facilitate infiltration and hold the soil in situ and reduce soil erosion severity.

This study is therefore initiated to detect Enset-Based land use land cover change and its impact on soil erosion, to articulate the sub-watershed based soil loss risk and to devise priority mapping for sustainable watershed management of Meki river watershed, Western Lake Ziway Sub-Basin, Central Rift Valley of Ethiopia.

2. Methods

2.1. Location and watershed descriptions

Meki river watershed is found in the western part of lake Ziway between 7^{0}45'N to 8^{0}30'N and 38^{0}10'E to 39^{0}00'E in the Central Rift Valley (CRV) of Ethiopia and based on digital elevation model (DEM) analysis, the Elevation in the watershed varies from 1612m.a.s.l (at the inlet to lake Ziway) to 3612m.a.s.l (at Zebidar Mountain). Oliver *et al.*, (2007) and Ethiopian meteorological agency data analysis shows the annual rainfall of 824mm to 1292 mm, the mean monthly minimum and maximum temperature are 15^{o}C and 29^{o}C respectively, the mean relative humidity of 60%, average wind speed of 1.66m/s and average sunshine of 7.3 hours.

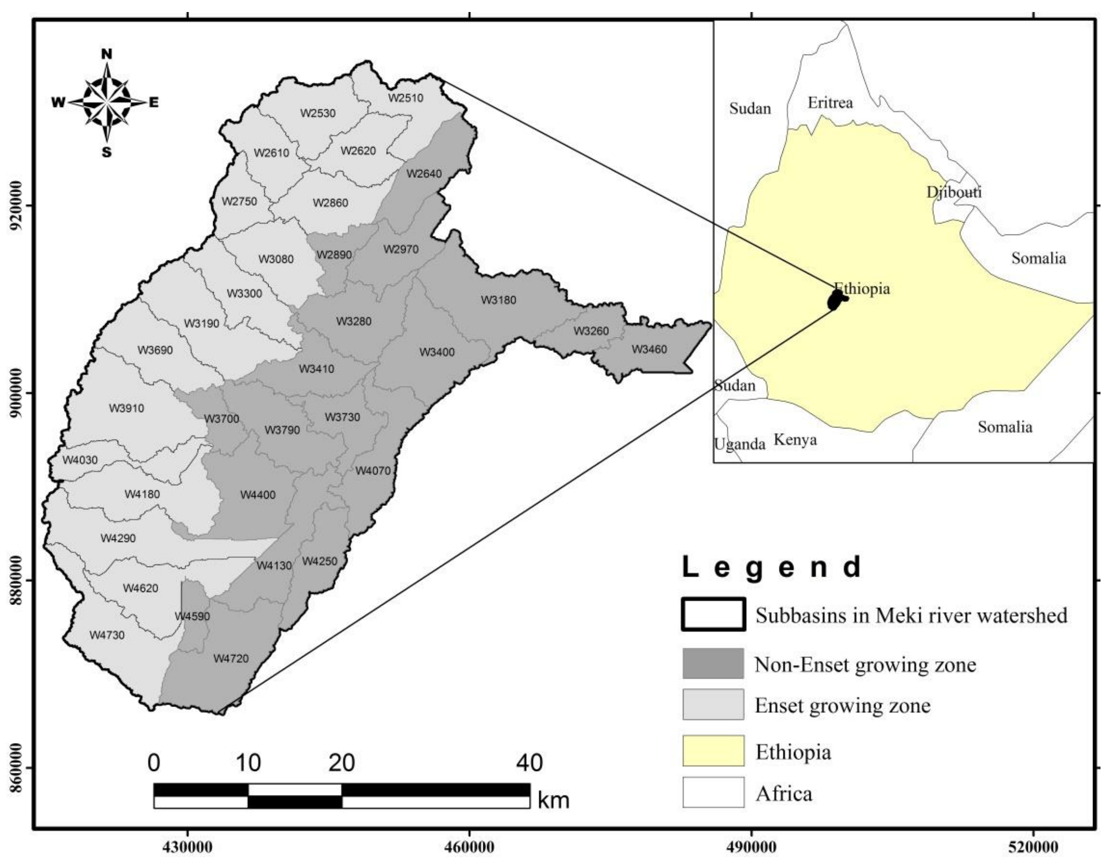

Figure 1: Study area map

2.2. Research Framework

Due to consideration of EBLUS in the land cover classification process, cover factor and management factor of Meki river watershed will vary and hence, there may be a change in the soil loss rate. Therefore, this study articulates the change in EBLUS in relation with soil loss risks in Meki river watershed which is presented in the Flow diagram of soil erosion modeling processes considering EBLUS in Figure 2.

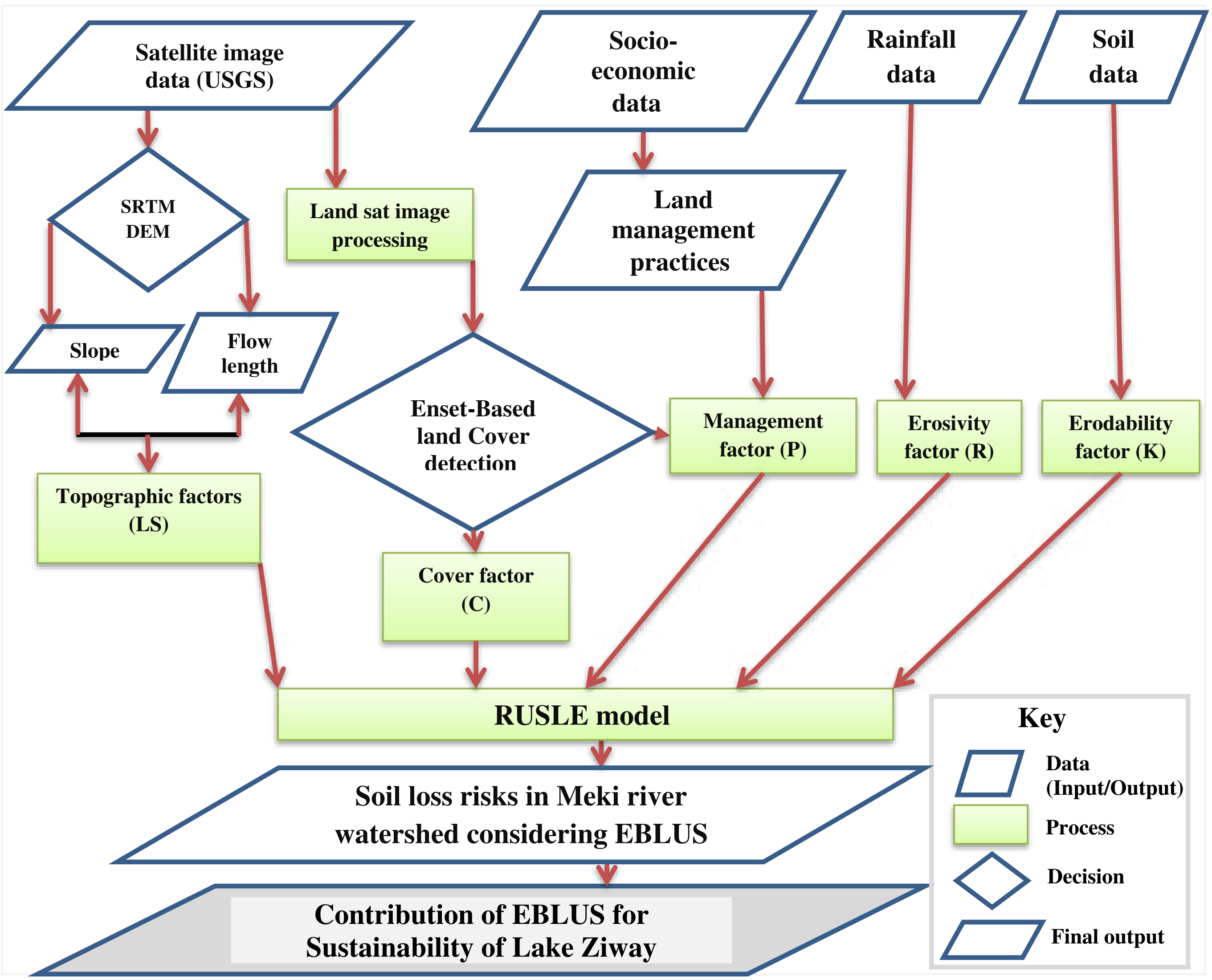

Figure 2: RUSLE model flow diagram

2.3. Digital Image processing & Land Cover Change detection

Enset-Based land use system (EBLUS) was not considered in all former land use studies in Meki river watershed and now in this portion more focus is deputed to Enset-Based land cover classification and change detection while giving consistent attention to all land cover system analysis in Meki river watershed by collecting images from different sources and following the technical procedures and scientific methods as follows.

Data collection and pre-processing

United States Geological Survey (USGS) landsat images are downloaded from USGS portal of earth explorer database as shown in Table 1. Image registration, extracting images, band correlation done for their band similarity using ArcGIS 10.1 software & tasseled cap analysis is done to improve the differentiability of features such as soil, green features, moisture availability of the land and canopy & so as to remove the noise. Different bands of the imageries with similar spatial resolution have been stacked, radio-metrically calibrated (Haze & Noise reduction), resolution merge have been done for different spatial resolution imageries such as merging 30m spatial resolution imageries with 15m spatial resolution imagery (PAN) to sharpen the area & topographically normalized with DEM of the area.

Mosaics have been performed for four different scenes to get full area of interest (AOI) and it is delineated using HEC-GEO-HMS software from DEM & the image subset is prepared for the imageries based on the AOI. All images and maps are geo-referenced or Projected to: Datum: UTM/WGS 84, 37 N. & classified with unsupervised classification methods for further field survey sampling and to assist the supervised classification.

Table 1: Satellite image data collected from different sources

Year	Sensor	No. of bands	Date of acquisition	Path/Row	Land sat Mission	Resolution (m)	Image Source
1987	TM	7	01-01-87	168/054-169/054 & 168/055-169/055	5	30	USGS
2017	ETM+	12	01-01-17	168/054-169/054 & 168/055-169/055	7	15m PAN / 30	USGS
SRTM DEM			10-01-17			30	USGS

Field work and Image classification processes

Evidence was collected from local elders and experts of Woreda Agriculture offices and NGOs in Meki river watershed through key informant interview with the idea extending to 30 years regarding the retrospective and prospective cover and erosion conditions of the watershed.

The ground truth data collected in the field using geographical positioning system (GPS) at an accuracy of 2m with its corresponding photographs at the point of data gathering and descriptions of the data was prepared based on vegetation zone of the area. Accordingly, three vegetation zones were obtained as upper zone (Afro-alpine vegetation zone), middle zone (Afro-montane vegetation zone) and lower zone (Acacia wooded vegetation zone).

Based on the field observation, the upper zone of Meki river watershed composed of Erica dominated natural forest lands; patches of grazing lands; eucalyptus plantations and EBLUS with highly sensitive ecological setups as shown in Figure 3. The high slope with sparse population is found but encroachment of the existing dense natural vegetation by cultivation including at a slope of greater than 50% is manifested as a prominent problem of the upper zone which poses a degradation threat for the watershed and for the water bodies found in the downstream.

Figure 3: Land cover in the resourceful upper zone of Meki river watershed

The middle zone (Afro-montane vegetation zone) of Meki river watershed is dominated by EBLUS with dense natural and eucalyptus tree cover. The eucalyptus tree cover is well mixed with the cultivated land with agro-forestry trees and at the same time there are small patches of grazing land as shown in Figure 4.

Irrigation practice is not common in the middle zone at which the rain-fed agricultural practice is the dominating one with most of degraded areas are detected in the middle zone of the watershed because of the population pressure and high numbers of cattle per head based on the observation during transact walking and interviews.

Figure 4: Land cover in the middle zone of Meki river watershed

The lower zone (Acacia wooded vegetation zone) of Meki river watershed is dominantly covered by cultivated land with acacia dominated bushes as shown in Figure 5 with expansion of irrigation practices which are under the threat of sodicity development due to a long term accumulation of salts from irrigation water.

Figure 5: Land cover in the lower zone of Meki river watershed

Ground truth information was collected using the primary unsupervised classification image, land form types, and visual interpretation of multi-temporal imagery of Google earth images.

Field surveying was carried out as a transect walk and data was collected to train the algorithm or the interpreter and data collected to evaluate the land cover map and the algorism was trained to the land cover for supervised classification based on the ground control points (GCP) taken by GPS on the upper zone, middle zone and lower zone of the watershed.

The classification of the satellite images was performed using ERDAS Imagine 2014 after a careful signature creation from the collected sets of points of the land covers and the per-pixel classifier was trained on a representative sample of each of the land cover classes by using a supervised maximum likelihood classification (MLH) algorithm with equal prior probabilities for each class.

According to Ermias *et al* (2013), image differencing appeared to perform generally better than other methods of change detection. It involved subtracting one date of imagery from a second date that was precisely registered to the first with ENVI 4.3 software and also ArcGIS extension of image differencing.

The change in land cover is discussed in the result part of the paper which shows a significant increase in cultivated land cover and a significant decrease in forest cover while a considerable increase in enset land cover proportional to the population number.

2.4. Soil erosion modeling

Soil erosion by water is the most pressing environmental problem in the Highlands of Ethiopia, where the topography is highly rugged, population pressure is high, steep lands are cultivated and rainfall is erosive (Ermias Teferi et al., 2013; Bewket and Teferi, 2009). Similarly Meki river watershed shows considerable erosion sign posts evident from the numerous gullies in cultivated and grazing lands.

Land use change effects on soil loss risks were estimated using revised universal soil loss equation (RUSLE) and GIS models. Yueqing et al. (2011), Shi et al. (2004), Ouyang and Bartholic (2001) and Mallick et al. (2014) investigated soil erosion risk using RUSLE and GIS and displayed the results as erosion risk maps and they confirmed that the model is practical for soil conservation plans and natural resources management.

GIS and RS based RUSLE is one of the widely used mathematical models developed for estimating soil erosion and used in different studies (N.Kayet, 2018; A.Kavian *et al*. 2016; Shi *et al*. 2004; Angima *et al*. 2003; Merrit *et al.,* 2003; Liu *et al*. 2000; Andrew *et al*. 1999).

The soil loss of Meki river watershed to compute the relative influence of EBLUS on sediment load for the sustainability of lake Ziway is done using ArcGIS based RUSLE model (N.Kayet, 2018; Jetten et al., 1988; Bork and Hensel, 1988; Saha, 1996 and Gupta, 2001) and pair wise comparison is done for Enset growing zones and Non-Enset growing zones of the watershed to evaluate the contribution of EBLUS to soil erosion for sustainability of downstream water bodies including lake Ziway.

Therefore, the average annual soil loss can be estimated from equation 1 based on Asnake & Amare (2019); Mengesha et al. (2018); N.Kayet (2018); Renard *et al.*, (1997); Yoder and Lown, (1995); Renard and Freimund (1994); Wischmeier and Smith, (1978):

$$A = RKLSCP \qquad \text{Equation 1}$$

Where A is the amount of soil erosion (t $ha^{-1}yr^{-1}$) that is eroded within unit area during the corresponding period of rainfall-runoff; R is a rainfall-runoff erosivity factor; K is a soil erodibility factor; LS is a surface characteristic factor (slope-length and steepness factors; C is a cover management factor; P is support practice factor.

Determination of Rainfall- runoff erosivity factor (R)

Rainfall data have been collected from Ethiopian National Meteorological Agency (ENMA) for Meki watershed for the last 30 years and rainfall records of 10 surrounding representative stations have been analyzed in excel and converted to shape file in Arc Catalogue to determine R factor.

The rainfall erosivity (R) factor expresses the energy of rainfall to erode the soil which is the influenced by the intensity and amount of rainfall. The value of R is interpolated using excel based on the values Modified in (Mekuria Argaw, 2005; Hurni, 1993) for Ethiopian condition which was developed by Hurni (1985) and adopted by different researchers (Mengesha et al., 2018; Asnake & Amare, 2019; Bewket and Teferi, 2009) and presented as shown in Table 2 and the average R values derived between 478.3 and 700 for Meki river watershed as shown in Table 2 and interpolated in Figure 6.

$$\mathbf{R = 0.562P - 8.12} \qquad \text{Equation 2}$$

Table 2: Rainfall Erosivity interpolation

Station	Annual Average rainfall (mm)	Erosivity (R) (Mekuria, 2005; Hurni, 1985)	R = (0.562P-8.12)	Average R ($MJmmha^{-1}h^{-1}year^{-1}$)
Agena	1438.82	799.334	801.94	800.63
Bui	1042.69	576.908	578.91	577.91
Butajra Police Station	1119.58	619.963	622.2	621.08
Hasen Usuman	1048.98	580.428	582.46	581.44
Imdibir	1229.16	681.401	683.9	682.65
Koshe	826.087	455.609	456.97	456.29
Lemen	917.872	507.008	508.64	507.82
Meki	767.77	422.951	424.13	423.54
Werabe	1527.01	848.944	851.59	850.27
Ziway	759.005	418.043	419.2	418.62
Average	1067.7	591.059	593	592.03

Based on Webster & Oliver (2007) & Bewket and Teferi (2009), the Geo-statistical extension of ArcGIS 10.1 is used to interpolate the spatial value of R with the geo-statistical method of kriging/cokriging and the kriging type is simple normal score with the prediction output surface types because it is easy to generate relatively accurate rainfall erosivity information from known sample points to the points of unknown values at a closer distance than those located far.

Transformation of annual average R is performed at a five number of bins and one number of kernels (μ=591.059, σ= 142.4 and π=1). It is a general optimize model at a false examine bivariate distribution of the covariance variable with a model nugget of 0.5 true enabled at a measurement error of 100.

The model number is one with stable type at a parameter of 1.83 and major range of 0.735 with a false anisotropy. Partial sill is calculated as a true with a partial sill of 0.5 at a lag size of 0.103 and number of lags 12.

The standard neighborhood type at a maximum neighbors of five and at a minimum neighbors of two with four sectors of 45° offset and true variogram at zero angle with major semi-axis of 0.735, minor semi-axis of 0.735, anisotropy factor of 1, predicted Value (x=38.3765 & y=8.17) of 606.2 and weights (10 neighbors) (Webster & Oliver, 2007).

The export result table shows that regression function is given as 0.286X + 406.65, mean of -4, root-mean-square of 103.55, mean standardized at -0.0262, root-mean-square standardized at 0.811, average standard error of 126.56. The value of R is reclassified to suitably compute the average annual soil loss (A) and the R value ranged from 478.3 to 700 MJ mm ha^{-1} h^{-1} $year^{-1}$ for Meki river watershed and mapped as shown in Figure 6. A similar approach was adopted to compute the R factor in Ethiopia (Bewket and Teferi, 2009; Abate, 2011; Mengesha et al., 2018; Asnake & Amare, 2019).

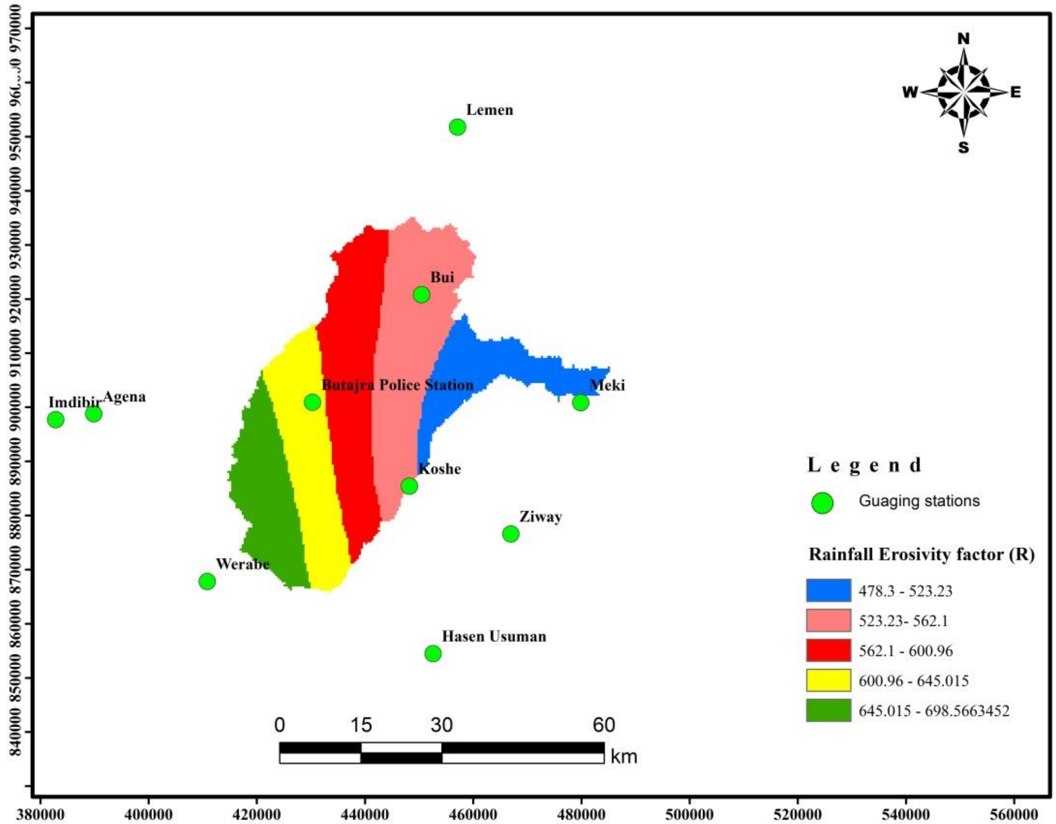

Figure 6: Rainfall Erosivity factor (R) map of the watershed

Determination of soil erodibility factor (K)

Erodibility factor (K) is a measure of soil susceptibility to detachment as well as transport, and ranges from 0.05 for low erodibility to 0.4 for high erodibility. Clays have low K values because they are not as easily detached, sandy soils also have low K values because they are difficult to transport via runoff. Silt loam soils have medium K values and soils high in silt have high K values.

The Soil property (soil texture, soil structure, organic matter, water content and density chemical and biophysical characteristics of the soil) affects infiltration capacity and the extent to which the soil particles can be detached and transported (El-Swaify and Dangler, 1976).

Hurni (1985) has developed the factor table from the USLE monograph (A. Kavian *et al.*, 2017; Yang *et al.*, 2005; Wischmeier & Smith, 1978) & adopted by Bewket and Teferi (2009); Mekuria (2005) relating the color of soil used to assign K value of the soil for Ethiopian condition. The color of the soil is determined through an intensive literature review of the relationship of soil type to its color supported by a field observation. Harmonized World Soil Database (HWSD) is used to determine the soil type and soil color is assessed and K value is assigned for each soil type as shown in Table 3 as black, brown, red and yellow, and their corresponding K factor values are 0.15, 0.2, 0.25 and 0.3 respectively.

A similar method of determining K factor values from colour of soils has also been suggested by the Soil Conservation Research Project (SCRP, 1996) and adopted by Bewket and Teferi, 2009; Mekuria, 2005. According to Asnake and Amare (2019), due to scantiness of data, only soil colors and stone covers were selected to determine K factor. Those different color polygons are reclassified to assign K values and finally K map is prepared.

Table 3: Erodibility (K) value of soils of Meki watershed

<table>
<tr><th>Soil type</th><th>Soil Code</th><th>Color of soils</th><th>K</th><th>Adopted by researchers</th></tr>
<tr><td>Vertisol</td><td>16851</td><td>Black</td><td>0.15</td><td rowspan="5">Asnake and Amare, 2019;Bewket and Teferi, 2009; Mekuria, 2005; Hurni, 1985</td></tr>
<tr><td>Luvisol</td><td>16739</td><td>Brown</td><td>0.2</td></tr>
<tr><td>Cambisol</td><td>16932</td><td>Red</td><td>0.25</td></tr>
<tr><td>Leptosol</td><td>16808</td><td>Yellow</td><td>0.3</td></tr>
<tr><td>Fluvisol</td><td>16903</td><td>Brown</td><td>0.2</td></tr>
<tr><td>Water</td><td>16994</td><td></td><td>0.4</td><td>Hurni, 1985</td></tr>
</table>

The K factor is rasterized after assignment of those values to each soil types based on their inherent characteristics and reclassified as shown in Figure 7.

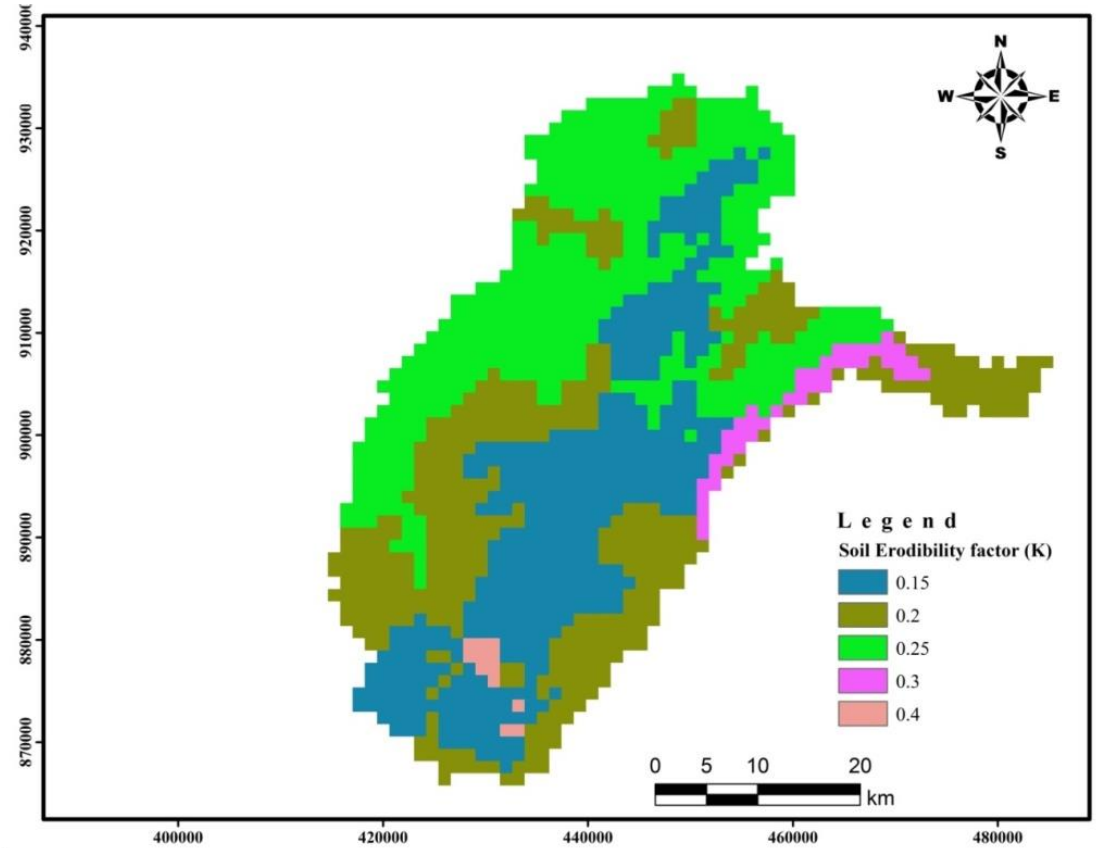

Figure 7: Soil erodibility (K) value map of Meki watershed

Determination of topographic factor (LS)

The LS factor expresses the effect of topography (hill slope length and steepness) on soil erosion. The increase in L and S results in an increase in the LS factor and soil erosion (Asnake and Amare, 2019; A.Kavian *et al*. 2017) for which various approaches have been used to estimate the LS factor. DEM (30 m resolution) with ArcGIS techniques devised to obtain slope gradient (S) and slope length (L) (Wolka et al., 2015; Bewket and Teferi, 2009; Nekhay et al., 2009).

Several researchers followed different methods of computing LS factor using Arc-GIS as shown in Table 4.

Table 4: Table of topographic factors formula for different studies

Equation	**Description**	**Source**	**Av. LS**	**Area**
$\mathbf{LS = 1.4[\frac{As}{22.13}]^{0.4} * \left(\frac{sin(\beta)}{0.0896}\right)^{1.3}}$	As = the specific area defined as the upslope contributing area for overland grid per unit width normal to flow direction, and β is the slope gradient in degrees	A.Kavian et al., 2017	2.83	Iran
$\mathbf{LS = [\frac{\beta\chi}{22.13}]^{0.5} * (\frac{sin(0.01745s)}{0.0896})^{1.3}}$	β is flow accumulation, χ is grid cell size (30m), 22.13 is the RUSLE standard plot length; 0.5 is the exponent of slope length; s is Slope of DEM in degrees	Asnake and Amare, 2019; Fenta et al., 2016	7.3	Blue Nile Basin
$\mathbf{LS = [\frac{fac*DEM\ resolution}{22.13}]^{0.4} * (\frac{sin(s)}{0.0896})^{1.3}}$	fac is flow accumulation, s is slope in degree	Habtamu et al, 2020	33	West Shoa Ethiopia
$\mathbf{LS = \left(\frac{\lambda^{0.3}}{22.1}\right) * (\frac{S}{9})^{1.3}}$	λ is Flow length and S is Slope in percent	Wolka et al., 2015	3.5	CRV of Ethiopia
$\mathbf{LS = \left(\frac{\lambda}{22.1}\right)^{m} * (0.065 + 0.045x + 0.0065(x)^2}$	λ is flow length, m is an exponent that depends on slope steepness	Bewket and Teferi, 2009	2	Blue Nile Basin

From those equations listed in the table, the following equation was selected as it has been widely used and tested in several studies in Ethiopia context and specifically applied in central rift valley of Ethiopia and the flow chart for LS value determination is shown in Figure 8.

$$\mathbf{LS = \left(\frac{\lambda^{0.3}}{22.1}\right) * (\frac{S}{9})^{1.3}} \qquad \text{Equation 3}$$

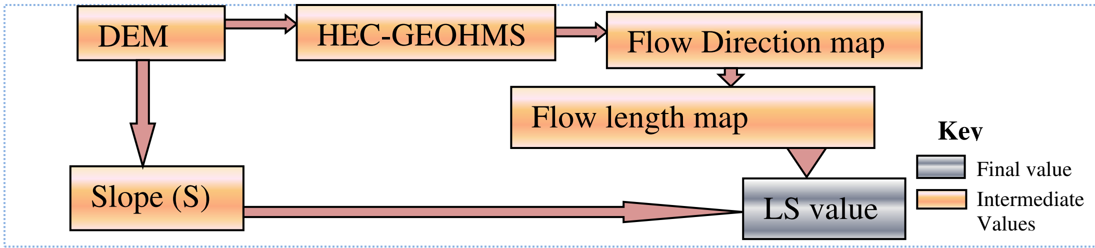

Figure 8: Flow chart for LS value determination

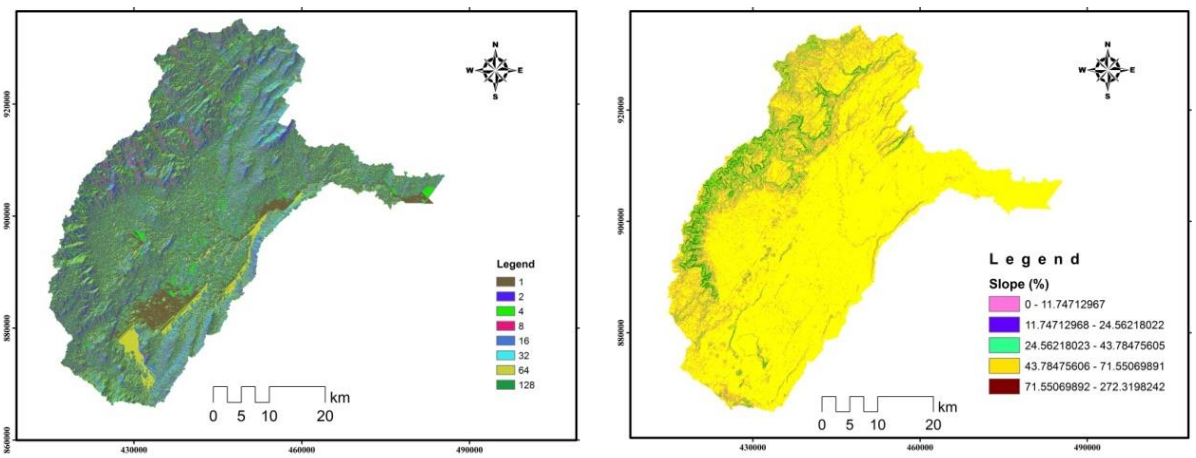

Figure 9: Flow length & Slope map of Meki watershed

Based on the model for LS determination, the flow direction map and slope map are converted to LS value using raster calculator and mapped as shown in Figure 10.

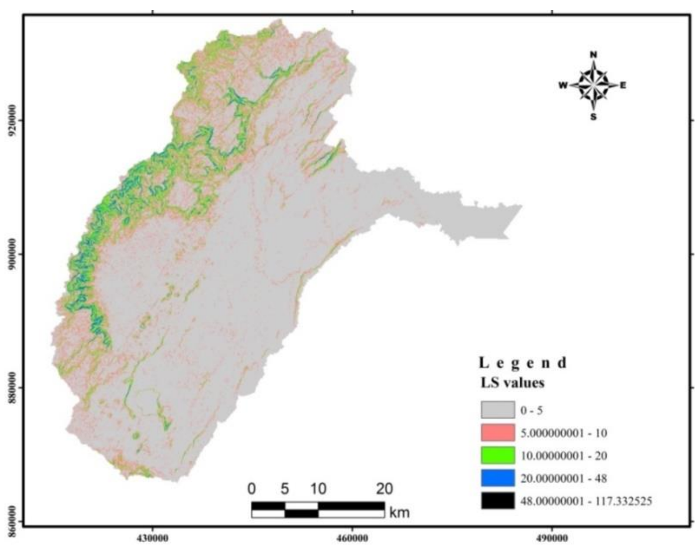

Figure 10: Topographic (LS) map of Meki watershed

Determination of land cover factor (C)

The cover-management factor (C) and support practice (P) are dynamic factors through time (A.Kavian et al., 2017) and C factor expresses the effect of plants and soil cover to reduce the runoff velocity and to protect surface pores and that is most readily changed by human activities.

C factor is assigned to the classified satellite images supported by interviews of local farmers for land use land cover condition of the area. C-value was assigned to each land use classes using reclassify method in Arc GIS 10.1 as reviewed in literatures as shown in Table 5. Concerning the cultivated unit of the map, the C-value varies annually. Wheat, Enset, maize and teff are the dominant crops and also it is surrounded by woody agro forestry trees.

Table 5: Land cover factor assigned

Land cover	C value	Source
Cultivated & Degraded	0.15	Asnake and Amare (2019); Bewket and Teferi, (2009); Mekuria Argaw (2005); Hurni, (1985b);
Forest & other natural vegetation	0.001	Asnake and Amare (2019); Bewket and Teferi, (2009); Mekuria Argaw (2005); Hurni, (1985b);
Enset	0.02	Asnake and Amare (2019); Bewket and Teferi, (2009); Mekuria Argaw (2005); Hurni, (1985b);
Grass	0.05	Asnake and Amare (2019); Bewket and Teferi, (2009); Mekuria Argaw (2005); Hurni, (1985b);
Eucalyptus	0.05	Asnake and Amare (2019); Bewket and Teferi, (2009); Mekuria Argaw (2005); Hurni, (1985b);
Bush & chat	0.1	Tamene et al. (2014); Haregeweyn et al. (2013); Bewket and Teferi, (2009); Mekuria Argaw (2005); Hurni, (1985b);
Built up	0.6	Asnake and Amare (2019); Bewket and Teferi, (2009); Mekuria Argaw (2005); Hurni, (1985b);

Hence, the land cover factor map of the watershed was prepared for the 1987 & 2017 land sat image classified land covers and mapped as shown in Figure 11.

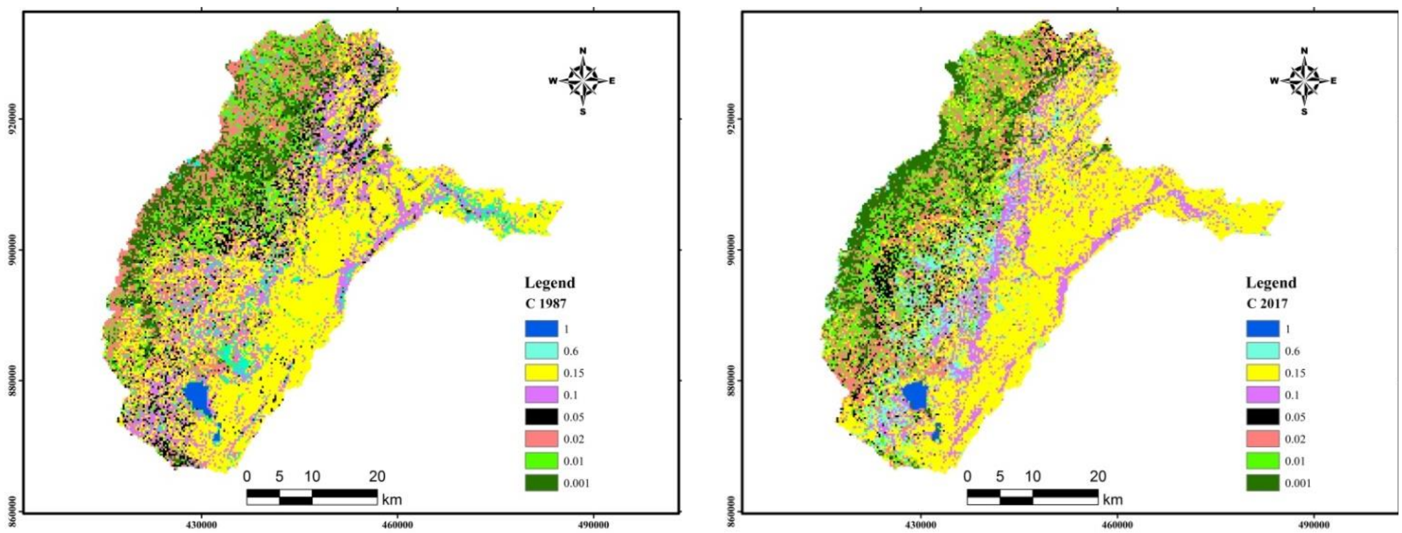

Figure 11: Land cover factor map of Meki watershed in 1987 & 2017

Determination of land management factor (P)

The P factor expresses the effects of supporting conservation practices, such as contouring, buffer strips of close-growing vegetation and terracing at a particular site. A good conservation practice will result in reduced runoff volume, velocity and less soil erosion.

The present management practices have been collected through observation of the site and secondary information collected from different governmental and non-governmental organizations working on conservation practices in the watershed and also an interview of local farmers who lived at least for the last 30 years for its change on management practices done using structured questionnaire with GPS based site specific checkup of the reported cases of conservation structures.

The key informant interview, field observation and secondary information collected from different governmental and non-governmental organizations shows that almost all land covers are without conservation measures although some watershed management trials by the government. Therefore, a unity was assigned to all land covers as a management factor except for forest and enset land covers for which 0.5 & 0.6 is assigned respectively because enset is planted in rows serving as a contour with mulching practices and mapped as shown in Figure 12.

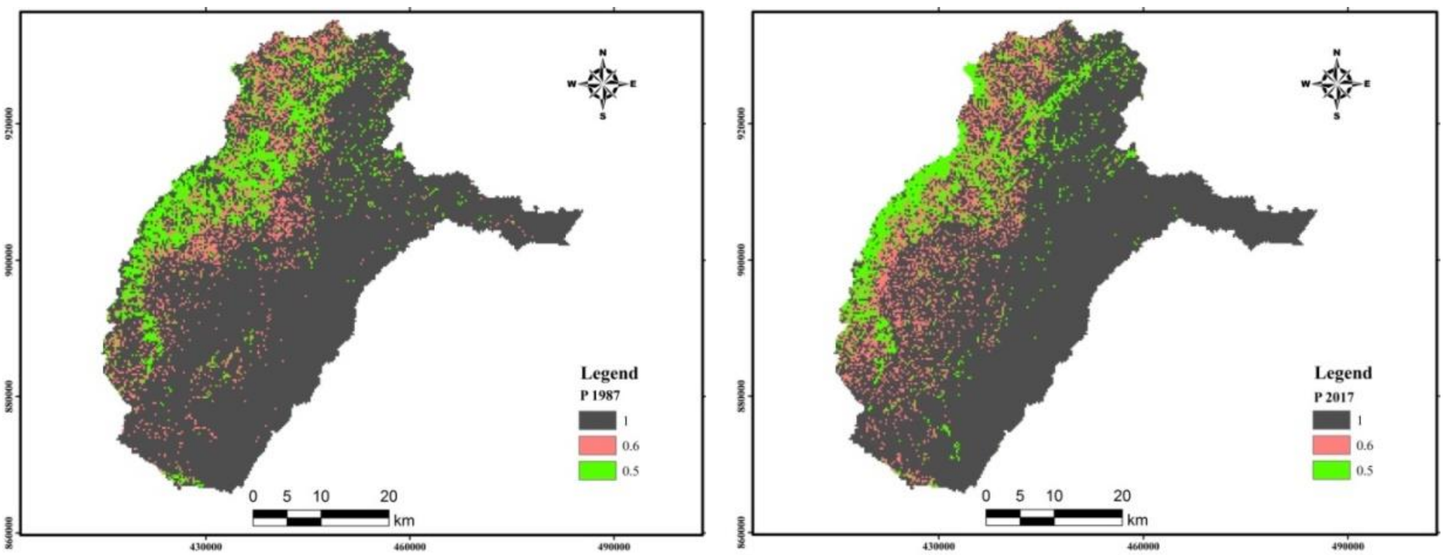

Figure 12: Management factor map of Meki watershed in 1987 & 2017

Determination of mean annual soil loss

All the factors of the RUSLE model were transformed into raster format and same coordinate system (UTM WGS 1984 37^0 North) with a pixel size of 30×30m. Then, all layers were multiplied together using raster calculator in Spatial Analyst tool in ArcGIS 10.1. The mean annual soil loss was therefore determined for each pixel for 1987 and 2017 and the soil loss of Meki river watershed was calculated from all the inputs and the difference in soil loss for the 1987 and 2017 was computed.

The result was extracted and reported for the classified land use land covers of Meki river watershed and also it was extracted to 34 sub-watersheds and two major growing zones (Enset growing and non-Enset growing zones) of Meki river watershed as shown in Figure 13.

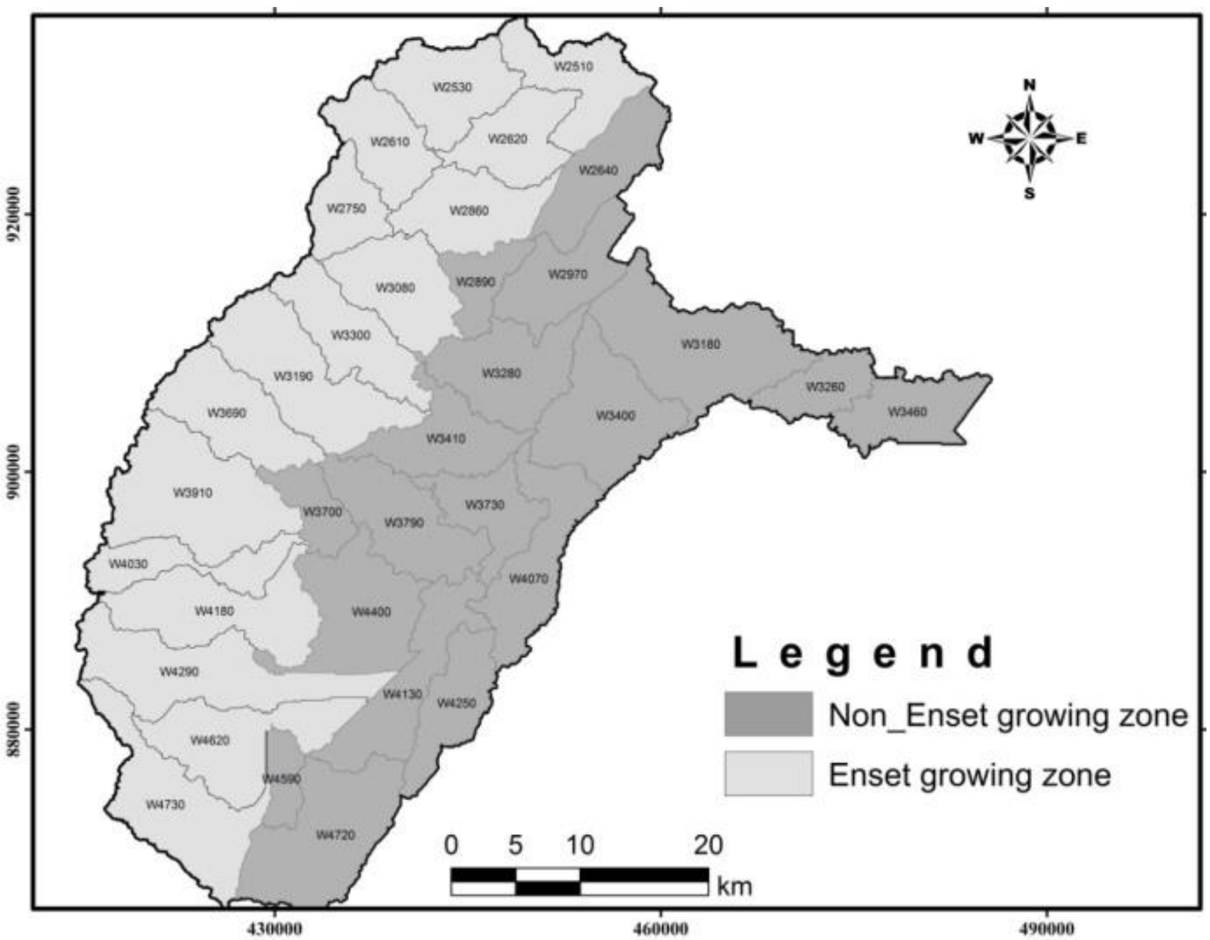

Figure 13: Sub-watersheds and major zones in Meki river watershed

The enset growing zone is known for its medium altitude but the non-enset growing zone of Meki river watershed is known for its lower altitudes although enset plant has the capacity to resist droughts.

3. Result and Discussion

3.1. Land use Land Cover Change detection

Enset-Based land use system (EBLUS) was not considered as a separate land use system in former researches that classified land use systems in Meki river watershed as cultivated land, afro-alpine and sub afro-alpine, forest, woodland, riparian vegetation, shrub land, grassland, swamp and marshland, exposed surface & water bodies as a land cover (MoWR, 2008). Therefore, land cover classification devised for 2017 satellite image to treat EBLUS as a separate unit which results in eight categories as: EBLUS, built-up, water bodies, bush and chat land, cultivated land, grass land, eucalyptus plantations and forest and natural vegetation.

The land cover change detection performed among 1987 and 2017 satellite images to fit with modeling objective of the study and consequently, more than 40% of the watershed is covered by cultivated land that increased in area coverage which may have a significant implication to hydrology (Ermias Teferi et al, 2013; DeFries and Eshleman, 2004; Uhlenbrook, 2007), ecology (A. Kavian, 2017) and sustainability of water resources (Wolka et al., 2015) in the watershed.

Evidence from elders and experts interviewed, data from Woreda Agriculture offices and NGOs in the watershed shows the EBLUS, cultivated land and built-up area coverage is increasing over the last 30 years while the forest cover and grass land coverage are decreasing which was evidenced by a significant positive change in cultivated land (Wolka et al., 2015), EBLUS and built up land use systems 1987 to 2017. Grass land, eucalyptus plantation, forest and natural vegetation, bush and chat land and water bodies decrease in their area coverage over the last 30 years in their order of decreasing change as shown in Table 6.

Table 6: Percent of Land use land cover and changes

Class name	Area (ha) in 1987	Area (ha) in 2017	Difference	Percent of LU in 2017
Built-up	9865.01	15911.22	6046.21	7.85
Grass land	29716.45	25533	-4183.44	11.9
Forest and Natural vegetation	21768.76	20967.58	-801.18	10.07
EBLUS	20534.87	22733.9	2199.03	10.8
Eucalyptus plantation	12499.19	9111.22	-3387.98	4.2
Cultivated land	85816.29	86677.53	861.25	40.16
Bush and Chat land	29455.42	28896.83	-558.59	14.46
Water bodies	1383.07	1207.76	-175.31	0.58

Mesfin et al., (2017) and Deng et al., (2016) articulates that soil carbon stocks considerably decreased after the conversion from grassland and forest to farmland. Similarly, Charles et al., (2016) and Bewket and Teferi (2009) expresses that expansions of subsistence crop production into ecologically marginal areas and deforestation have been the common forms of transitions.

In 1930s more than 20% of Gurage Mountain landscape were covered with natural forests and primarily oriented to subsistence agriculture (Woldetsadik, 2004) and since then the forests have been decreasing and the removal has been particularly rapid from 1991 to 1992 because of the political system change in the country (Bekalu and Feleke, 1996). Hence, Meki river watershed is practicing a significant land use system change from forest and grass land use systems to EBLUS, cultivated land use system and built-up.

3.2. Soil erosion modeling result and discussion

Land use land cover based soil loss for the last 30 years

SCRP (1996) and Hurni (1989) underlines that rapid population increase, deforestation, over cultivation, expansion of cultivated land at the expense of lands under communal use rights (grazing and forests), cultivation of marginal and steep lands, overgrazing, and other social, economic and political factors have been believed to be the driving force to soil degradation and also Bewket and Teferi (2009) expresses that the conversions of marginal areas and forests to cultivated land have apparently contributed to the existing high rate of soil erosion and land degradation in the highlands of Ethiopia, which is evident from the numerous gullies in cultivated and grazing lands.

Similarly, the result of this research found that the upper catchments of the watershed are facing sever degradation irrespective of the land use systems which is evidenced by the high increase in soil loss in the forest land cover from 14.5 t $ha^{-1}yr^{-1}$ to 25.94 t $ha^{-1}yr^{-1}$, in EBLUS from 17 t $ha^{-1}yr^{-1}$ to 22.65 t $ha^{-1}yr^{-1}$, in cultivated land from 26 t $ha^{-1}yr^{-1}$ to 27.15 t $ha^{-1}yr^{-1}$, in grass land use system from 25 to 27 t $ha^{-1}yr^{-1}$, in eucalyptus plantation from 28.5 t $ha^{-1}yr^{-1}$ to 31.17 t $ha^{-1}yr^{-1}$ and in bush & chat land from 32 t $ha^{-1}yr^{-1}$ to 40.5 t $ha^{-1}yr^{-1}$ but there is a decrease in soil loss in built-up from 69.2 t $ha^{-1}yr^{-1}$ to 64.4 t $ha^{-1}yr^{-1}$ in 1987 and 2017 respectively as shown in Table 7.

Based on regression analysis, the annual average soil loss of the watershed increased from 25 t $ha^{-1}yr^{-1}$ (SD = 71.22) to 30.1 (SD = 89.3) for 1987 and 2017 respectively. Meshesha *et al.* (2012) also reported annual soil loss of 31 t $ha^{-1}yr^{-1}$ in 1973 and 56 t ha^{-1} in 2006 in the Central Rift Valley of Ethiopia which is attributed to conversion of forests or woodlands to croplands.

Table 7: The soil loss change in land covers (1987 to 2017)

Class_Name	Soil Loss 1987 (t ha-1yr-1)		Soil Loss 2017 (t ha-1yr-1)	
	Mean	**SD**	**Mean**	**SD**
Grassland	25	83	27	90
Forest and Natural vegetation	14.5	57	25.94	124.2
Eucalyptus plantation	28.5	72	31.17	88
EBLUS	17	61	22.65	68
Cultivated land	26	44	27.15	44
Bush and Chat land	32	70	40.22	78.3
Built-up	69.2	175.25	64.4	120.65

In both years the annual average values are beyond the permissible limit of soil loss for Ethiopian highlands reported by Wolka et al. (2015) as the 'tolerable' range of soil loss for the central rift valley as less than 10 t ha^{-1}yr^{-1} and Hurni (1993) expresses the range as 6 t ha^{-1}yr^{-1} to 10 t ha^{-1}yr^{-1}.

The rate found in this study is more than the tolerable limit mentioned in both cases but the lowest level of loss is recorded in the EBLUS in 2017 analysis as shown in Figure 15 which is visualized from the shift of high soil loss distribution from enset growing zone to the non-enset growing one. The dominant factor for the retarded soil loss in the EBLUS is the protective nature of the land use system through long leaves with good leaf area index (LAI) to dissipate the energy of rain drop although the slope gradient is high in the enset growing portion of the watershed and according to Wolka et al., (2015), the perennial crop such as 'Enset' based agroforestry contribute to arrest soil movement in these areas.

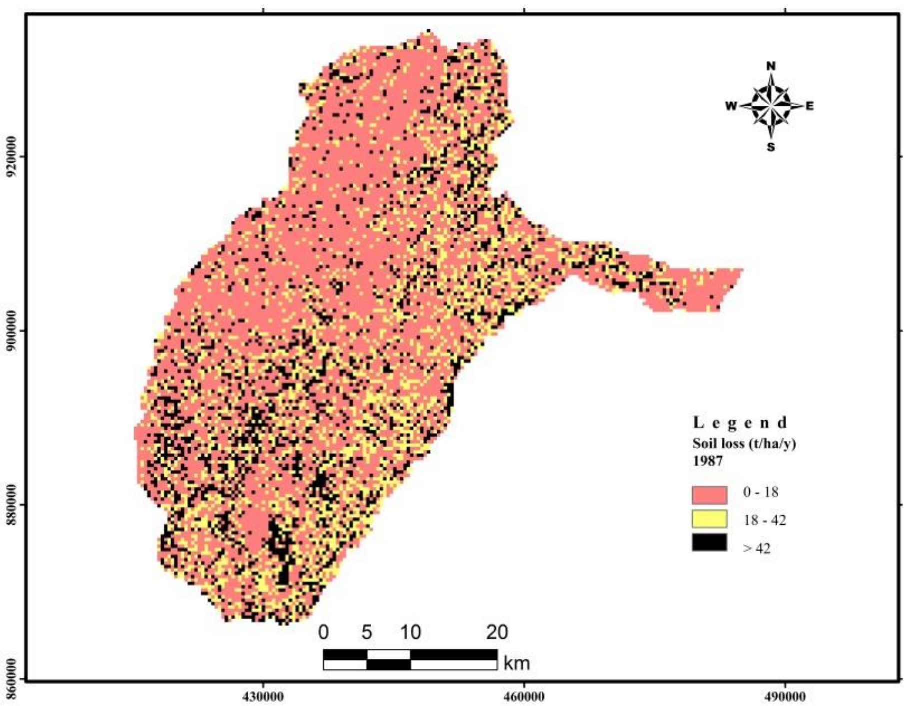

Figure 14: Soil loss (ton $ha^{-1}year^{-1}$) in 1987

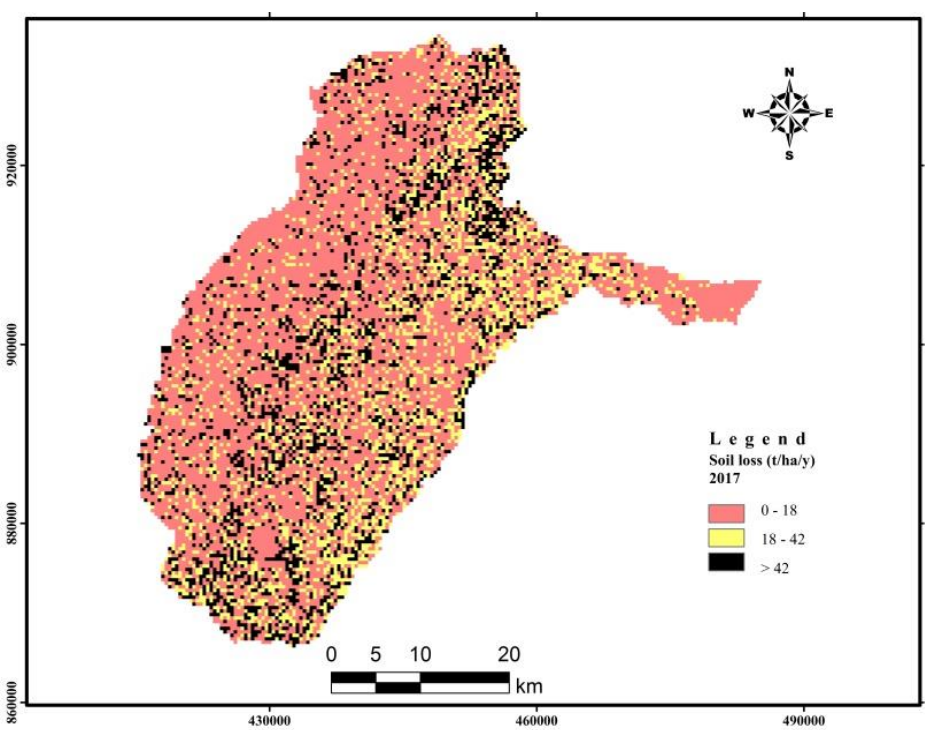

Figure 15: Soil loss (ton $ha^{-1}year^{-1}$) in 2017

A pairwise comparison of soil loss from each land use system indicates that on average EBLUS can save 11.426 t $ha^{-1}yr^{-1}$ relative to other land use systems which is a significant amount of sediment that can be kept in-situ if EBLUS expansion is enhanced in the watershed. If the whole watershed is covered by EBLUS (scenario 1), a significant amount of soil (2,411,332.3 t yr^{-1}) will be saved from marching downstream to lake Ziway from 2110.4 sq.km of area of land which is under threat of siltation so that EBLUS will contribute for sustainability of the lake.

The highest soil loss was verified in the built-up areas in 1987 than the recent years because of the new construction activities and extraction of materials were ongoing without giving due attention to the environmental components and current awareness is growing concerning the environmental problems of construction activities. Although the soil loss is low relative to the former years, the soil loss in 2017 shows higher in built-up areas than other land use systems which are attributed to construction activities in the newly established urban settings.

Bush lands are also one of the leading soil loss zones due to overgrazing and annual mass burning activities of those bushes on the upper zone of the watershed. Based on the farmer's response, they are burning the bushes and forests to get fire wood easily and to avoid wild animal attack on their crop, cattle and themselves.

Observation during field visit (transect walk) and information from elders of upper zone of the watershed, eucalyptus on steep slope can aggravate the movement of soil downward due to absence of root fiber to hold the soil in-situ which is manifested by high value of soil loss in eucalyptus land use system followed by cultivated land use system which are temporarily covered by annual crops during high rainfall season while it has high record at the onset of rainfall which brings its soil loss higher than soil loss from forest and EBLUS.

Alemu et al. (2018), found bathymetric differencing of lake Ziway as 3.13 t ha-1yr-1 sediment was accumulating that is attributed to the existence of outlet to Bulbula river, floodplain depositions and sand mining from the tributary rivers especially Meki river before entering to the lake. The other reason may be attributed to EBLUS which was not considered in former studies that generated the lowest soil loss in 2017 as shown in Figure 16.

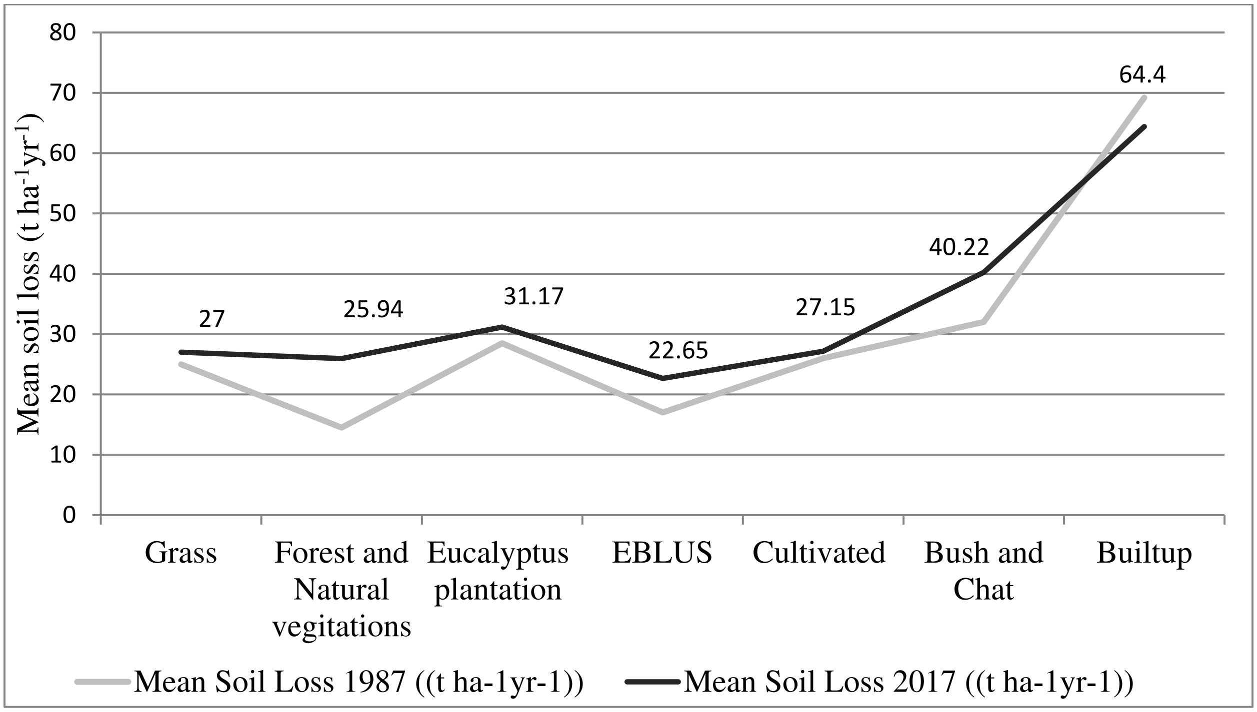

Figure 16: Soil loss curve in 1987 and 2017 for different land use systems

Sub-watershed based soil loss

Soil loss is evaluated for 34 sub-watersheds over the last 30 years (1987 and 2017) against the national standard range of 2 to 18 t ha^{-1}yr^{-1} (Hurni, 1985) and currently only six sub-watersheds (W3080, W3260, W3300, W3460, W3690 and W3730) out of 34 sub-watersheds (17.65%) are nearest or below the standard line which shows almost majority of the area in the watershed are suffering from soil loss risk as shown in Figure 17.

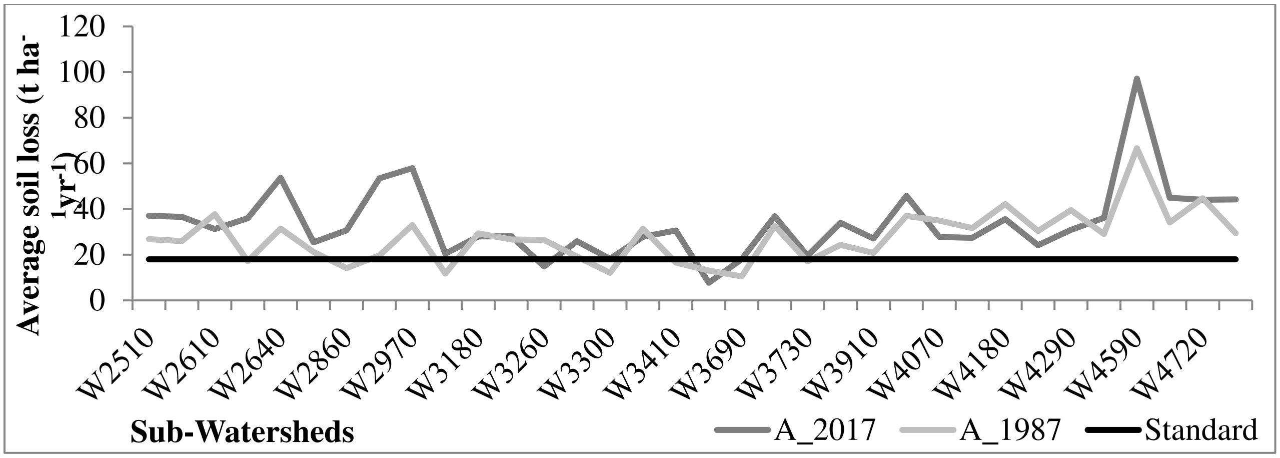

Figure 17: Evaluation of mean soil loss from sub-watersheds with respect to national standard

The range of soil loss rate in the central rift valley should not be beyond its formation rate of 10 t $ha^{-1}yr^{-1}$ as shown in Table 8. Accordingly, comparison of soil loss from sub-watersheds with the standard in the central rift valley given in Table 8, only two sub-watersheds (W3260 and W3460) (5.88%) are nearest or below the standard line that shows a terrible soil loss risks that threatens the annual crop production and the productivity of the land impacting the local farmers' food security (Wolka et al., 2015; Brevik, 2013; Pimentel and Burgess 2013) in the Meki river watershed as shown in Figure 18.

Table 8: Zonal variability of soil formation rates (Sources: Hurni, 1993)

Zone	Soil Formation Rates (t ha-1yr-1)
Gonder, Rift Valley	6-10
Gojam, Arsi Regions	10-14
Welega, Kefa, Shewa	18-22
Gemo Gofa	10-14
Kenya border	6-10

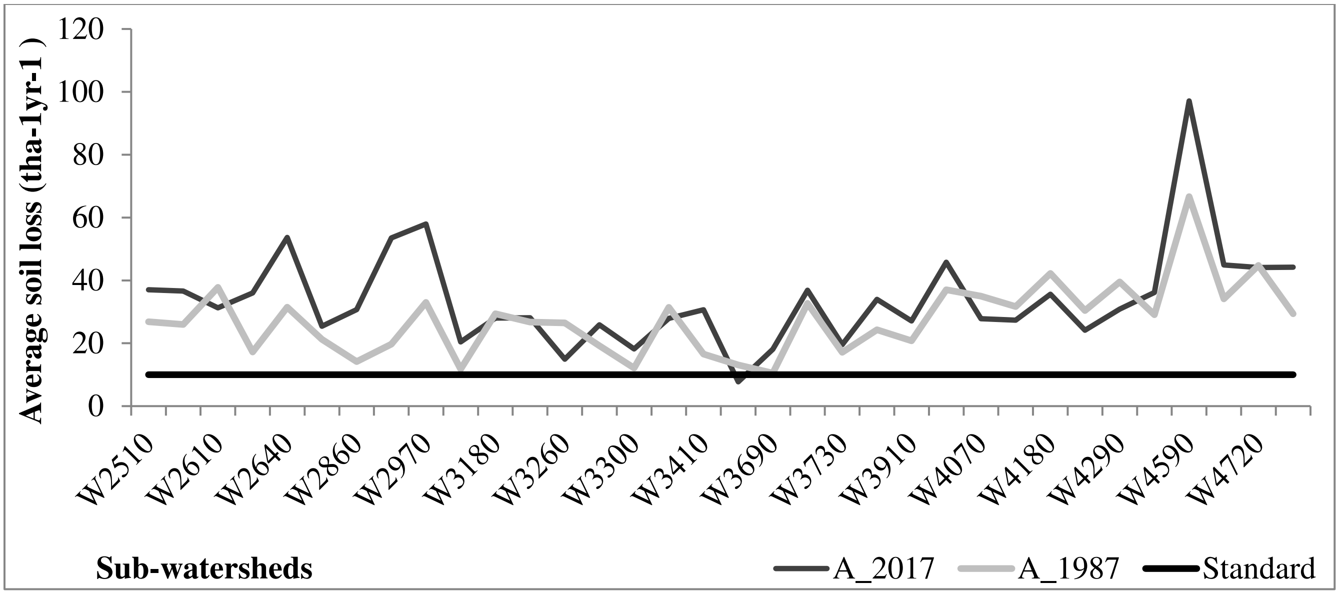

Figure 18: Evaluation of mean soil loss from sub-watersheds with respect to Rift valley limits

Recently, erosion is manifested in all parts of the watershed but more pronounced in the middle zone because of intensive cultivation practice without conservation measures and also overgrazing of grasslands relative to the former years as shown in Figure 19.

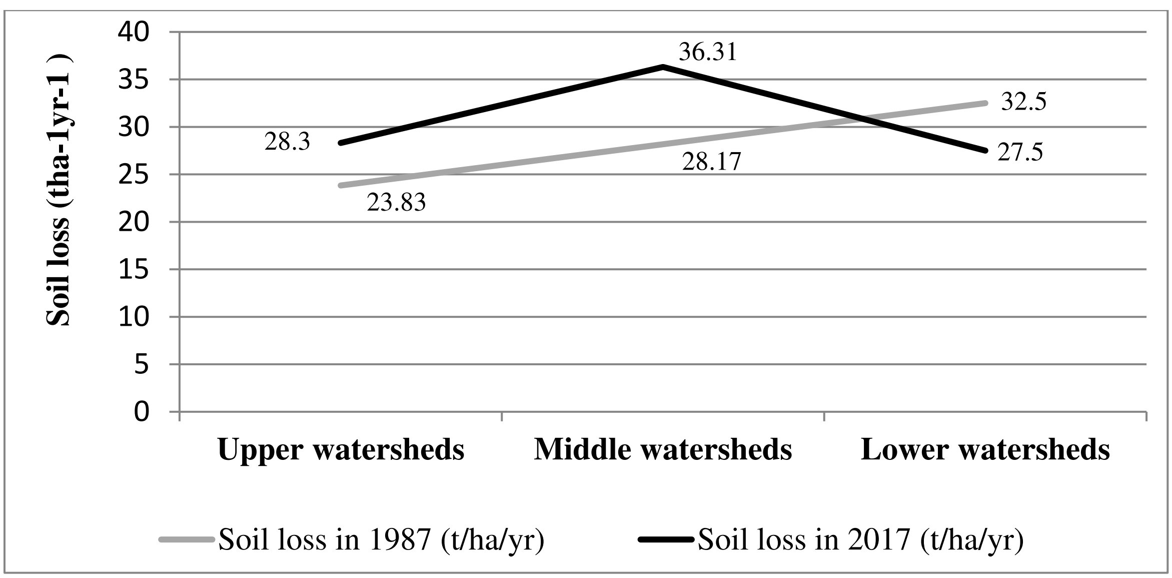

Figure 19: Zone based soil loss in Meki river watershed

Considering the mean soil loss values of Non-enset growing region of the watershed (the lower watershed with that of middle watershed) and comparing it with the upper enset growing portion of the watershed, there is a noticeable difference in soil loss as shown in Figure 20. Based on the soil loss in 2017, the algebraic difference of Non-enset growing and enset growing zones are evaluated as 1.405t $ha^{-1}yr^{-1}$ so that 296,509.9 tons of soil can be saved from Meki river watershed every year marching down to lake Ziway due to EBLUS which implies that EBLUS can contribute to the sustainability and life of the Lake.

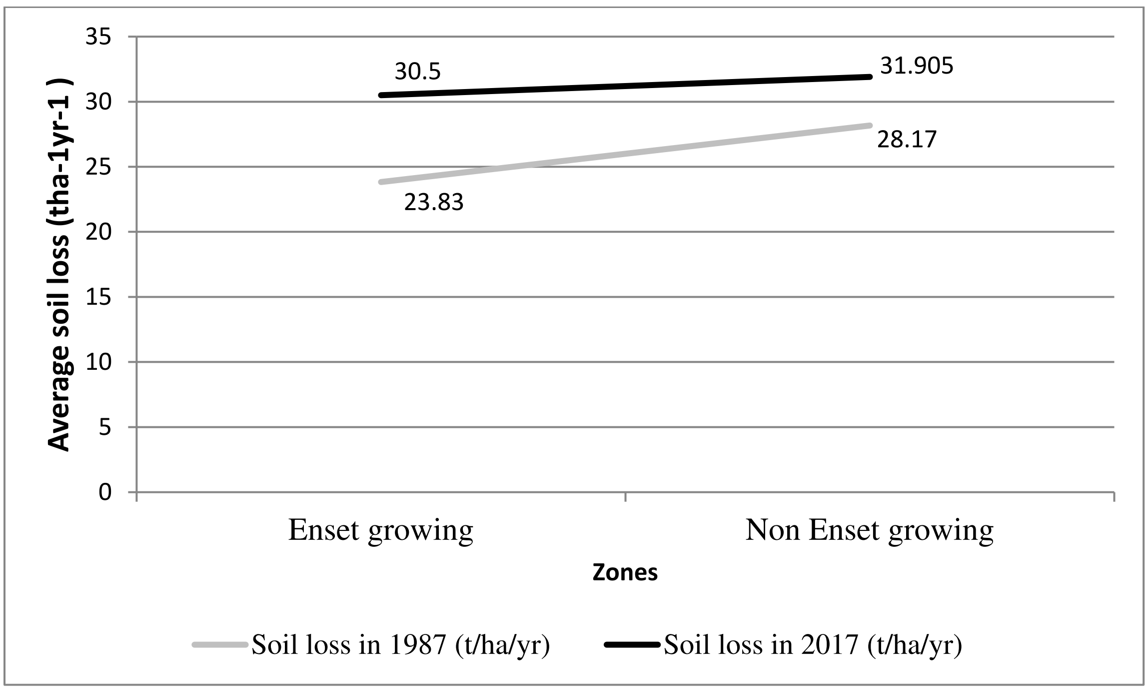

Figure 20: EBLUS and its contribution to reduce soil erosion in Meki river watershed

Therefore, the expansion of EBLUS will contribute for the ecological sustainability of the surrounding in addition to its social, economic, food security, environmental and microclimatic prominence and also it can reduce the soil erosion risk and contributes in the sustainability of water bodies especially lake Ziway by reducing sedimentation problem.

Soil erosion severity class for management priority

The estimated annual mean soil loss rates erosion risk classes and ranges of soil loss rates were adopted following the FAO soil description guidelines (FAO, 2006), other similar studies from different locations and expertise judgment (Wolka et al., 2015), with some modification to suit the local condition of Meki river watershed as shown in Table 9.

Table 9: Annual soil loss Range and severity class adoption

Severity class	Annual soil loss Range (t ha-1yr-1) (Bewket and Teferi, 2009)	Annual soil loss Range (t ha-1yr-1) (Wolka et al., 2015)	Annual soil loss Range (t ha-1yr-1) (Habtamu et al., 2020)	Annual soil loss Range (t ha-1yr-1) (Asnake and Amare, 2019)	Annual soil loss Range (t ha-1yr-1) (A. Kavian, 2017)	Annual soil loss Range adopted (t ha-1yr-1)
Very low	-	-	-	<5	0-5	<5
Low	<12	0-10	0-10	5-15	5-25	5-10
Moderate	12-25	10-20	10-20	15-30	25-50	10-18
High	25-50	20-30	20-30	-	50-80	18-30
Very high	50-80	30-45	30-50	-	>80	30-42
Severe	80-125	45-60	>50	30-50		42-80
Very sever	>125	60-80	-	>50		>80
Extremely severe	-	80-85.64	-	-		

Bearing in mind the range taken by Wolka et al (2015) is in the central rift valley, including the very low range, and modifying the ranges to fit with the standards stated in Hurni (1985) for highlands of Ethiopia (18 t $ha^{-1}yr^{-1}$) and for cultivated land (42 t $ha^{-1}yr^{-1}$), the adopted ranges are given as Very low (<5), Low (5-10), Moderate (10-18), High (18-30), Very high (30-42), Severe (42-80) and Very sever (>80) and hence, the result of Meki river watershed is presented in the sub-watershed basis as shown in Table 10.

Table 10: Annual soil loss rate and severity class

Severity class	Soil loss (t ha-1yr-1)	Priority class	Sub-watersheds	Area (ha)	Percent
Low	5-10	VI	W3460	4627.5	2.2
Moderate	10-18	V	W3260	3115.8	1.48
High	18-30	IV	W2750,W3080,W3180,W3190, W3280,W3300,W3400,W3690, W3730,W3910,W4070,W4130 &W4250	89988.9	42.64
Very high	30-42	III	W2510,W2530,W2610,W2620, W2860,W3410,W3700,W3790, W4180,W4290&W4400	67907.2	32.18
Severe	42-80	II	W2640,W2890,W2970,W4030, W4620,W4720&W4730	43531.5	20.6
Very sever	>80	I	W4590	1868.2	0.9

Spatial distribution of severity and its priority class is mapped for priority of soil and water conservation programs to be held based of the severity order as shown in Figure 21.

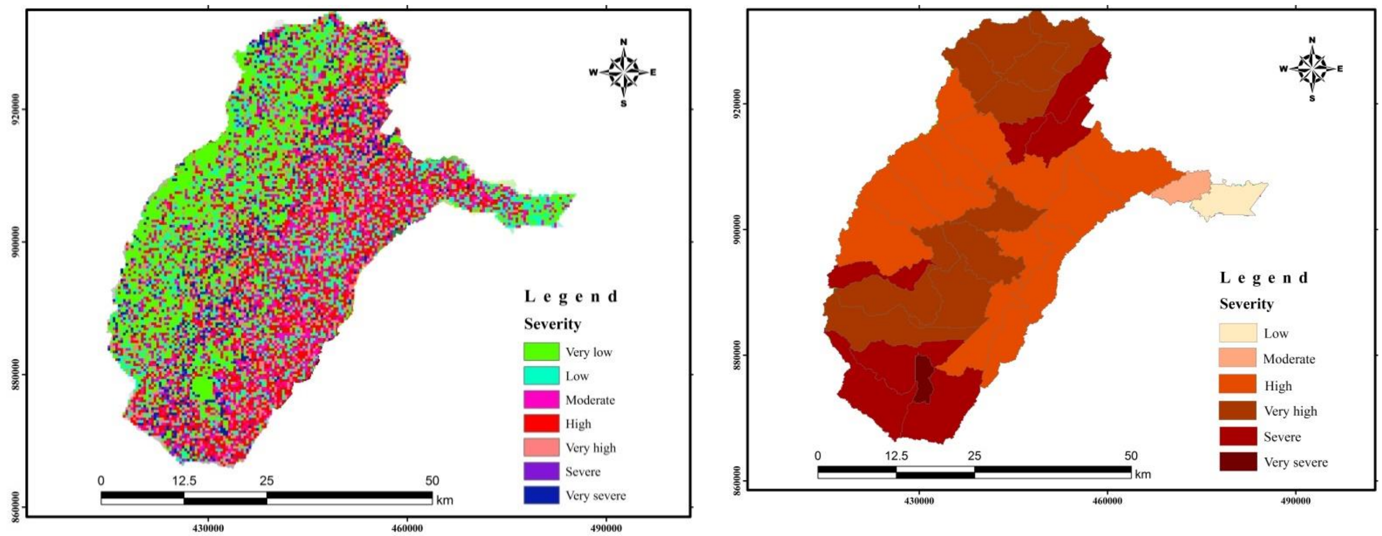

Figure 21: Spatial distribution of severity and its priority class

The distribution map shows that very low soil loss is spatially well distributed on the Enset growing portion of the watershed but, the mean of both Enset growing zone of the watershed (30.5 t $ha^{-1}yr^{-1}$) and non-Enset growing zone of the watershed (31.905 t $ha^{-1}yr^{-1}$) falls in the same severity class (very high) and priority class III. Hence, although the effect of topography is very high in Enset growing zone of the watershed, the soil loss is modified by the presence of vigitation cover, especially Enset-Based agroforestry system that could contribute to arresting soil movement in these areas (Wolka *et al.*, 2015).

4. Conclusion and Recommendation

Conclusion

Enset-Based land use system (EBLUS) is dominantly practiced on the upper zone of Meki river watershed and evidence from socio-economic assessment in the watershed shows that there is an increase in area coverage in EBLUS and cultivated land use system over the last 30 years while the forest cover and grass land coverage are decreasing.

GIS based RUSLE used in the modeling of soil loss in Meki river watershed and most parts of the watershed are experiencing high to very severe soil erosion risks beyond the tolerable soil loss level which is manifested by 82.35% and 94.12% of the sub-watersheds are beyone 18 t $ha^{-1}yr^{-1}$ and 10 t $ha^{-1}yr^{-1}$ respectively which threatens the annual crop production and the productivity of the land impacting local farmers' food security. The erosion may also have off-site consequences in the wetlands and have the possibility to modify its nature and function.

The soil loss in the watershed is modified by EBLUS that could contribute to arrest soil movement. The lowest soil loss is generated from EBLUS with a soil loss of 22.65t ha-1yr-1 in the year 2017 better than forest land with a soil loss of 25.94 t ha-1yr-1. Soil loss in Enset growing zones (30.5 t ha-1yr-1) which are influenced by very high slopes of the watershed has less soil loss than the non-Enset growing zones (31.905 t ha-1yr-1) with the difference of 1.405t ha-1yr-1 so that EBLUS can save 296,509.9 tons of soil every year from marching down to lake Ziway which implies that EBLUS can have contribution for the sustainability and life of water bodies.

Recommendation

Soil erosion is the most appealing problem in Meki river watershed, particularly in the upper part of the watershed where the topography is highly rugged, population pressure is high, steep lands are cultivated and rainfall is erosive. Therefore, soil and water conservation is important in the upper watershed in addition to expanding EBLUS.

The increased coverage with Enset based agroforestry practices can be considered a positive step to minimize the already intensified soil erosion risk in the watershed which demands an immediate action and intervention in the form of integrated watershed management that encourages local people to participate.

The current national watershed management campaign can contribute to the success of improving land cover and soil conservation activities to reduce soil erosion and its consequences and priority class is suggested for intervention which should be considered for integrated watershed management.

The presence of EBLUS brought several ecological and hydrological benefits as it is discussed and hence, expanding it requires a policy change and awareness creation to the community for the market based production of shade loving agroforestry trees like coffee and cassava under the Enset cultivation and decision makers should intervene in enhancement of EBLUS. Therefore, crafting special land use policy considering such a multipurpose agroforestry system and incorporating fruit production to the system is mandatory and also creating conducive environment to the extension program that the upper part of the watershed can produce sufficient inputs or raw material to the industries to be established in the watershed.

Abbreviations

CRV	Central Rift Valley
DEM	Digital Elevation Model
EBLUS	Ensed-Based Land Use System
EGSIA	Ethiopian geospatial information agency
ENMA	Ethiopian National Meteorological Agency
ERDAS	Earth Resources Data Acquisition System
GIS	Geographical Information System
GPS	Geographical Positioning System
HEC-GEO-HMS	Hydrologic Engineering Center's Geospatial Hydrologic Modeling System
HEC-HMS	Hydrologic Engineering Center's Hydrologic Modeling System
HSG	Hydrologic Soil Group
HWSD	Harmonized World Soil Data
LULCC	Land Uses and Land Cover Change
m.a.s.l.	Meter above Sea Level
MOWIE	Ministry of Water, Irrigation and Electricity
RUSLE	Revised Universal Soil Loss Equation
USGS	United States Geological Survey

DECLARATION

Originality of work

We assure that, this paper is the original work and have not been presented for a degree in any other university, and all sources of material used for this paper have been duly acknowledged.

Ethics approval and consent to participate

'Not applicable'

Consent for publication

'Not applicable'

Availability of data and material

Data are acquired from Ministry of Water, Irrigation & Electricity (MOWIE) of Ethiopia for flow data, Ethiopian Meteorological Agency (EMA) for meteorological data, Ethiopian Central Statistical Agency (ECSA) for population data, Ethiopian Geospatial & Mapping Agency (EGMA) for Satellite images and topo-maps, Satellite images from USGS earth explorer and field materials acquired from Ethiopian Institute of Water Resources (EIWR) in Addis Ababa University.

Competing interests

"The authors declare that they have no competing interests"

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Authors' contributions

Authors in this article made substantial contributions to the conception and design of the work; the acquisition, analysis and interpretation of data and finally have drafted the work or substantively revised it together and the authors read and approved the final manuscript.

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Figures

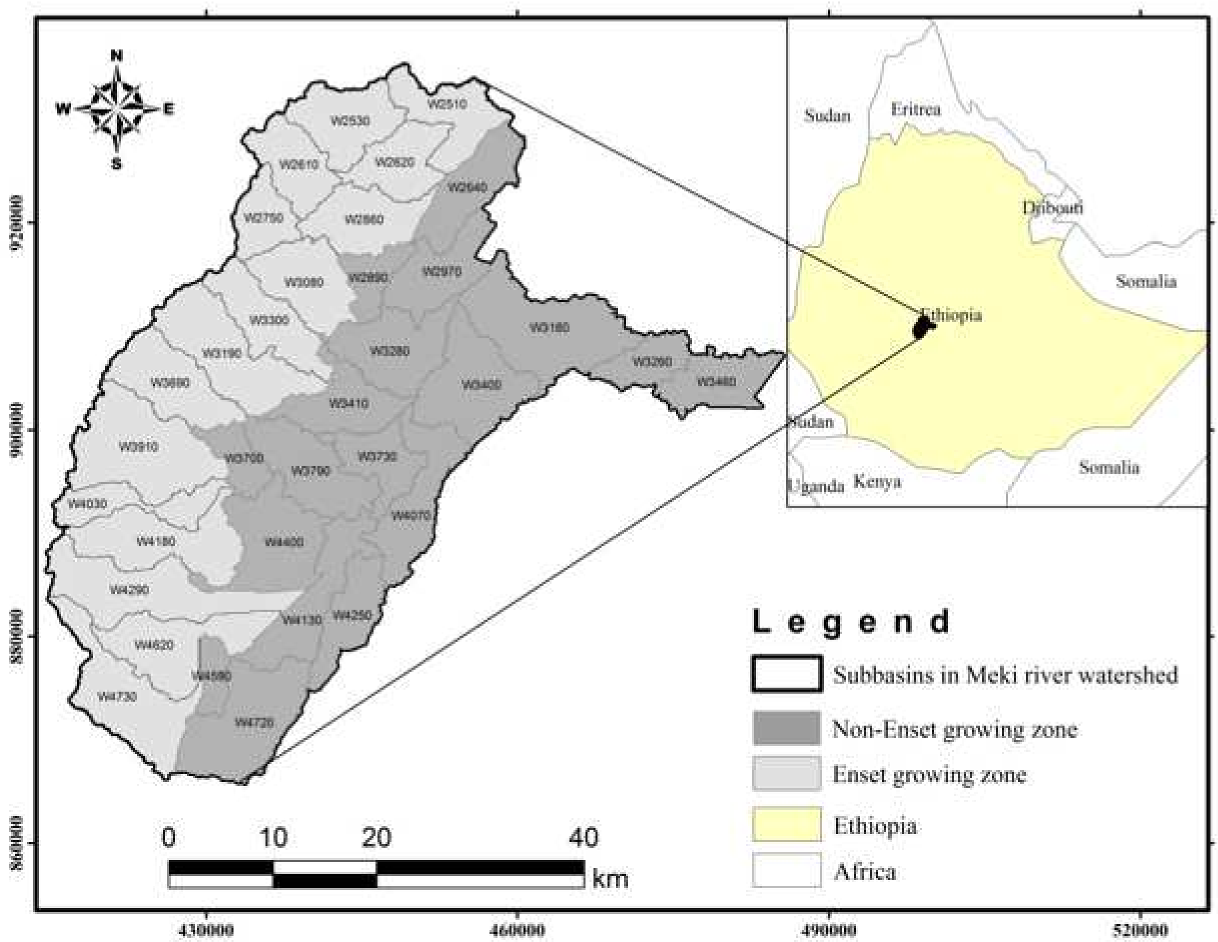

Figure 1

Study area map

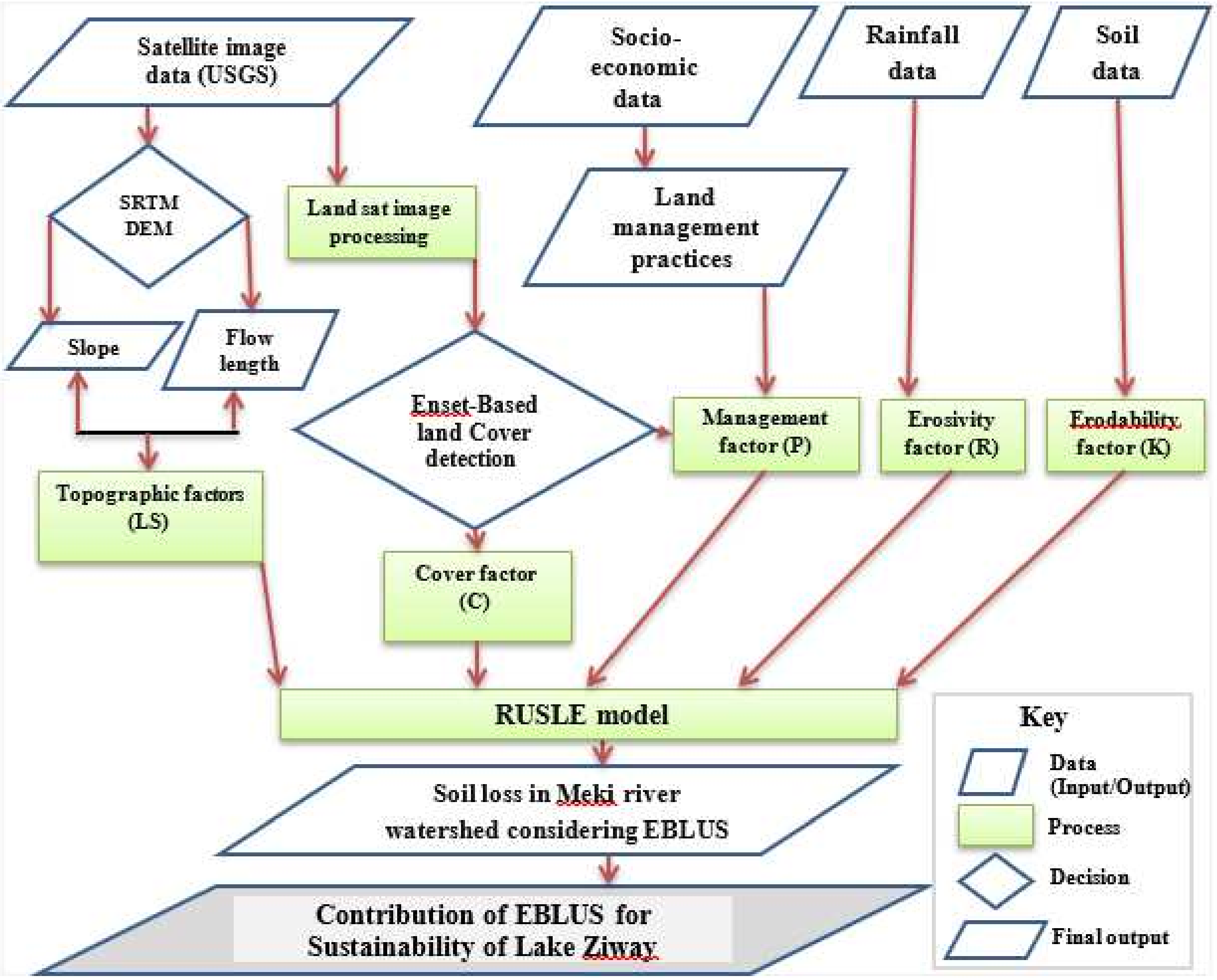

Figure 2

RUSLE model flow diagram

Figure 3

Land cover in the resourceful upper zone of Meki river watershed

Figure 4

Land cover in the middle zone of Meki river watershed

Figure 5

Land cover in the lower zone of Meki river watershed

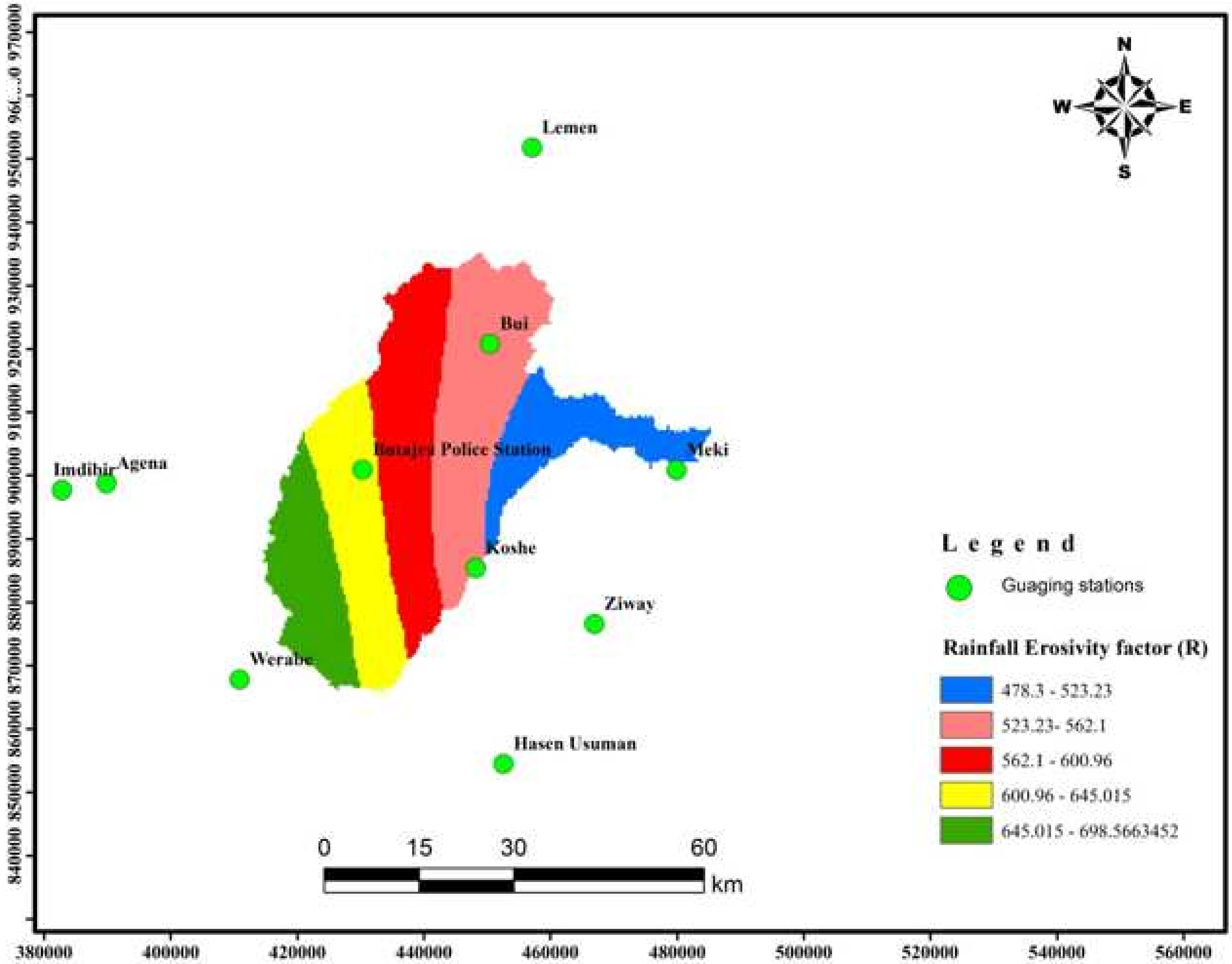

Figure 6

Rainfall Erosivity factor (R) map of the watershed

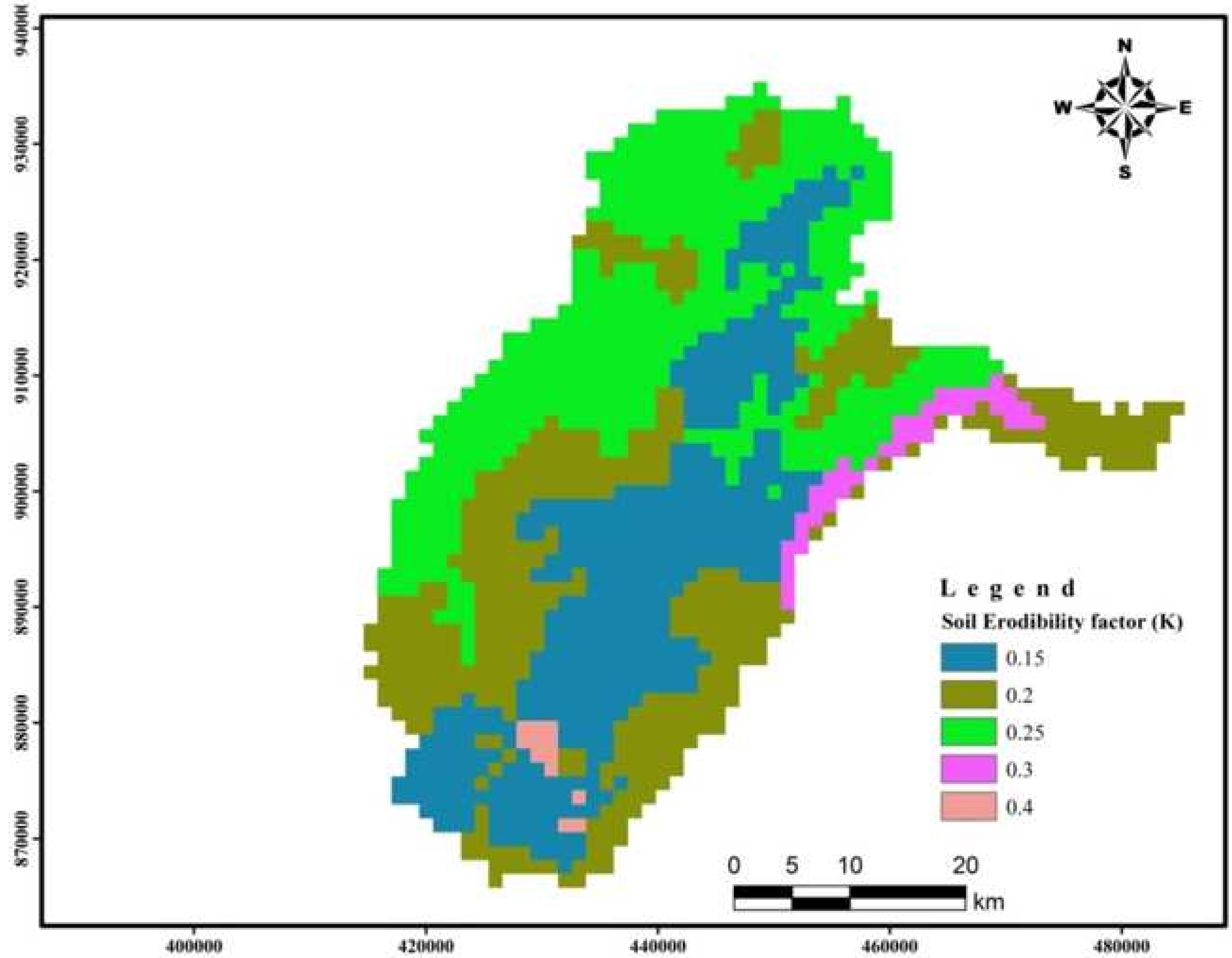

Figure 7

Soil erodibility (K) value map of Meki watershed

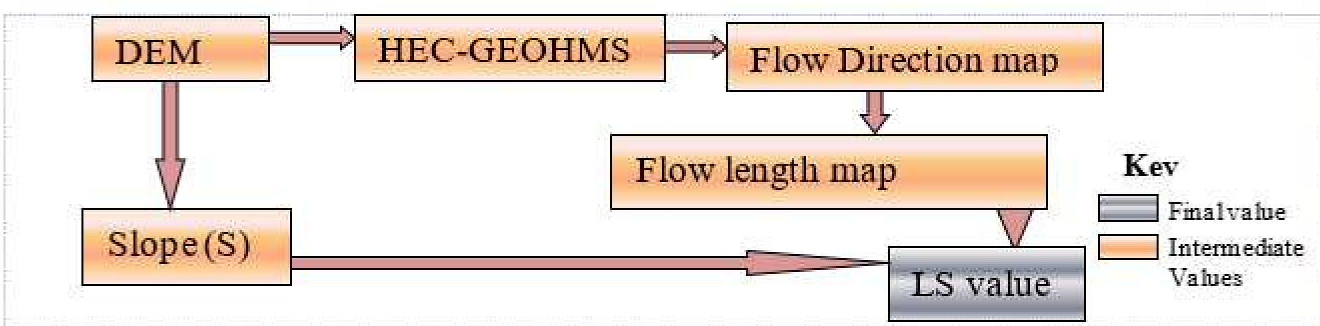

Figure 8

Flow chart for LS value determination

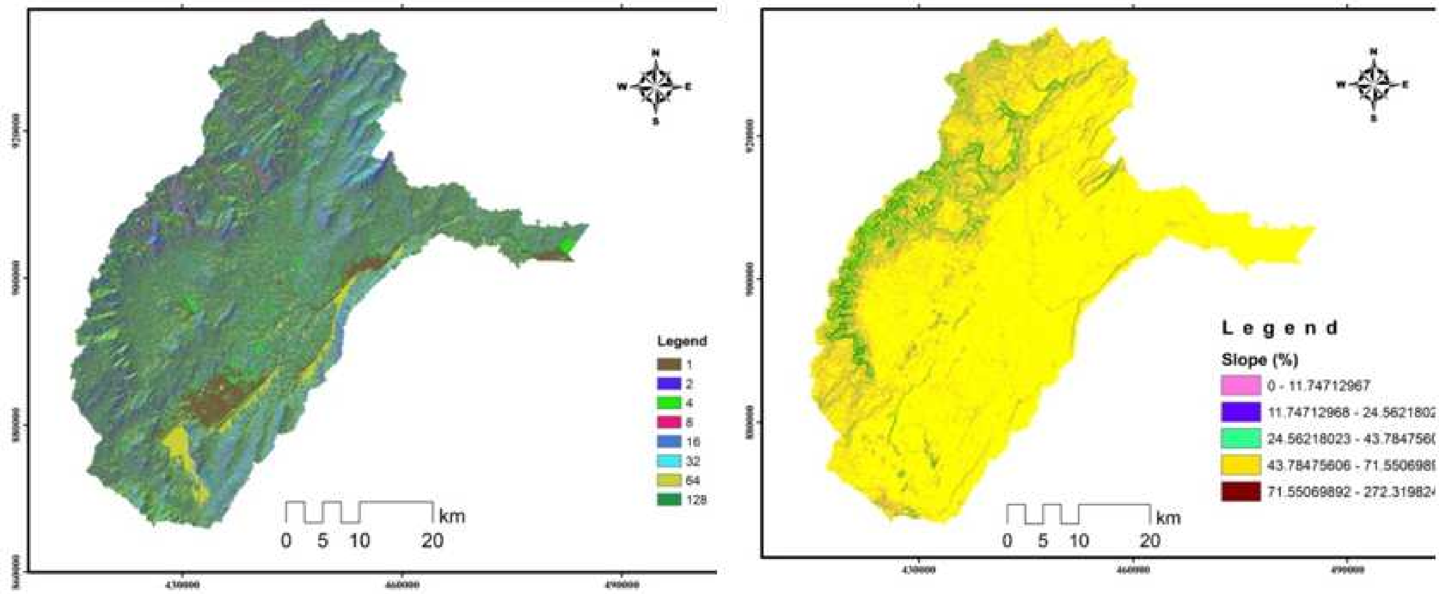

Figure 9

Flow length & Slope map of Meki watershed

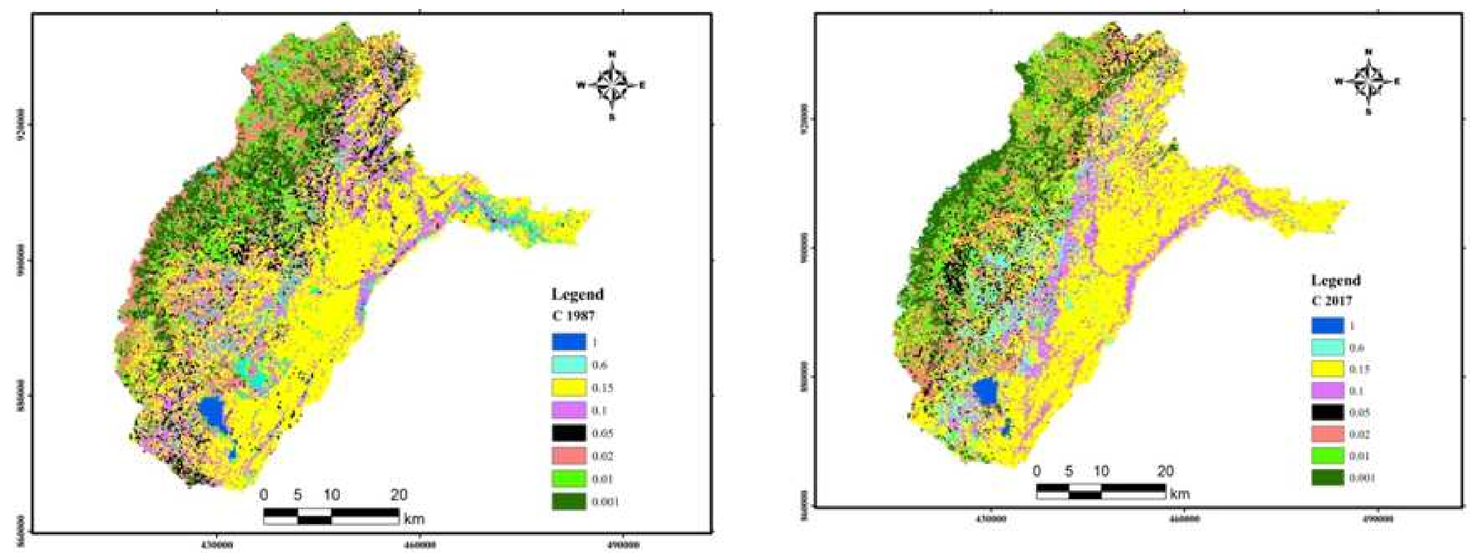

Figure 10

Land cover factor map of Meki watershed in 1987 & 2017

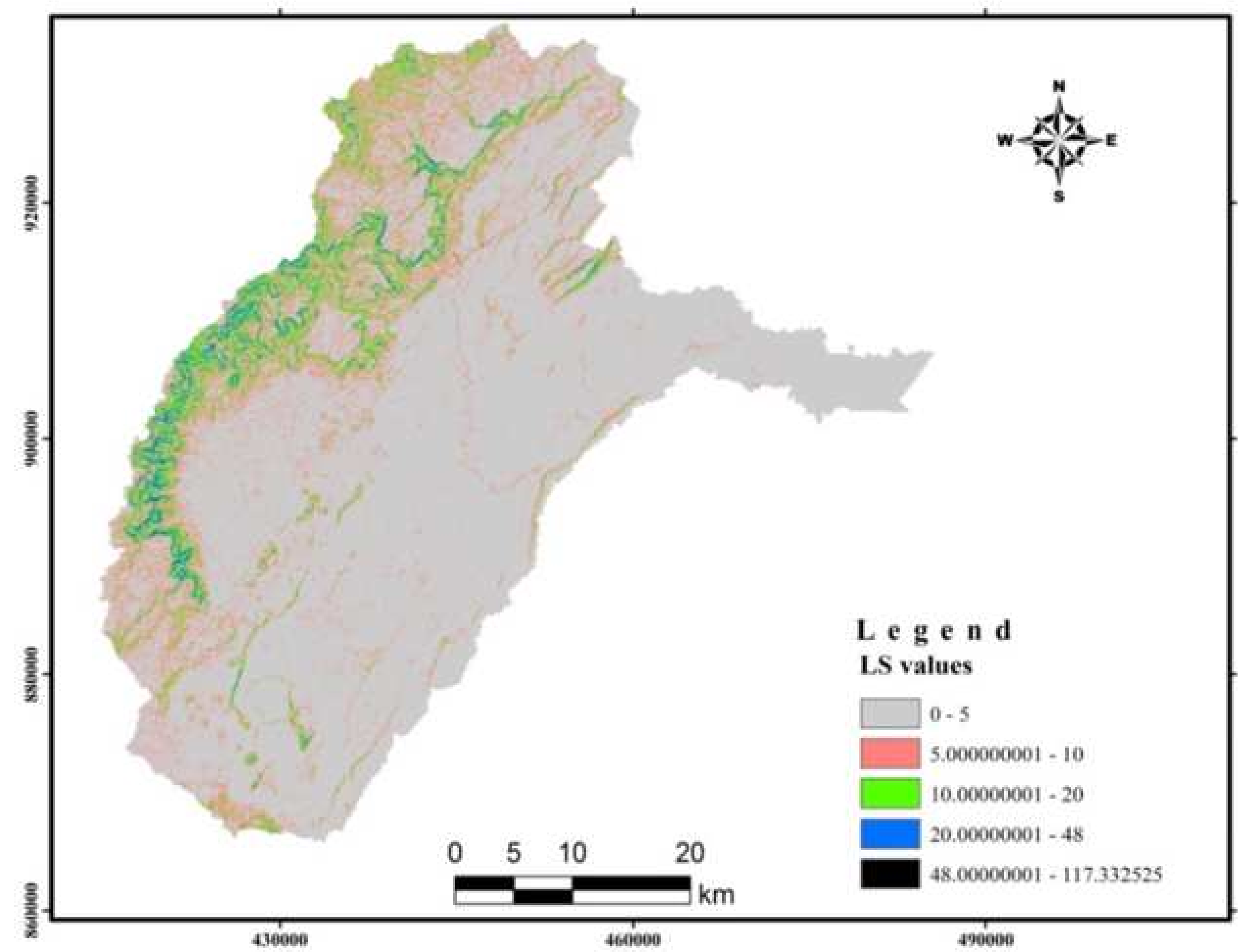

Figure 11

Topographic (LS) map of Meki watershed

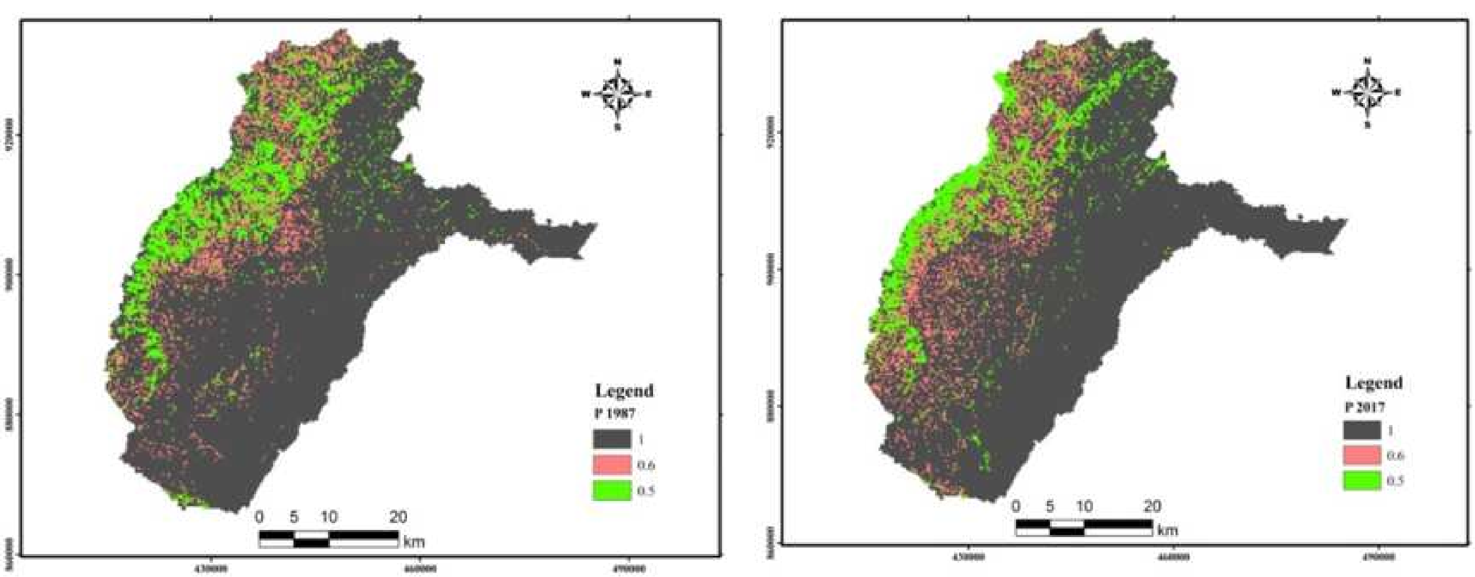

Figure 12

Management factor map of Meki watershed in 1987 & 2017

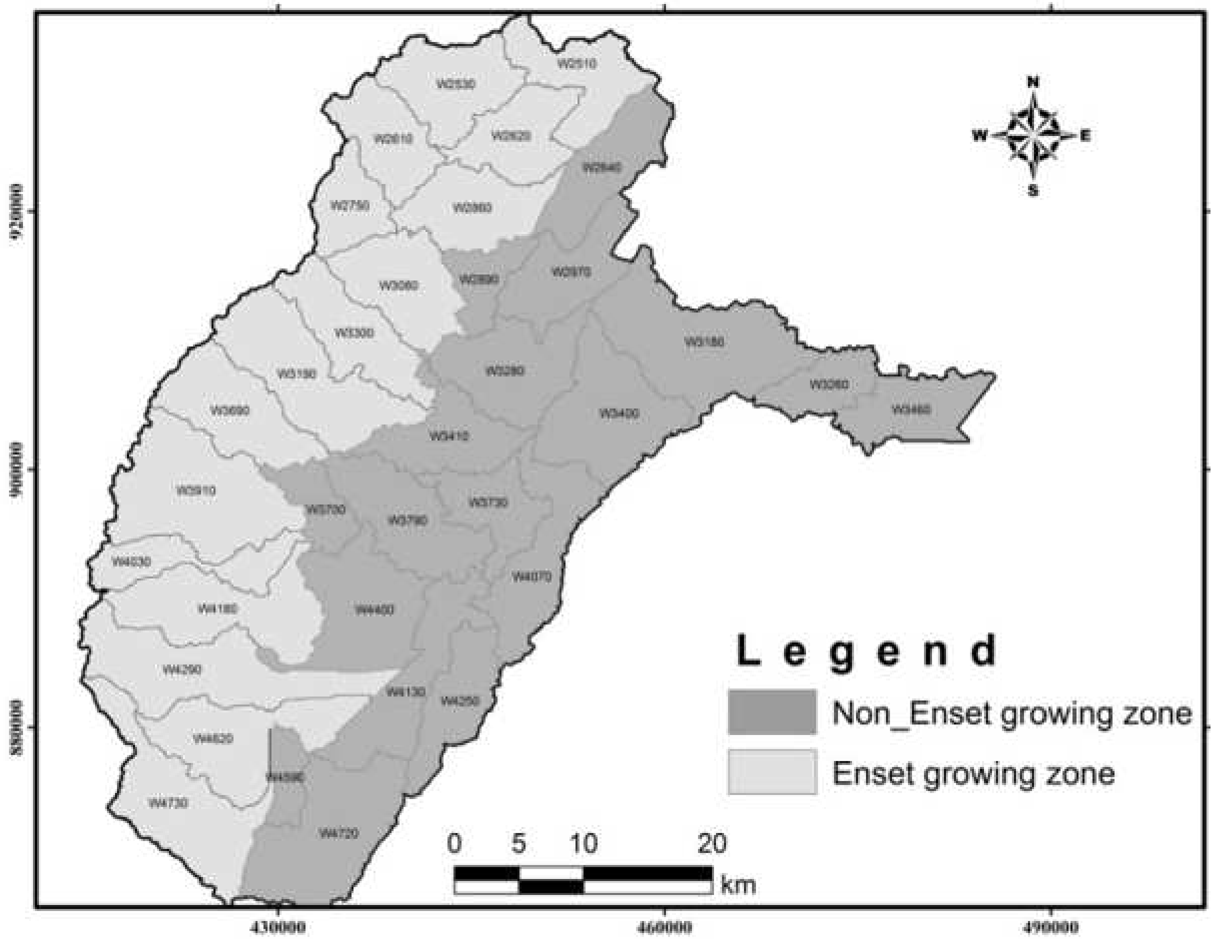

Figure 13

Sub-watersheds and major zones in Meki river watershed

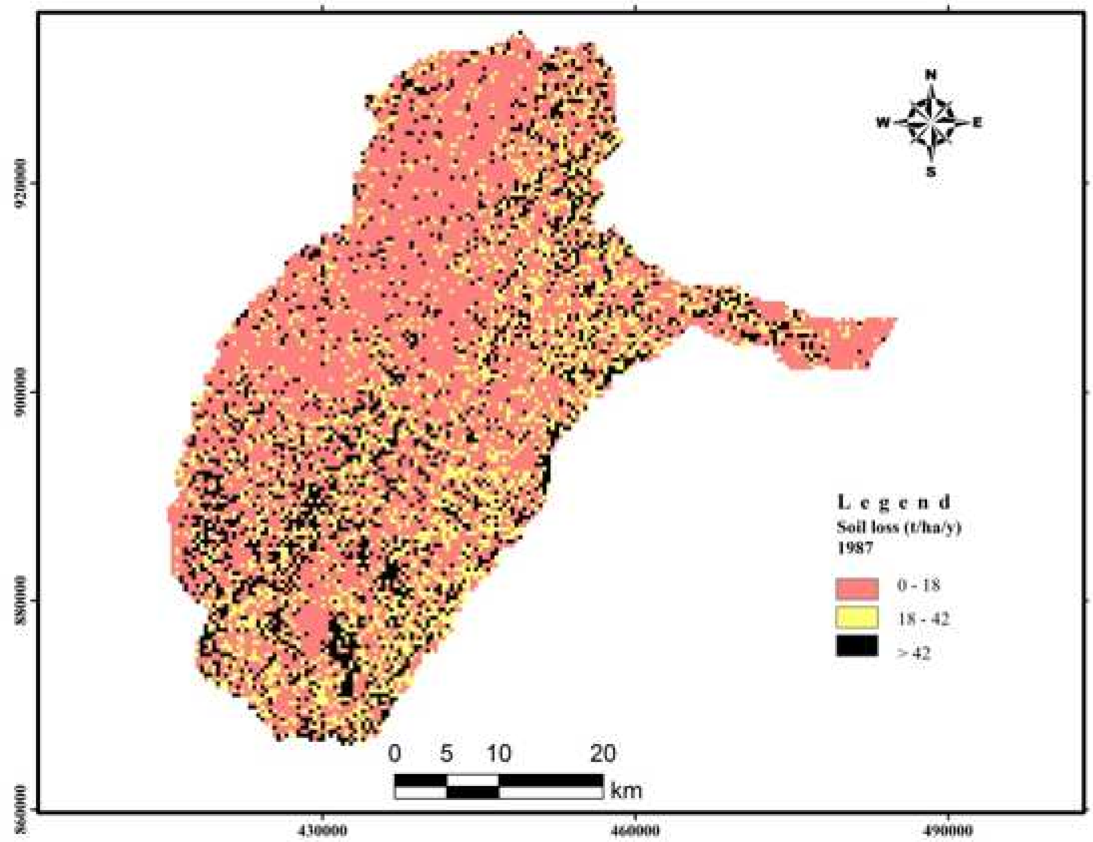

Figure 14

Soil loss (tone/ha/year) in 1987

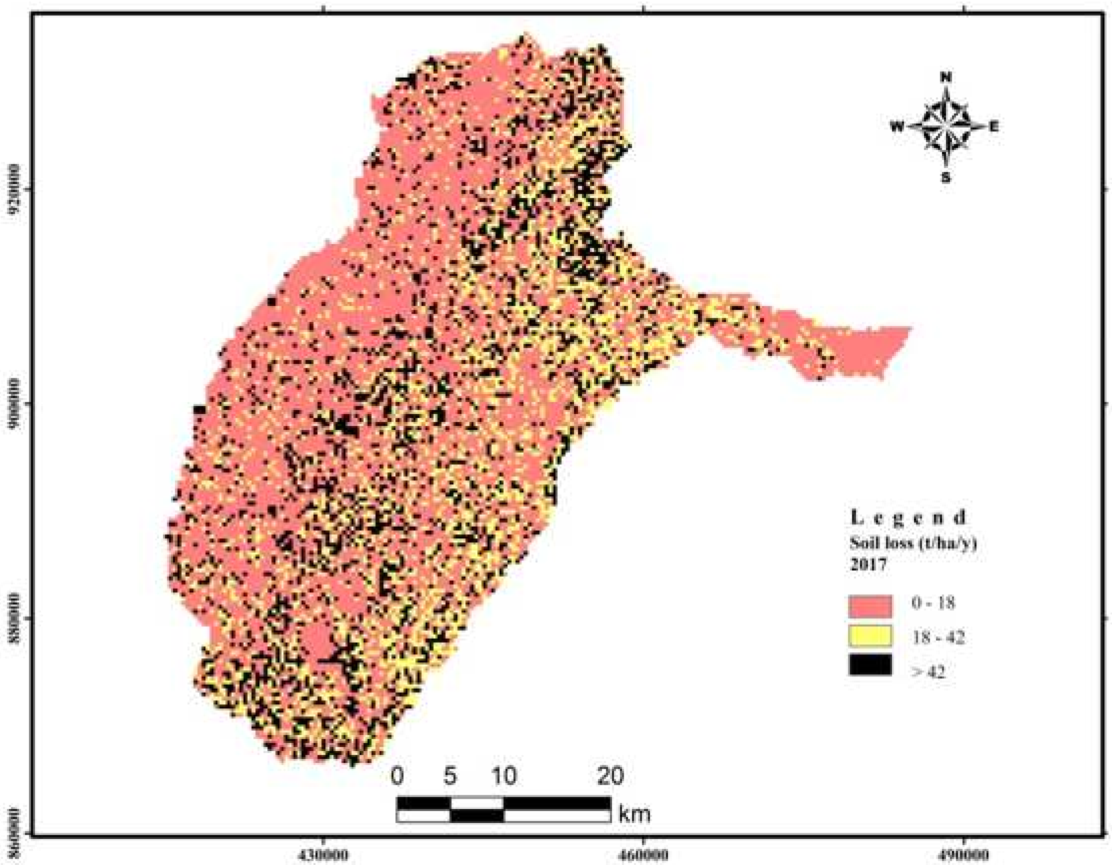

Figure 15

Soil loss (tone/ha/year) in 2017

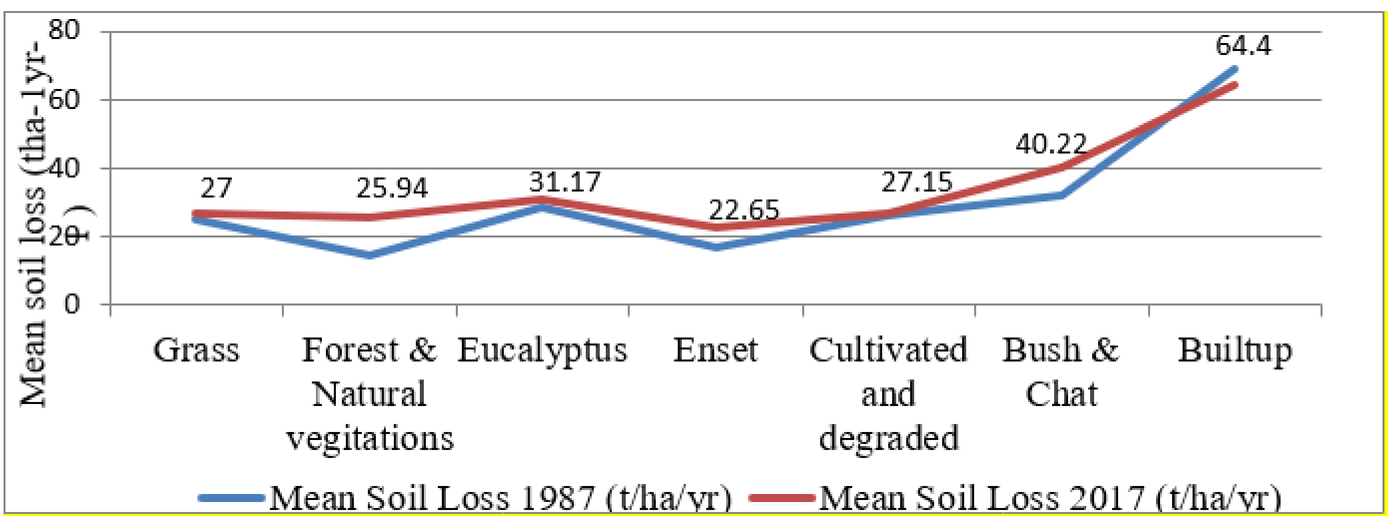

Figure 16

Soil loss curve in 1987 and 2017 for different land use systems

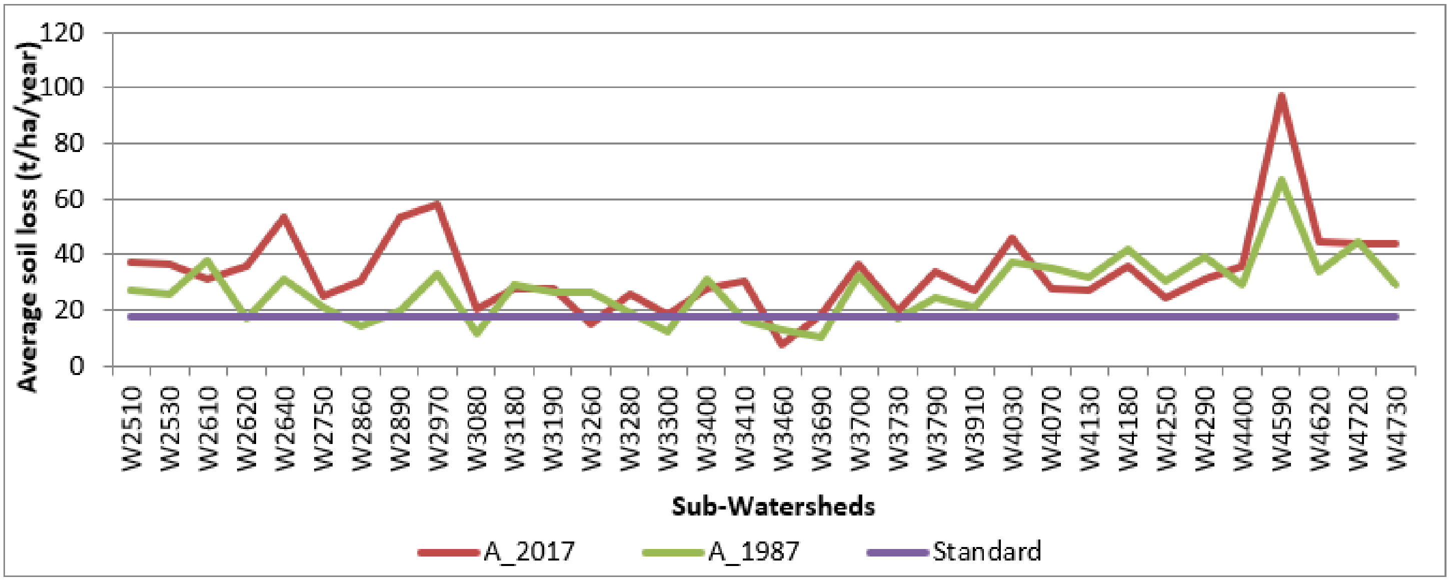

Figure 17

Average soil loss from sub-watershed of Meki river with respect to national average

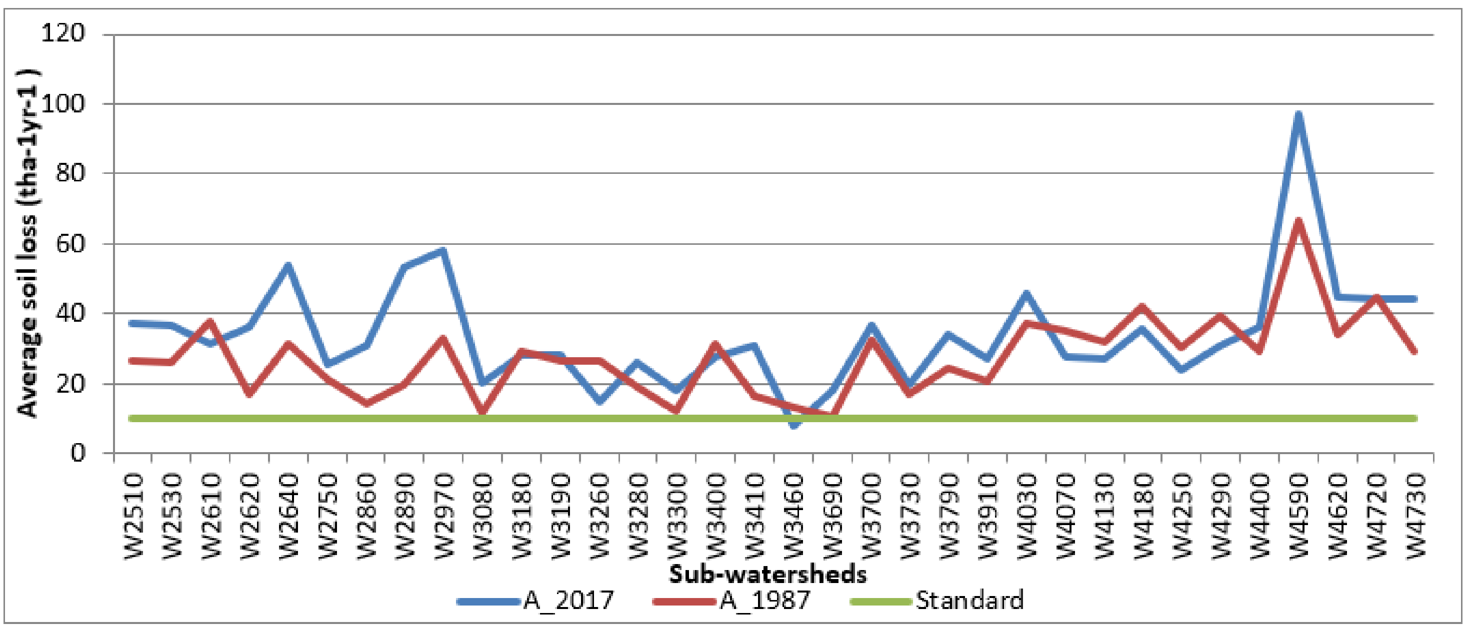

Figure 18

Average soil loss from sub-watersheds with respect to Rift valley limit

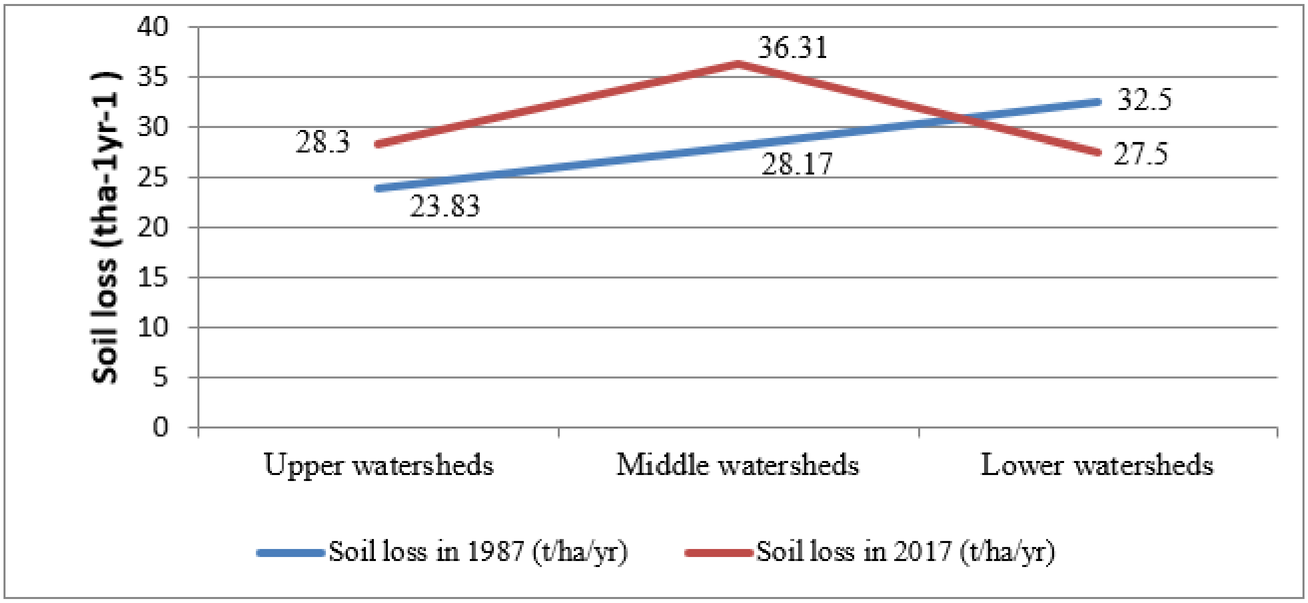

Figure 19

Zone based soil loss in Meki river watershed

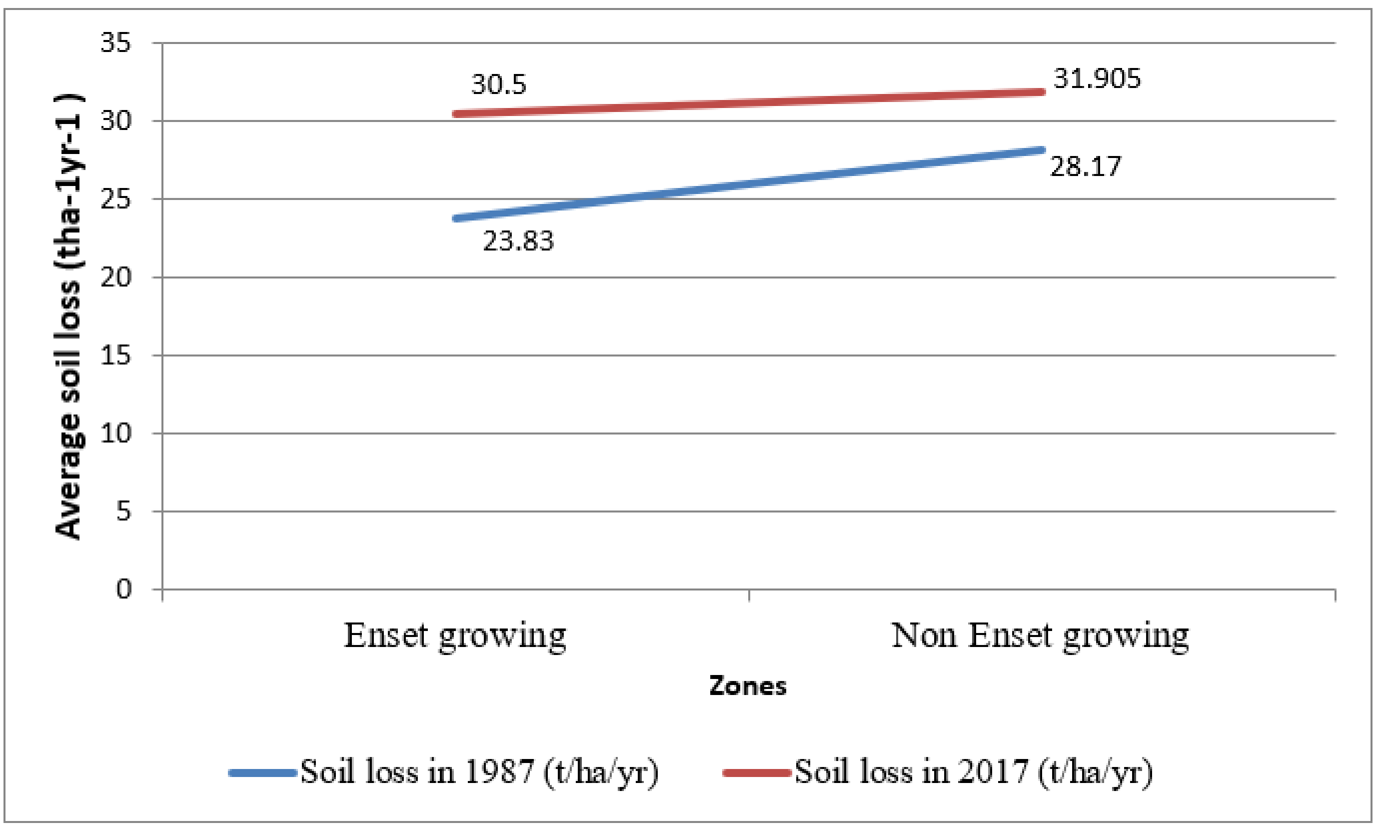

Figure 20

Enset-Based land use system based soil loss in Meki river watershed

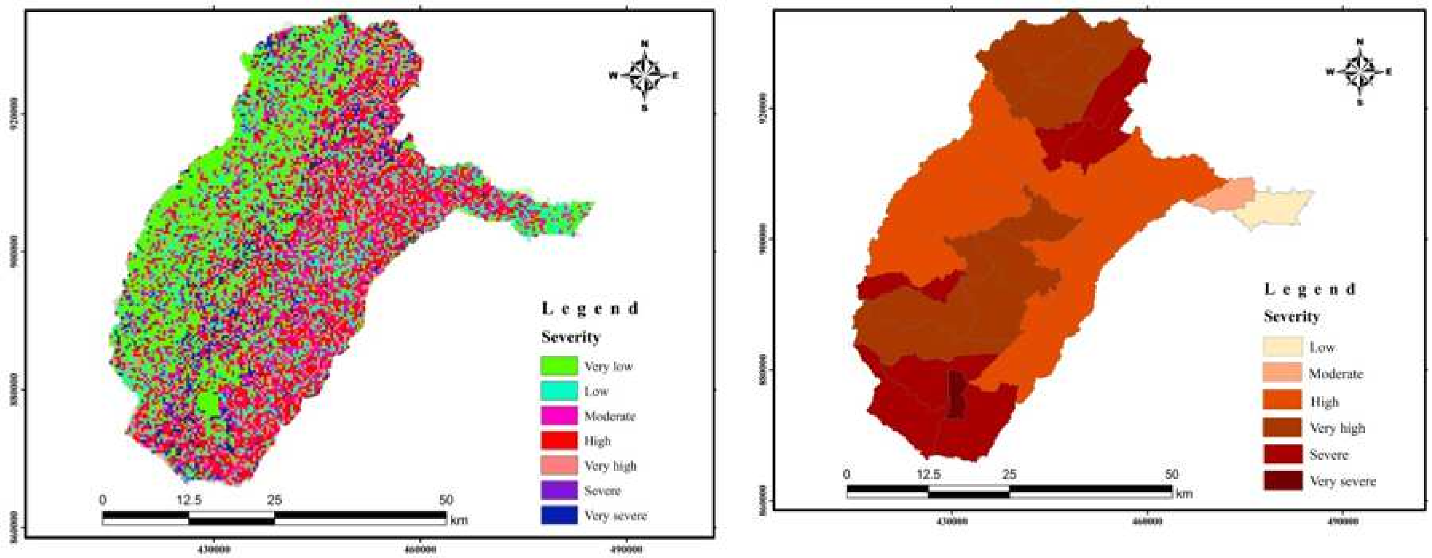

Figure 21

Spatial distribution of severity and its priority class