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 Meki river watershed. . The study assessed the land use land cover change (LULCC) over the last 30 years, examined the contribution of the indigenous Enset-Based land use system (EBLUS) which was not studied so far in reducing soil erosion and preventing Lake Ziway from sedimentation. Based on the outcomes, the research recommended appropriate management interventions based on priority mapped to sustainably manage the watershed. GPS based Ground truth data sampling and collection, Geo-statistical interpolation and RUSLE model were applied for soil erosion modeling. The LULCC detection and analysis was conducted to generate the spatial inputs using ERDAS Imagine 2014.

Result

Meki river watershed has 2110.4 km² of area which is dominantly covered by cultivated land use system (41.5%), Enset-Based land use system (EBLUS)(10.65%), Bush and Chat land use system (25.6%), Forest and plantations land use system (14.14%), built up (7.4%) and water bodies (0.75%). Severity class of High to severe range (18-125tha^{-1}yr^{-1}) recorded in the sub-watersheds irrespective of the land use systems and facing sever degradation problem that increase in soil loss in all land use systems from 1987 to 2017. The average soil loss of 30.5tha^{-1}yr-1 and 31.905tha-1yr-1 verified from Enset growing zones and non-Enset growing zones of the watershed respectively.

Conclusion

Enset-Based land use system (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 Lake Ziway by reducing soil loss rate and sedimentation problem for ecological sustainability of the watershed. Therefore, separate land use policy and awareness creation are mandatory for such EBLUS expansion, integrated watershed management and conservation of the natural environment in the watershed.

Key words: *Enset, Soil-loss, RUSLE, Geo-Statistics, Land use policy, Meki-river-watershed*

1. Background

Enset is an indigenous and herbaceous monocot plant and widely grown as a food crop (James S *et al*, 2020; Uloro & Mengel, 2014) and it is banana-like perennial plant that the enlarged pseudo-stem and underground corm (carbohydrates) of the plant is used for human consumption (Michael , 2002) and it is called “a national commodity” of Ethiopia (Anita, et al., 1996). According to Uloro & Mengel (2014), its leaves reaches a height of 5 to 13 m that mainly used for fodder and fiber and their products are used for everything from food wrapping to medicine throughout the Southern Highlands of Ethiopia including Meki river watershed (Michael , 2002).

It grows at an altitudes range between 1600 and 3100 meter above sea level but the main cultivation zone lies between 1800m and 2450m above sea level with an average temperature of 16 ° C to 20° C with a relative humidity of 60 to 80% (Uloro & Mengel, 2014) at an annual rainfall of 1100mm to 1500mm.

Enset resists a considerable period of soil moisture stress or drought and the tolerance of this plant to relatively prolonged soil moisture stress, its higher yield compared to other cultivated crops in the region and the minimum input required to produce it makes it attractive to farmers (Uloro & Mengel, 2014) and also the anti-famine, anti-drought, and food security enhancing nature of Enset-based farming systems point to the need for further consideration of the crop in terms of research, development and policy (Anita, et al., 1996).

According to Tilahun & Robert (2006), food security in the Enset-based Ethiopian highlands is constrained mainly by land degradation and Uloro & Mengel (2014) noted that historically, very little attention has been paid to the Enset crop by policymakers and researchers as most of their efforts have been concentrated on cash crops or the more familiar grains.

Root crops, including Enset, were regarded as food mainly for the poor. There was a 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).

The change in Enset-based land use system do have significant impact on the socio-economic of Meki river watershed since it is one of the major farming systems in Ethiopia (Fetta, 2019; Westphal E., 1975) and cultivated as the main staple or co-staple food with other crops (Borrell JS et al., 2020) and its change 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 and to devise priority mapping for integrated watershed management of Meki river watershed, Western Lake Ziway Sub-Basin, Central Rift Valley of Ethiopia.

2. Methods

2.1. Location

The study area is found in the western part of Ziway lake and located between UTM zone of $7^0$45'N - $8^0$30'N and $38^0$10'E - $39^0$00'E, which take part both in Oromia and SNNP Regional States as shown in the Figure 1 below.

Elevation in the watershed varies from 1612m.a.s.l (at the joining point to Ziway Lake) to 3612m.a.s.l at Zebidar Mountain with a mean elevation of 2169m.a.s.l and the annual rainfall ranges from 824mm – 1292 mm, as per the records from ten meteorological stations and the mean monthly temperature varies between 15ºC and 29ºC throughout the year to which the hottest season extends from December to late in May (Oliver *et al.*, 20

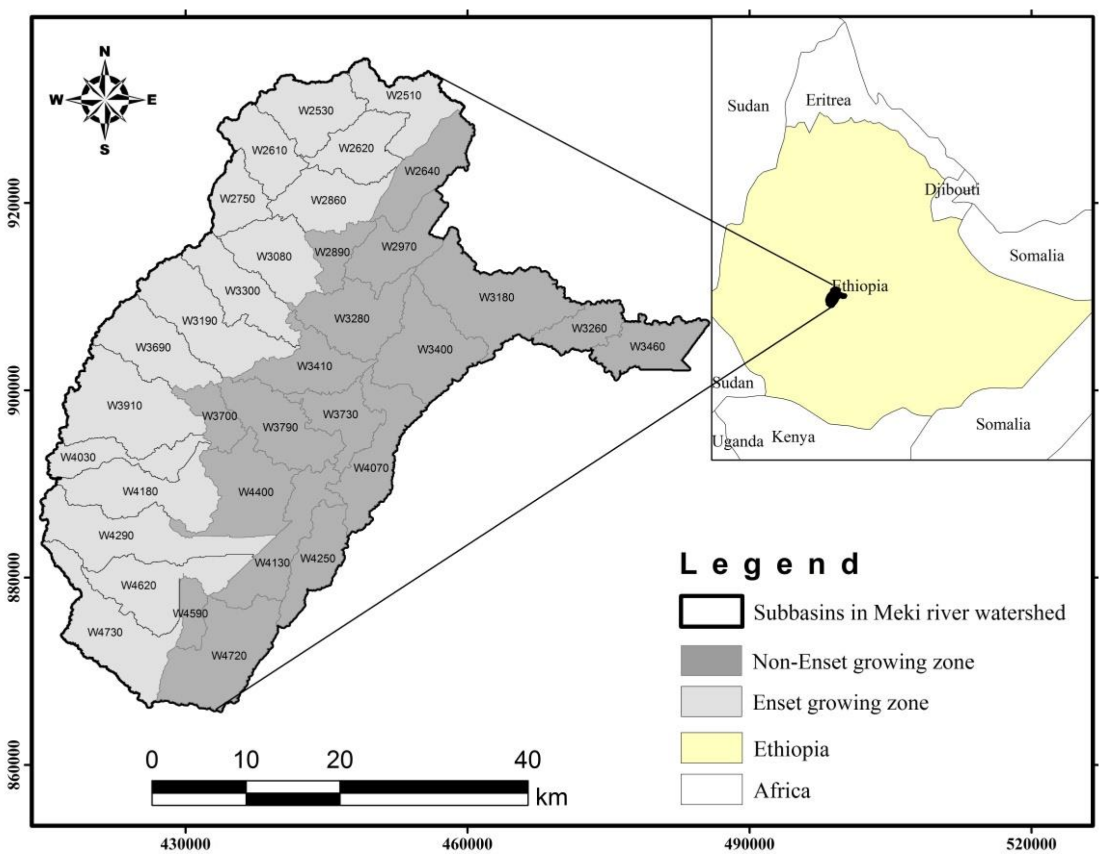

Figure 1: Study area map

Lake Ziway has two main tributaries continuously providing water which are under influence of population pressure in the form of abstraction of water for irrigation and domestic water supply of Ziway town. Precipitation is also one of the sources of water for the lake. The Western portion of the lake watershed drains to Meki River while the Eastern portion of the lake is fed through Katar River. There is no surface outflow identified except overflow of the lakes to the nearby rivers (Awulachew, 2001).

The Main Ethiopian Rift (MER) is a NNE–SSW to N–S- trending trough 80 km wide in its central portion and 1,000 km long. It separates the southern Ethiopian plateau to the west from the Somali plateau to the east (Ernesto *et al.*, 2015).

Northward, it progressively widens out into the complex Afar triple junction, while at its southern end, a200– 300km tectonically disturbed area (Gofa basin and range) marks the transition to the Kenyan Gregory Rift in the Turkana depression (Ernesto *et al.*, 2015).

A lower basalt unit with trachyte basalts and subordinate silicic flows from 11 to 8 Ma old followed by a widespread ignimbrite cover (e.g., Nazaret Group) ranging in age from 7 Ma in the northern sector to 2 Ma to the south and up to 700 m thick (Ernesto *et al.*, 2015). Most of the ignimbrite layers are believed to have formed by catastrophic eruptions related to the collapse of large calderas, such as the 3.5-Ma old Munesa caldera now buried beneath the Ziway–Shala lakes (Ernesto *et al.*, 2015; Ayenew, 2008).

2.2. Research Framework

Due to consideration of Enset-Based land use system (EBLUS) in the land cover classification process, cover factor and management factor of Meki river watershed will vary and hence, the soil loss may be affected. Therefore, this study articulates the change in EBLUS in relation with soil loss in Meki river watershed.

Flow diagram of soil erosion modeling processes considering EBLUS is presented in Figure 2.

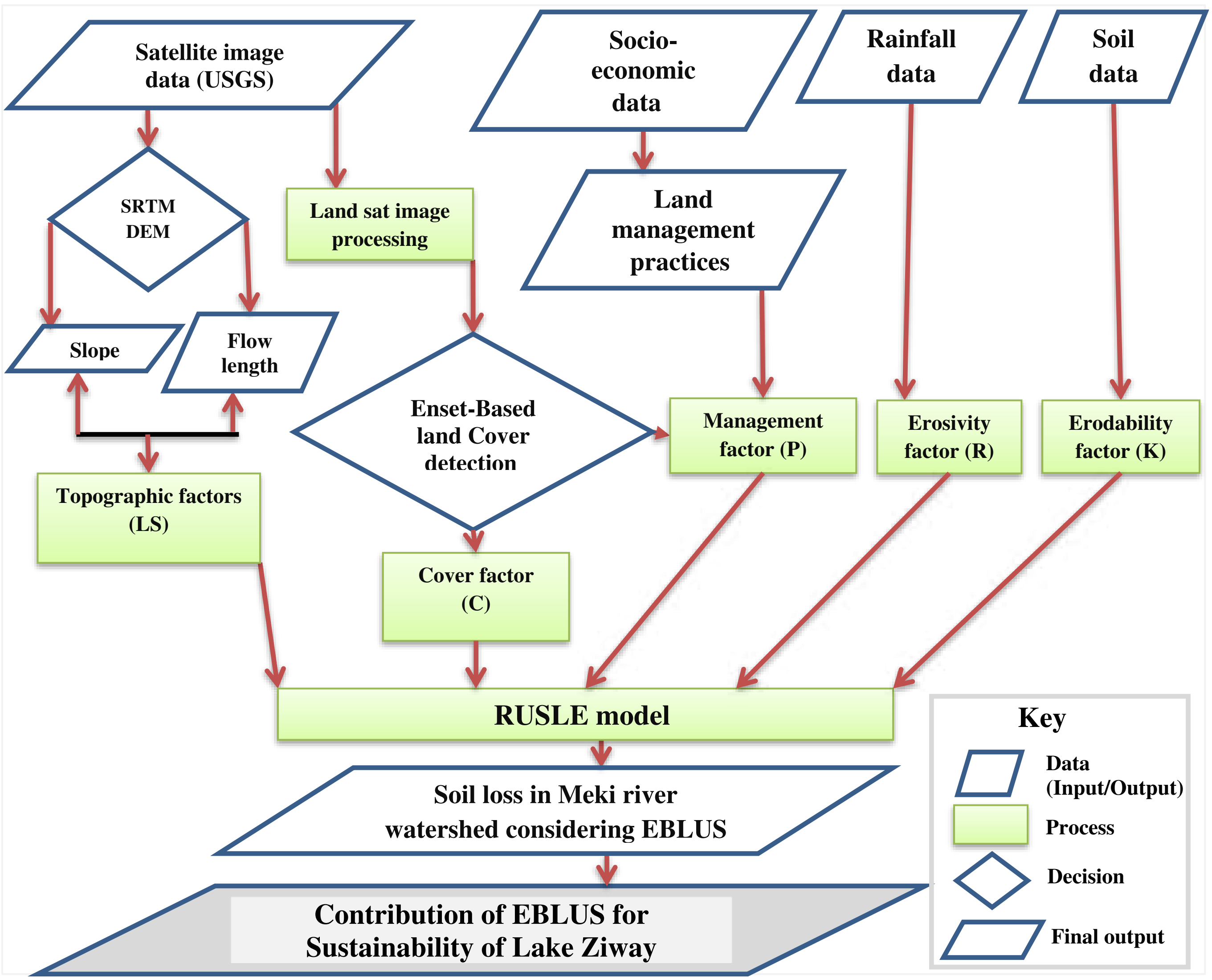

Figure 2: RUSLE model flow diagram

2.3. Digital Image processing & Land Cover Change detection

In the study area Enset-Based land use system (EBLUS) was not included in all former land use studies 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 as presented in Table 1.

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 AOI 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

The ground truth data have been 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 and assessment, the upper zone (Afro-alpine vegetation zone) of Meki river watershed composed of Erica dominated natural forest lands; patches of grazing lands; eucalyptus plantations and Enset-Based land use system as the main land cover types with highly sensitive ecological setups as shown in Figure 3. The high slope with sparse population is found but through time 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 area 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 Enset-Based land use system 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 with dispersed trees as shown in Figure 4.

In this portion of the watershed, irrigation practice is not common that the rain-fed agricultural practice is the dominating one with respect to the classification of the land cover and it is known for its degraded nature of the surface. 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. The Enset-Based land use system has better treatment than other land use systems in the middle zone of the watershed while high pressure is manifested in the grazing land use system.


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 result, 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 by their categories of 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 for which the modified version of the Anderson land cover classification scheme (Anderson, 1976) was adopted.

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.

The change in land cover was 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.

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 were estimated using revised universal soil loss equation (RUSLE) and GIS models by 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 that have been 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 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):

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

Where A is the amount of soil erosion (t ha-1yr-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 factor, L is the length of erosion slope, while S is the gradient of erosion slope); 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 Meteorological Agency (EMA) 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 erosivity occurring from rainfall and runoff at a particular location. An increase in the intensity and amount of rainfall results in an increase in the erosivity of rainfall and an increase in the value of R which is interpolated using excel based on the values Modified in (Mekuria Argaw, 2005; Hurni, 1993; Hurni, 1988) for Ethiopian condition and also formula developed by Hurni (1985) in Ethiopia context and adopted by different researchers (Mengesha et al., 2018; Asnake & Amare, 2019; Bewket and Teferi, 2009) and presented as shown in Table 2 and R values derived between 478.3 to 700 for Meki river watershed.

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

The value of R is computed from both methods and averaged to get the representative value and it is presented in Table 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).

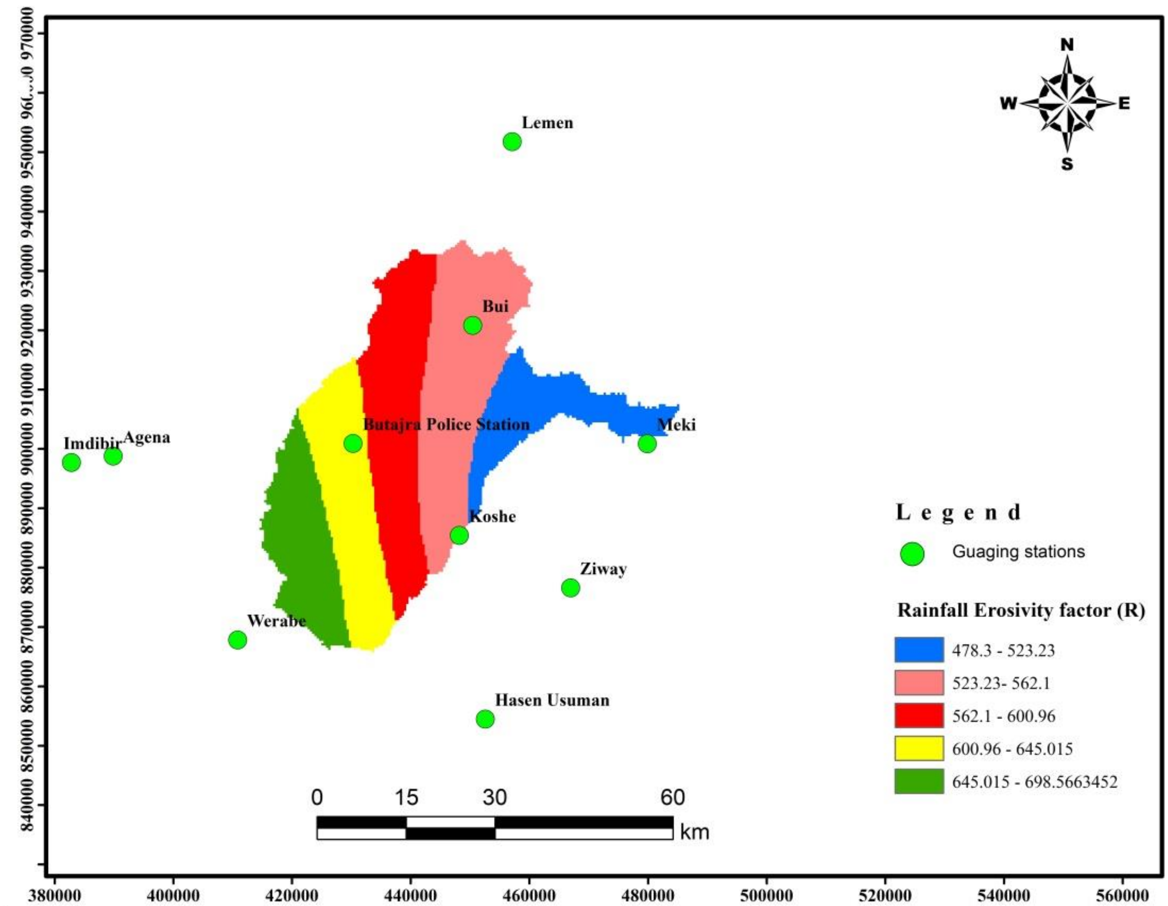

Figure 6: Rainfall Erosivity factor (R) map of the watershed

Determination of soil erodibility factor (K)

The K factor expresses inherent erodibility of the soil or surface material. It is a measure of soil erodibility in terms of susceptibility to detachment as well as transport, and ranges from 0.05 for low erodibility to 0.4 for high erodibility. While 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 affects infiltration capacity and the extent to which the soil particles can be detached and transported.

Texture is the dominant property determining erodibility, but soil structure, organic matter, water content and density or compactness, as well as chemical and biophysical characteristics of the soil also influence erodibility (El-Swaify and Dangler, 1976).

The soil erodibility factor K can be approximated from a monograph if this information is known. The USLE monograph estimates erodibility from equation 2 (A. Kavian *et al.*, 2017; Yang *et al.*, 2005; Wischmeier & Smith, 1978).

$$K = 2.73 * 10^{-6} M^{\frac{1}{14}} (12 - a) + 3.25 * 10^{-2} (b - 2) + 2.5 * 10^{-2} (c - 3)$$ Equation 3

Where, M is (% Silt + % Very Fine Sand) (100- % Clay), a is the percent organic matter content, b is the soil structure code, and c is the soil permeability rating.

Based on Hurni (1985), he has developed the factor table from the monograph & adopted by Bewket and Teferi (2009); Mekuria (2005) relating the color of soil used to assign erodibility 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 during land cover training sample collection and field measurement of infiltration rate of the soils. Accordingly, the erodibility factor (K) value is assigned for each soil type as shown in Table 3 and also black, brown, red and yellow, and their corresponding K factor values are 0.15, 0.2, 0.25 and 0.3, in order of sequence.

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 adopting the values of the color to the corresponding Erodibility (K) value.

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

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

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.

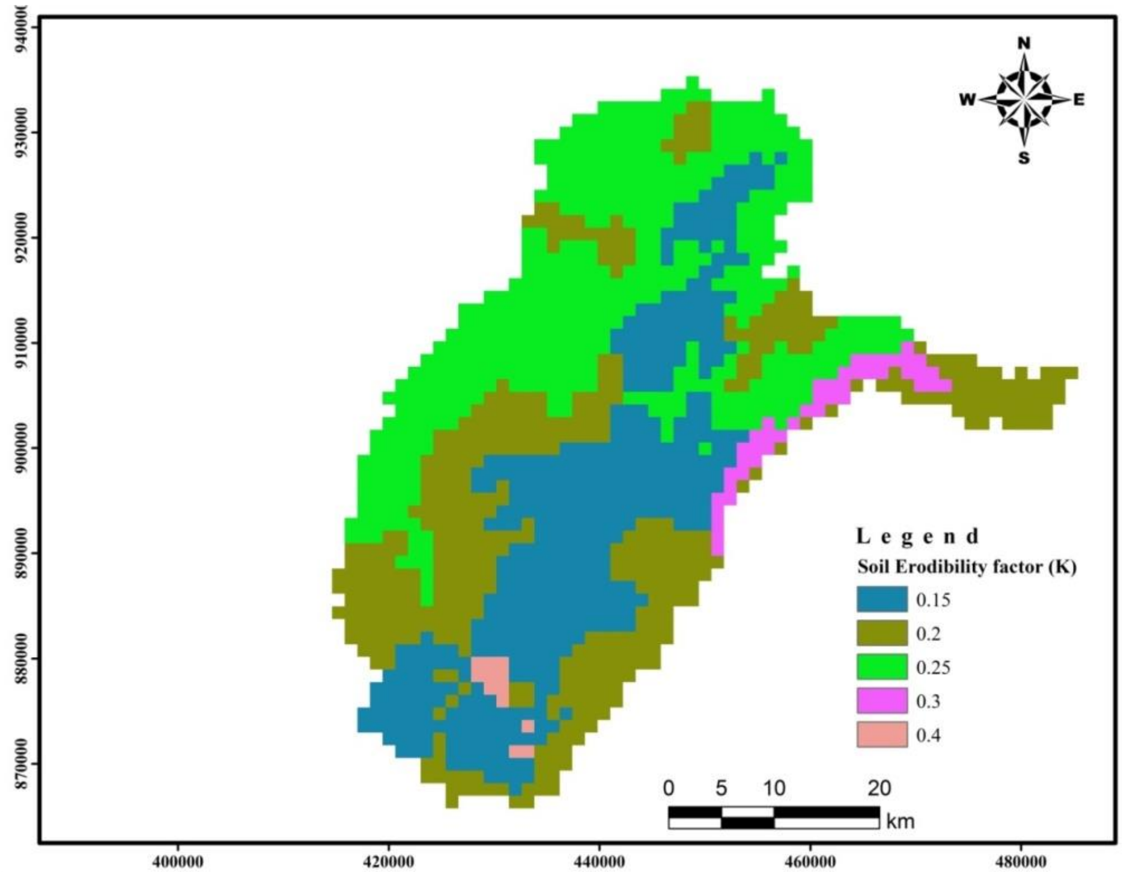

Figure 7: Soil erodibility (K) value map of Meki watershed

Determination of topographic factor (LS)

The LS factor expresses the effect of topography, specifically hill slope length and steepness, on soil erosion. The increase in hill slope length and steepness results in an increase in the LS factor and soil erosion (Asnake and Amare, 2019; Fenta *et al*., 2016 and A.Kavian *et al*. 2017).

Various approaches have been used to estimate the topographic (LS) factor. Digital Elevation Model (DEM) at 30 m resolution and GIS techniques were used to obtain both slope gradient (S) and slope length (L) (Wolka et al., 2015; Bewket and Teferi, 2009; Nekhay et al., 2009).

Several researchers followed variable methods which can express the study area and the access to data from various sources. Since the topographic factor (LS) determination devised using Arc-GIS, similar results may be manifested all over the world. But there may be different combination of Arc-GIS outputs and accordingly the LS factor was calculated using different equations as shown in Table 4.

Table 4: Table of topographic factors formula for different studies

Equation	**Description**	**Source**	**Av. LS**	**Area**
$\mathbf{LS = 1.4[\frac{\mathit{As}}{22.13}]^{0.4} * \left(\frac{\sin(\beta)}{0.0896}\right)^{1.3}}$	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
$\mathbf{LS = [\frac{\beta\chi}{22.13}]^{0.5} * (\frac{\sin(0.01745\mathit{s})}{0.0896})^{1.3}}$	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
$\mathbf{LS = [\frac{fac*DEM\ resolution}{22.13}]^{0.4} * (\frac{\sin(\mathit{s})}{0.0896})^{1.3}}$	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
$\mathbf{LS = \left(\frac{\lambda}{22.1}\right)^{\mathit{m}} * (0.065 + 0.045x + 0.0065(x)^2}$	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.

$$\mathbf{LS} = \left(\frac{\lambda^{0.3}}{22.1}\right) * \left(\frac{S}{9}\right)^{1.3} \qquad \text{Equation 4}$$

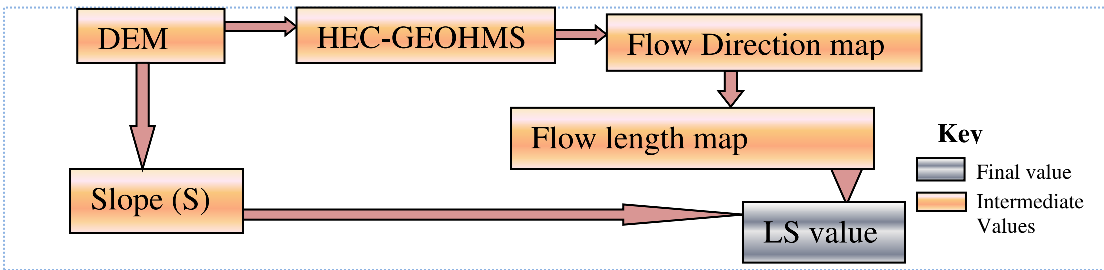

Figure 8: Flow chart for LS value determination

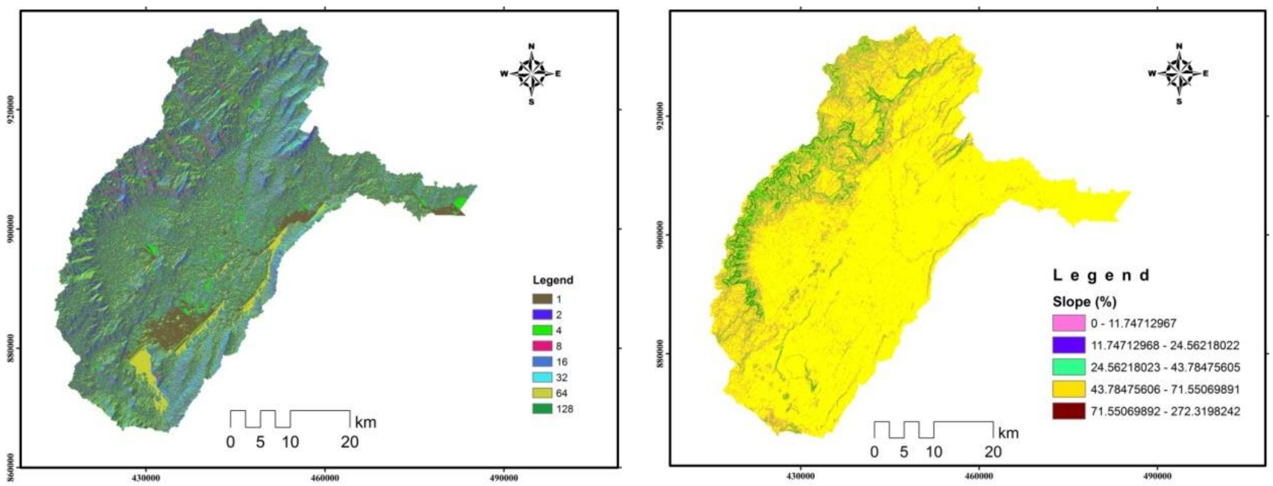

Figure 9: Flow length & Slope map of Meki watershed

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.

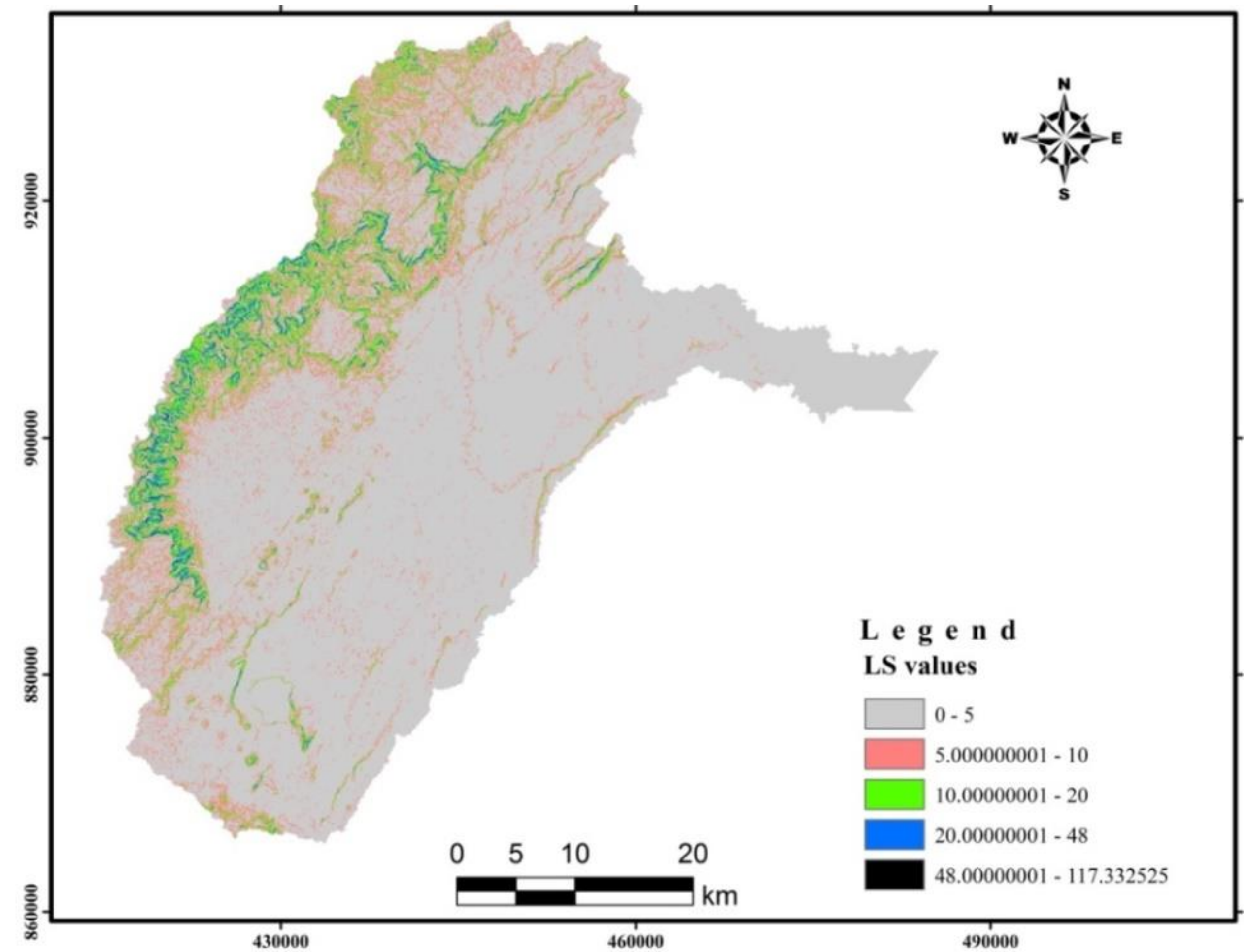

Figure 10: Topographic (LS) map of Meki watershed

Determination of land cover factor (C)

The cover and management factors (C) and support practice factor (P) are considered as dynamic factors that vary through time (A.Kavian et al., 2017). The C cover-management factor is used to express the effect of plants and soil cover. Plants can reduce the runoff velocity and protect surface pores. The C-factor measures the combined effect of all interrelated cover and management variables, and it is the factor that is most readily changed by human activities. To determine the cover factor, classified images and ground truth data are used.

Geographical positioning system (GPS) is used to find out the level of classification for major land use types & HEC_GeoHMS extension of ArcGIS 10.1 is used to determine other characteristics of the watershed. This is supported by interviews of local farmers for land use land cover condition of the area. After changing the classified raster date to vector, a corresponding C-value was assigned to each land use classes using reclassify method in Arc GIS 10.1 which is supported by different literatures as shown in Table 5. With regard to 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 is prepared for the 1987 & 2017 land sat image classified land covers and mapped as shown in Figure 11.

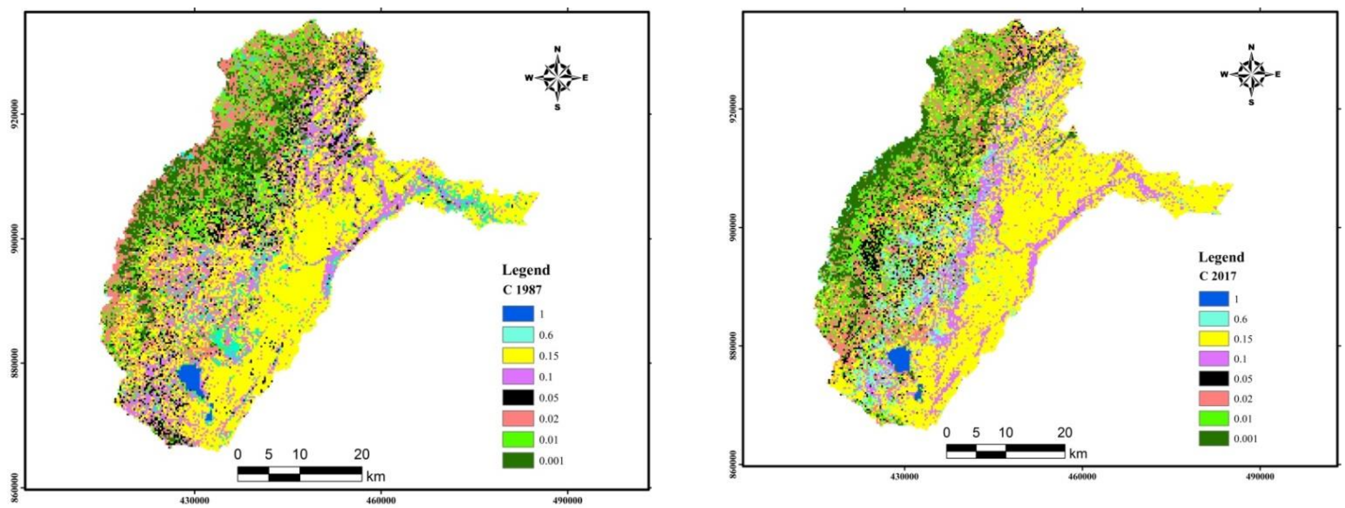

Figure 11: Land cover factor map of Meki watershed in 1987 & 2017

Determination of land management factor (P)

Field observations indicated that erosion management practices are not used in study area, so the erosion control practice factor (P) was set to 1.0 for all land uses.

The P factor is the support practice factor. It expresses the effects of supporting conservation practices, such as contouring, buffer strips of close-growing vegetation, and terracing on soil loss 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 offices. For the past management practices, it has been done an random based interview of local farmers who lived at least for the last 30 years for its change on management practices.

The result of interview, field observation and secondary information collected from different governmental offices shows that almost all land covers are without conservation measures although some watershed management trials by the government. Therefore, a unity is 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 for the enset is planted in rows serving as a contour with mulching practices and mapped as shown in Figure 12.

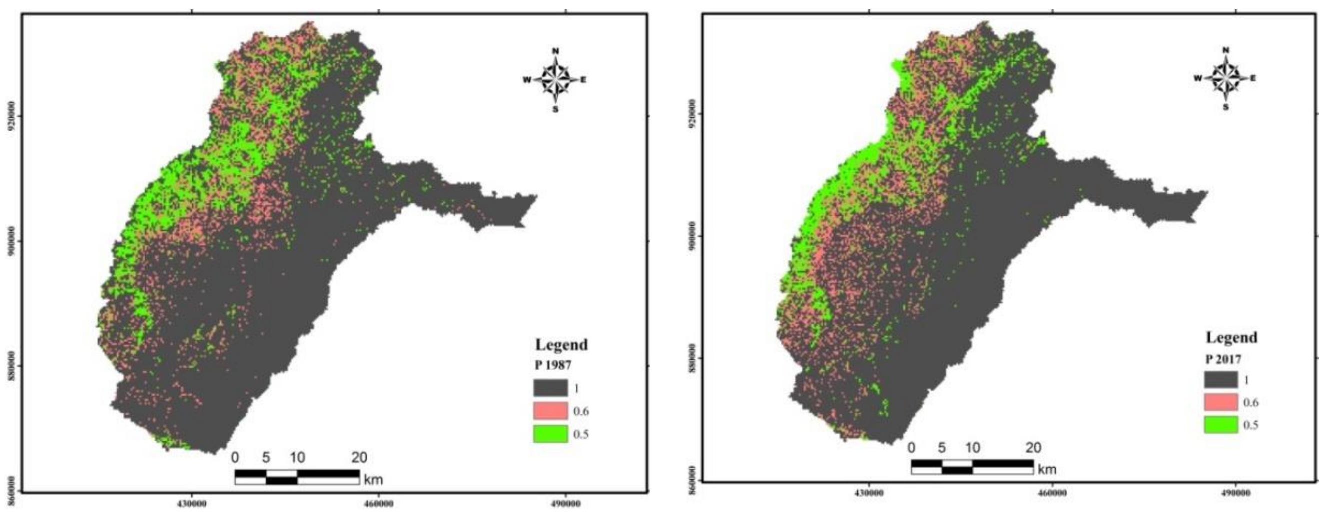

Figure 12: Management factor map of Meki watershed in 1987 & 2017

Determination of mean annual soil loss

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 is calculated from all the inputs and the difference in soil loss for the 1987 and 2017 is computed.

The result is extracted and reported for the classified land use land covers of Meki river watershed and also it is 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.

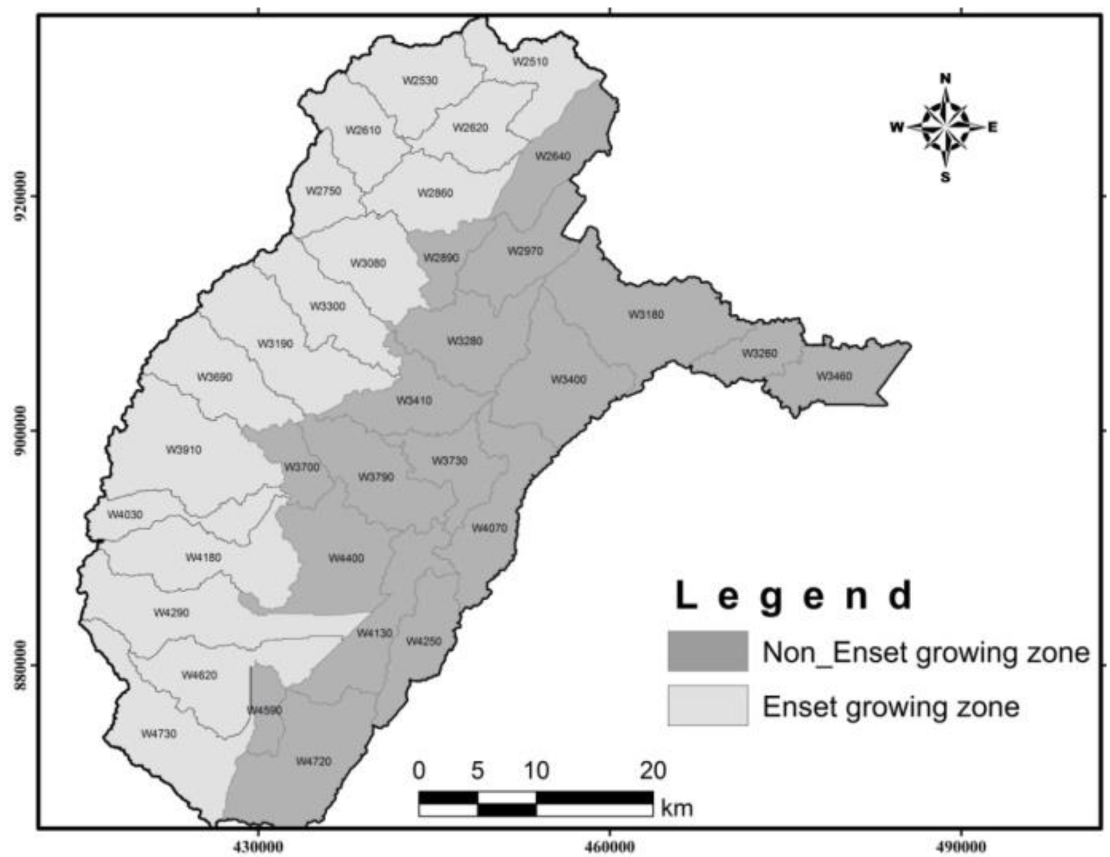

Figure 13: Sub-watersheds and major zones in Meki river watershed

3. Result and Discussion

3.1. Land use Land Cover Change detection

The Rift valley consultants[1] classified land cover of Meki river watershed in to Cultivated Land, Afro-alpine and sub Afro-alpine, Forest, Woodland, Riparian Vegetation, Shrub land, Grassland, Swamp and Marshland, Exposed Surface & Water body which didn't consider Enset-Based land cover as a separate entity (MoWR, 2008). Hence, land cover classification is devised for 2017 Landsat image to treat Enset land cover as a separate unit which results in eight land cover categories as: Built-up (7.8%), water bodies (0.6%), Enset (Eset)-Based land use system (10.8%), Bush and chat land (14.5%), Cultivated land (40.2%), Grass land (11.9 %), Eucalyptus plantations (4.2%) and Forest and natural vegetation (10.1%).

Enset-Based land use system is dominantly practiced on the upper watershed of the lake Ziway especially at an elevation of more than 1800m.a.s.l. which is evidenced by (Uloro & Mengel, 2014) that Enset grows at an altitudes range between 1600 and 3100m.a.s.l but the main cultivation zone lies between 1800 and 2450m.a.s.l.

The land cover change is performed for two images of 1987 and 2017 for which meteorological data is available to modeling purposes which covers 30 years with the same designations stated in the above descriptions for the 2017 Landsat image classified land cover.

More than 40% of the watershed is covered by cultivated land which is expanding starting from 1987 up to 2017 as shown in Table 6 and the change in such land use system can have a significant implication to the ecology (A. Kavian, 2017), hydrology (Ermias Teferi et al, 2013;

[1] HALCROW & Generation Integrated Rural Development Consultants

DeFries and Eshleman, 2004; Uhlenbrook, 2007) and sustainability of water resources (Wolka et al., 2015) in Meki river watershed.

There is a positive change in cultivated land (Wolka et al., 2015), Enset-Based land use system and Built up land use systems 1987 to 2017. The significant positive change is observed in all the three land use land covers stated while a significant decrement is recorded in Grass land, Eucalyptus plantation, Forest land, Bush land and water bodies in their order of decreasing change.

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	29716.45	25533	-4183.44	11.9
Forest & Natural vegetation	21768.76	20967.58	-801.18	10.07
Enset	20534.87	22733.9	2199.03	10.8
Eucalyptus	12499.19	9111.22	-3387.98	4.2
Cultivated and degraded	85816.29	86677.53	861.25	40.16
Bush & Chat	29455.42	28896.83	-558.59	14.46
Water bodies	1383.07	1207.76	-175.31	0.58

Evidence from elders and experts interviewed and also data from Woreda Agriculture offices and NGOs in the watershed shows that the enset based land use system, cultivated land and builtup area coverage is increasing over the last 30 years while the forest cover and grass land coverage are decreasing from time to time.

According to SCRP (1996) and Hurni (1989), rapidly increasing population, deforestation, over cultivation, expansion of cultivation at the expense of lands under communal use rights (grazing and woody biomass resources), 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 in general. According to Mesfin et al., 2017 and Deng et al., 2016 soil carbon stocks considerably decreased after the conversion from grassland and forest to farmland. The most important threats to forest genetic diversity are deforestation and forest fragmentation (Charles et al., 2016).

Similar results are found from different studies in different parts of the country over the different time periods which include expansion of subsistence crop production into ecologically marginal areas and deforestation have been the common forms of transitions (Bewket and Teferi, 2009). According to Bewket and Teferi (2009), these conversions 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.

According to Woldetsadik (2004), in 1930s more than 20% of Gurage Mountain landscape were covered with natural forests and primarily oriented to subsistence agriculture. Since then, these 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 cultivated land use system, Enset-Based land use system (EBLUS) and settlement.

3.2. Soil erosion modeling result and discussion

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

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 tha-1yr-1 to 25.94 tha-1yr-1, in Enset land use system from 17 to 22.65tha-1yr-1, in grass land use system from 25 to 27tha-1yr-1 and others in 1987 and 2017 respectively as shown in Table 7.

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

Class_Name	**Soil Loss 1987 (tha-1yr-1)**		**Soil Loss 2017 (tha-1yr-1)**	
	Mean	**SD**	**Mean**	**SD**
Grass	25	83	27	90
Forest & Natural vegetation	14.5	57	25.94	124.2
Eucalyptus	28.5	72	31.17	88
Enset	17	61	22.65	68
Cultivated and degraded	26	44	27.15	44
Bush & Chat	32	70	40.22	78.3
Builtup	69.2	175.25	64.4	120.65

The annual average soil loss of the watershed increased from 25 tha-1yr-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}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.

Both the annual average values are beyond the permissible limit of soil loss for Ethiopian highlands reported by Wolka et al. (2015) the ‘tolerable’ range of soil loss for central rift valley as less than 10 $tha^{-1}yr^{-1}$ and Hurni (1993) expresses the range as 6 $tha^{-1}yr^{-1}$ to 10 $tha^{-1}yr^{-1}$.

The rate found in this study is more than the tolerable level mentioned in both cases but the lowest level of loss is recorded in the Enset-Based land use system in 2017 analysis. The dominant factor for the retarded soil loss in these areas is the gentle slope gradient and the protective nature of the land use systems, predominantly the perennial crops such as ‘Enset’ based agroforestry system which could also contribute to arresting soil movement in these areas (Wolka et al., 2015).

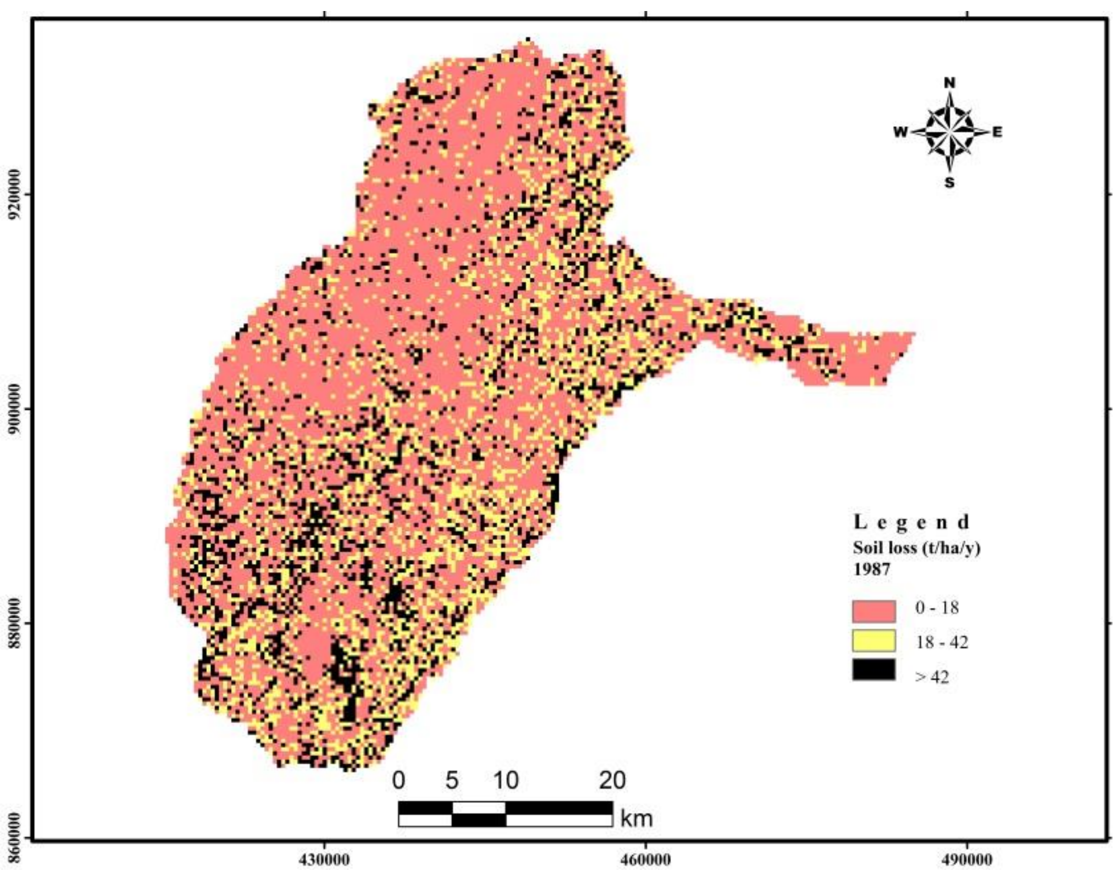

Figure 14: Soil loss (tone/ha/year) in 1987

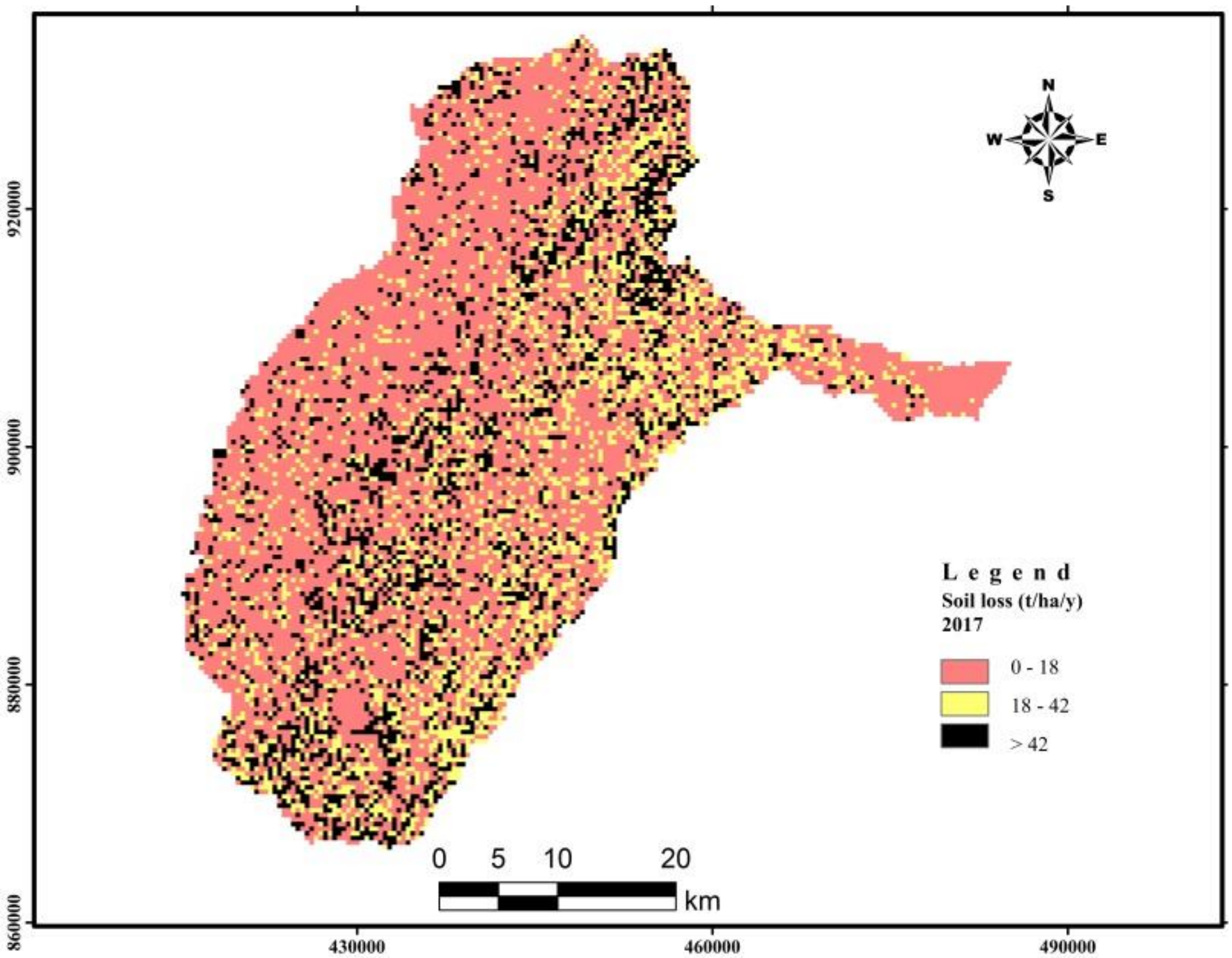

Figure 15: Soil loss (tone/ha/year) in 2017

A pairwise comparison of soil loss from each land use system indicates that on average Enset-Based land use system can save 11.426tha-1yr-1 relative to other land use systems which is a significant amount of sediment that can be kept in-situ if Enset-Based land use system is enhanced in the watershed. If the whole land cover system is replaced by Enset-Based land use system (scenario 1), 2,411,332.3t/yr soil will be saved from marching downstream to Lake Ziway from 2110.39056km² of land which is under threat of siltation so that Enset-Based land use system will contribute for sustainability of the lake.

The highest soil loss is recorded in the built up areas which currently is under construction that causes disruption of the natural ecological processes and irresponsible excavation activities in the construction sites of the newly established urban settings and their periphery.

Bush lands are one of the leading soil loss zones due to the overgrazing and annual mass burning activities of those bushes to get fire wood and also to eradicate different wild animals which attacks their crop, cattle and themselves from their surroundings as the farmers responding.

As it is observed during the field visit (transect) and also information gathered from the elders of the afro-alpine zone of the watershed, eucalyptus land use system on steep slope can aggravate the movement of soil downward since it has no root fiber to hold the soil in-situ which is manifested by high value of soil loss followed by cultivated lands which are temporarily covered by annual crops during high rainfall season while it has high record of soil loss at the onset of rainfall which brings the soil loss higher than soil loss from forest and Enset-Based land use systems.

According to Alemu *et al.* 2018, the bathymetric differencing of the lake indicates 3.13 t/ha/year sediment was accumulating which is attributed to the existence of outlet for the lake, floodplain depositions and sand mining from the tributary rivers before flowing to the lake but one of the reason may be attributed to Enset-Based land use system which was not considered in the study that generated the lowest soil loss in 2017 as shown in Figure 16.

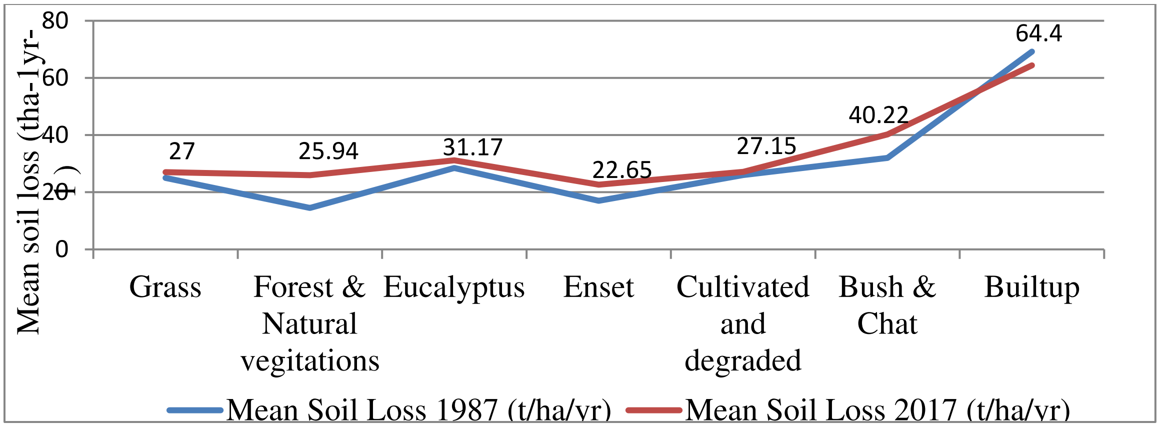

Figure 16: Soil loss curve in 1987 and 2017 for different land use systems

Sub-watershed based soil loss

Soil loss is evaluated for 34 sub-watersheds for 1987 and 2017 years over the last 30 years and evaluated against the national standard range from 2 to 18 tha^{-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 problem as shown in Figure 17.

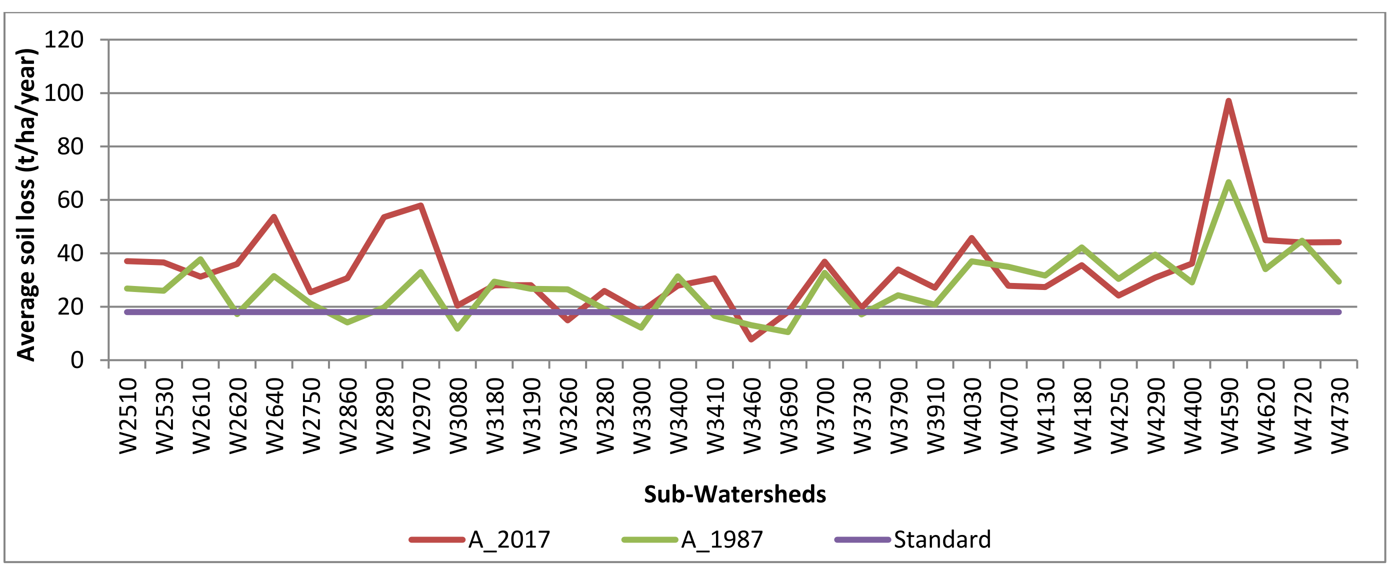

Figure 17: Average soil loss from sub-watershed of Meki river with respect to national average

A specifically standard is available for Rift valley soil formation rates and considered as a limit for evaluation soil erosion in the area. Soil removal rate (Loss) should not exceed the rate of replacement (formation). Therefore, the range of soil loss in the central rift valley should not be beyond 10 $tha^{-1}yr^{-1}$ as shown in Table 8.

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

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

Regarding the comparison with the standard in the central rift valley given in Table 8, currently only two sub-watersheds (W3260 and W3460) out of 34 sub-watersheds (5.88%) are nearest or below the standard line which indicates the presence of terrible soil loss problem on the area as shown in Figure 18.

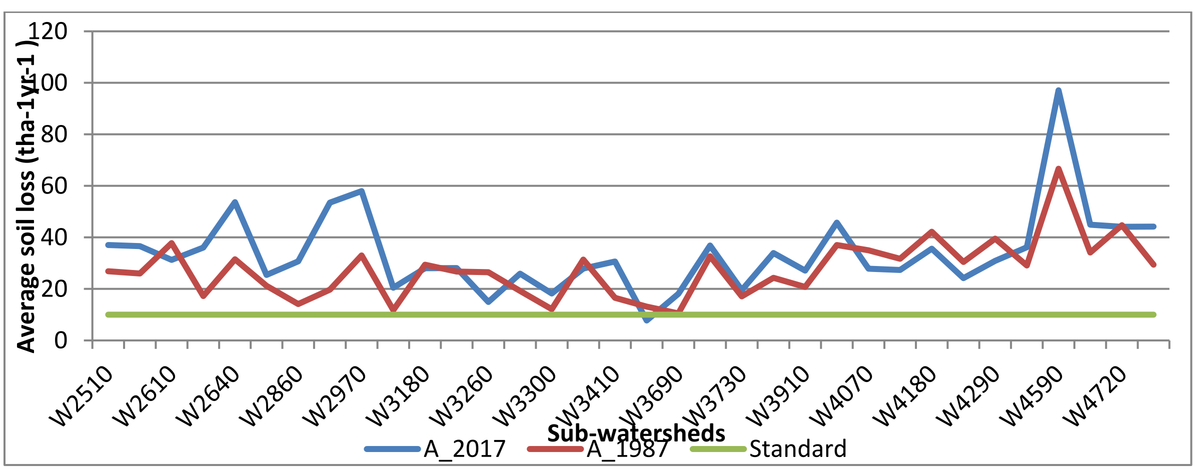

Figure 18: Average soil loss from sub-watersheds with respect to Rift valley limit

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.

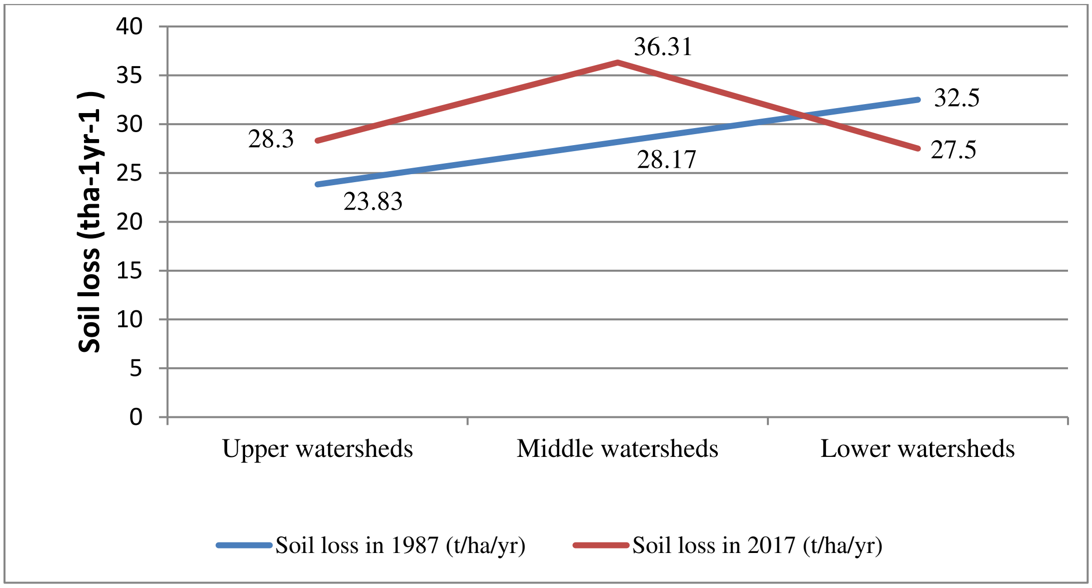

Figure 19: Zone based soil loss in Meki river watershed

Taking the averages of the lower watershed with that of middle watershed (Non enset growing region) and comparing with the upper enset growing portion of the watershed, there is a visible difference in soil loss as shown in Figure 20. Based on the soil loss in 2017, the soil loss difference between Non enset growing and enset growing zones is evaluated as 1.405$tha^{-1}yr^{-1}$ so that Enset-Based land use system can save 296,509.9tons of soil from 2110.39056km² area every year from the Meki river watershed marching down to Lake Ziway which implies that Enset-Based land use system can have contribution for the life of the Lake.

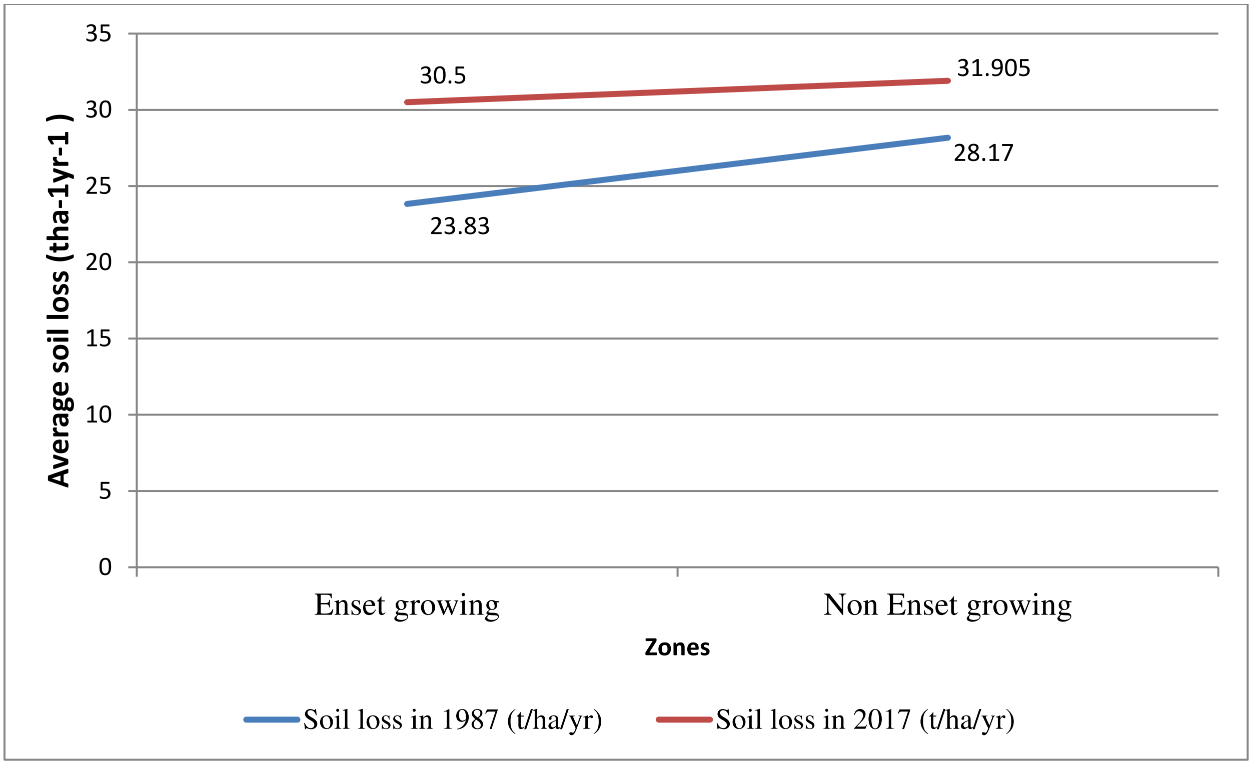

Figure 20: Enset-Based land use system based soil loss in Meki river watershed

Therefore, the expansion of Enset-Based land use system will contribute for the ecological sustainability of the surrounding in addition to its social, economic, food security, environmental and microclimatic importance and also it can reduce the soil loss rate and contributes in the sustainability of 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 ($tha^{-1}yr^{-1}$) (Bewket and Teferi, 2009)	Annual soil loss Range ($tha^{-1}yr^{-1}$) (Wolka et al., 2015)	Annual soil loss Range ($tha^{-1}yr^{-1}$) (Habtamu et al., 2020)	Annual soil loss Range ($tha^{-1}yr^{-1}$) (Asnake and Amare, 2019)	Annual soil loss Range (tha-1yr-1) (A. Kavian, 2017)	Annual soil loss Range adopted ($tha^{-1}yr^{-1}$)
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	-	-		

Considering 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 national average (18 $tha^{-1}yr^{-1}$) and for cultivated land (42 $tha^{-1}yr^{-1}$), the adopted ranges are given as Very low (<5), Low (5-10), Moderate (10-18), High (18-30), Very high (30-42), Severe (42-60), Very sever (60-80) and Extremely severe (>80) and hence, the result of 211039.06ha of the 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 (tha-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.

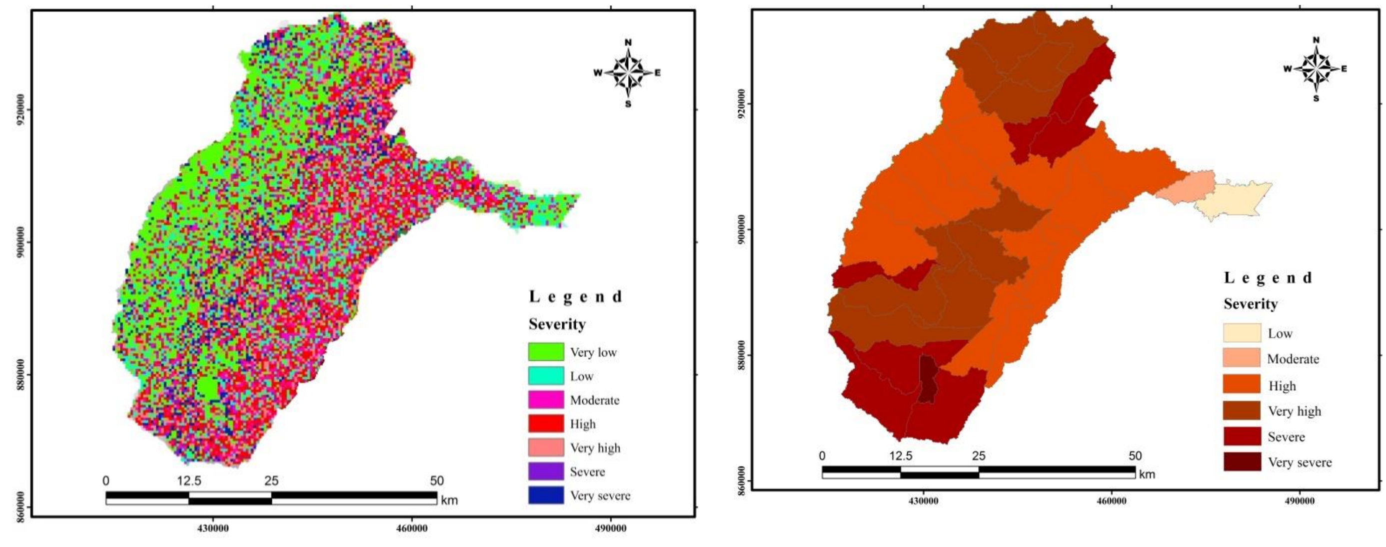

Figure 21: Spatial distribution of severity and its priority class

As shown in the distribution map, the very low soil loss is spatially well distributed on the Enset growing portion of the watershed but the average of both Enset growing (30.5 $tha^{-1}yr^{-1}$) and non-Enset growing (31.905 $tha^{-1}yr^{-1}$) zones of the watershed 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 vegitation 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 its main cultivation zone lies between 1800 and 2450 m.a.s.l. (Uloro and Mengel, 2014). The positive change in EBLUS from 1987 to 2017 will have substantial impact on sustainability of water resources (Wolka et al., 2015) in Meki river watershed.

Evidence from socio-economic assessment in the watershed shows that the Enset-Based and cultivated land use system area coverage are increasing over the last 30 years while the forest cover and grass land coverage are decreasing from time to time (Mesfin et al., 2017; Deng et al., 2016; Charles et al., 2016; SCRP, 1996; Hurni, 1989) and the most important threats to forest genetic diversity are deforestation and forest fragmentation which is manifested in the watershed.

GIS based RUSLE used in the modeling of soil loss in the Meki river watershed and 94.12% parts of the watershed are experiencing high severe to very severe soil erosion beyond the tolerable soil loss level (Wolka et al, 2015) which is manifested by 82.35% and 94.12% of the sub-watersheds are beyone 18 $tha^{-1}yr^{-1}$ and 10 $tha^{-1}yr^{-1}$ respectively which 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). The erosion may also have off-site consequences in the wetlands and have the possibility to modifying its nature and function (Wolka et al., 2015; Gleason RA et al. 2003).

The soil loss in the watershed is modified by EBLUS that could contribute to arrest soil movement (Wolka et al., 2015). The lowest soil loss is generated from Enset-Based land use system with a soil loss of 22.65tha^{-1}yr^{-1} in the year 2017 better than forest land with a soil loss of 25.94 tha^{-1}yr^{-1}. Soil loss in Enset growing zones (30.5 tha^{-1}yr^{-1}) which are influenced by very high topography of the watershed has less soil loss than the non-Enset growing zones (31.905 tha^{-1}yr^{-1}) with the difference of 1.405tha^{-1}yr^{-1} so that Enset-Based land use system can save 296,509.9tons of soil from 2110.39056km^2 area every year from marching down to Lake Ziway which implies that EBLUS can have contribution for the life of the Lake.

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 (Wolka et al., 2015) 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 (Table 10) 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. 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 area.

Abbreviations

DEM	Digital Elevation Model
GIS	Geographical Information System
EBLUS	Ensed-Based Land Use System
EGSIA	Ethiopian geospatial information agency
ERDAS	Earth Resources Data Acquisition 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

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

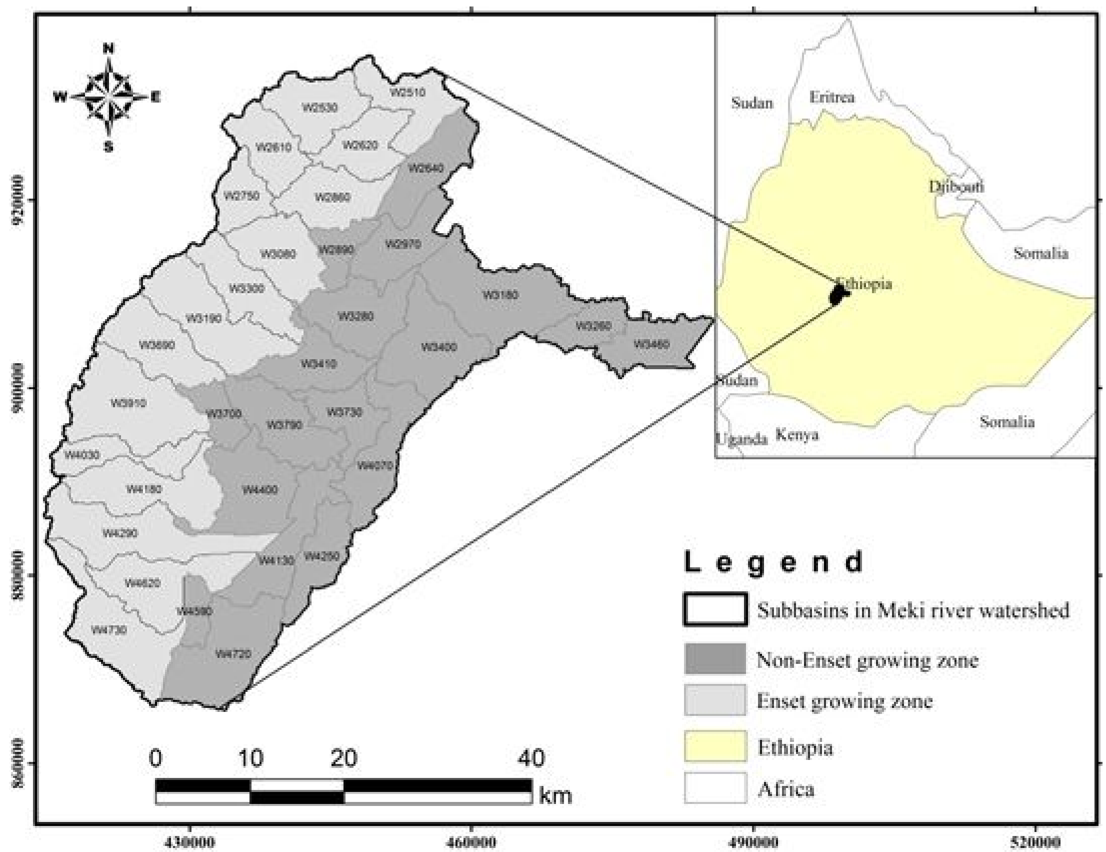

Figure 1

Study area map

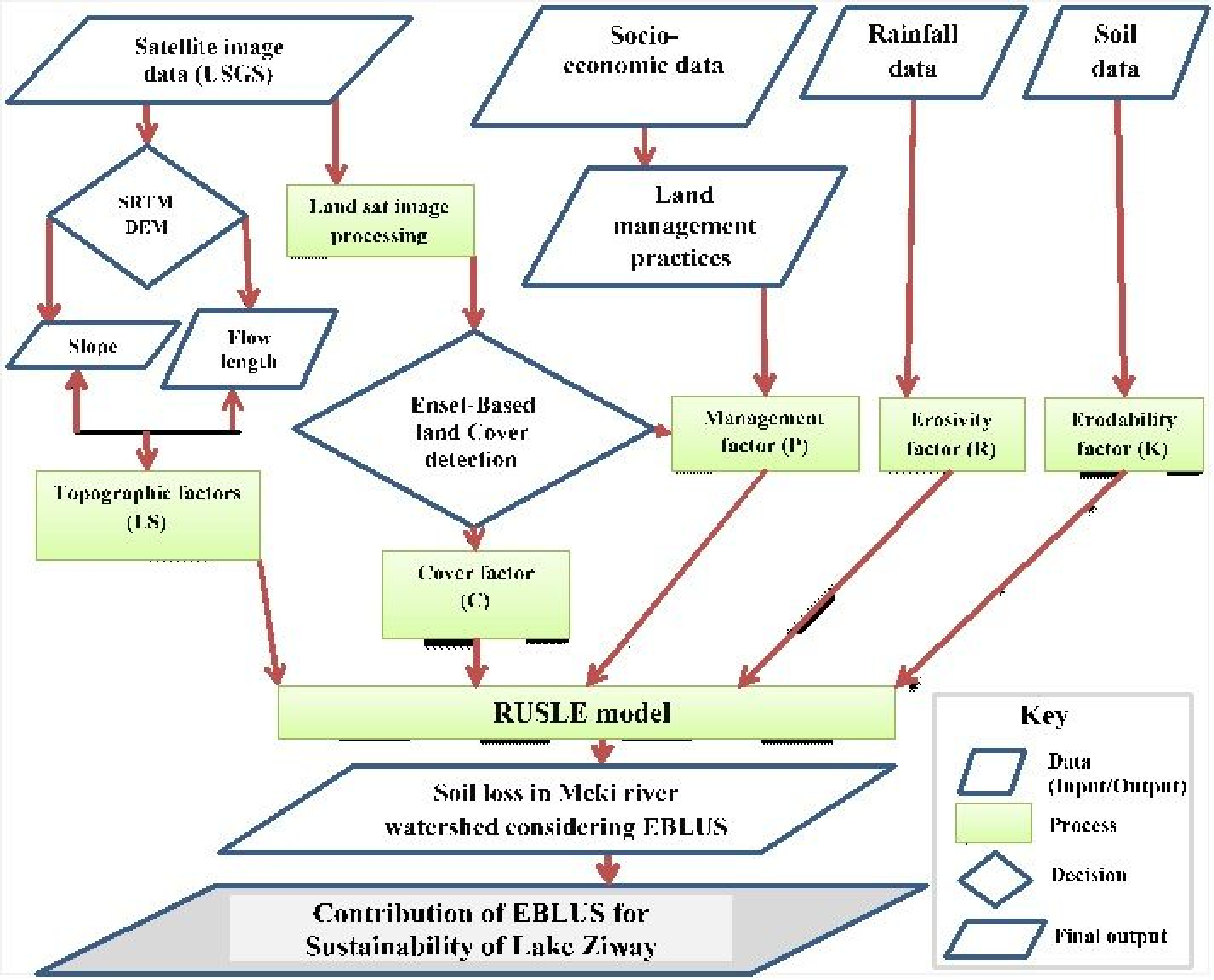

Figure 2

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

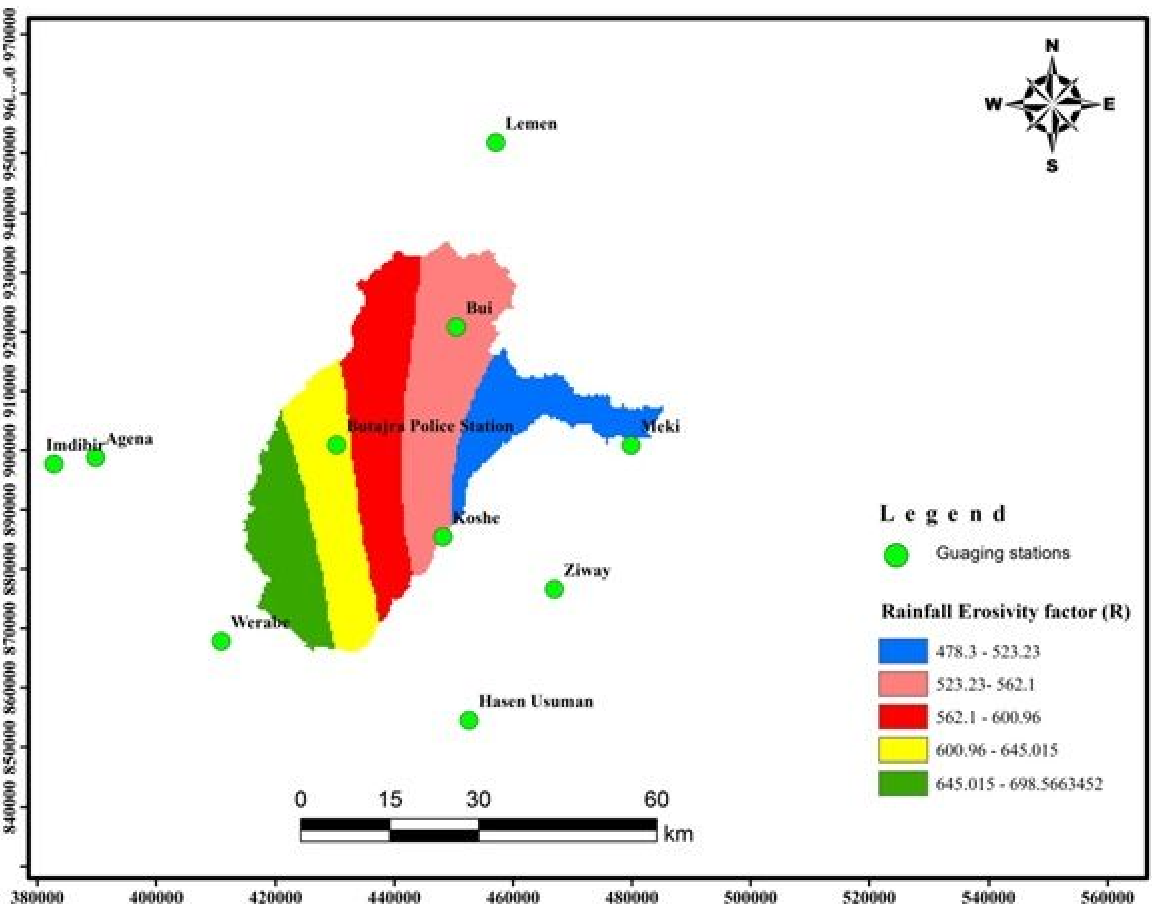

Figure 6

Rainfall Erosivity factor (R) map of the watershed

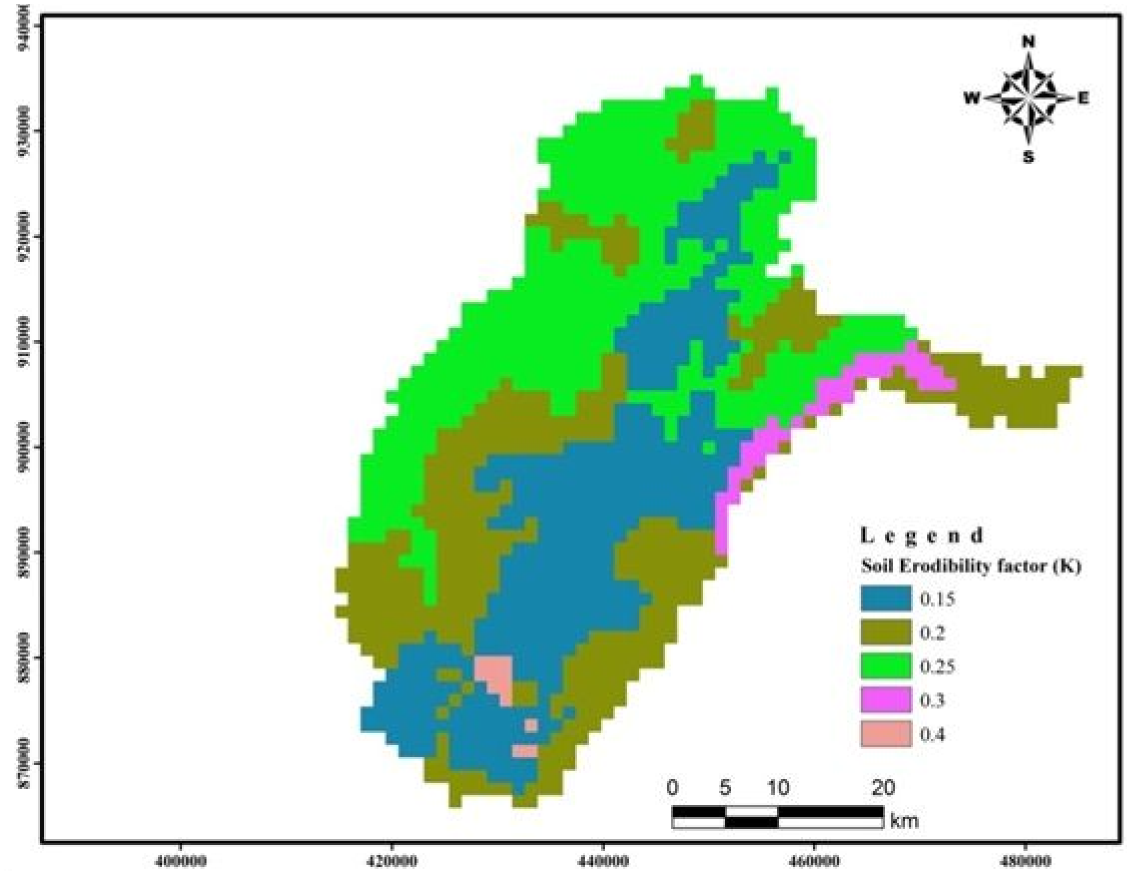

Figure 7

Soil erodibility (K) value map of Meki watershed

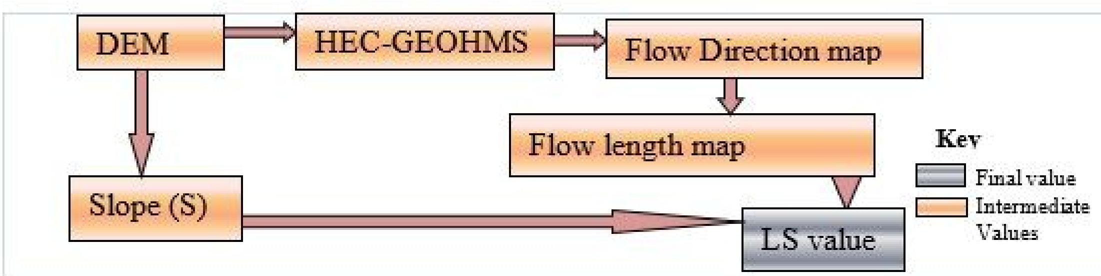

Figure 8

Flow chart for LS value determination

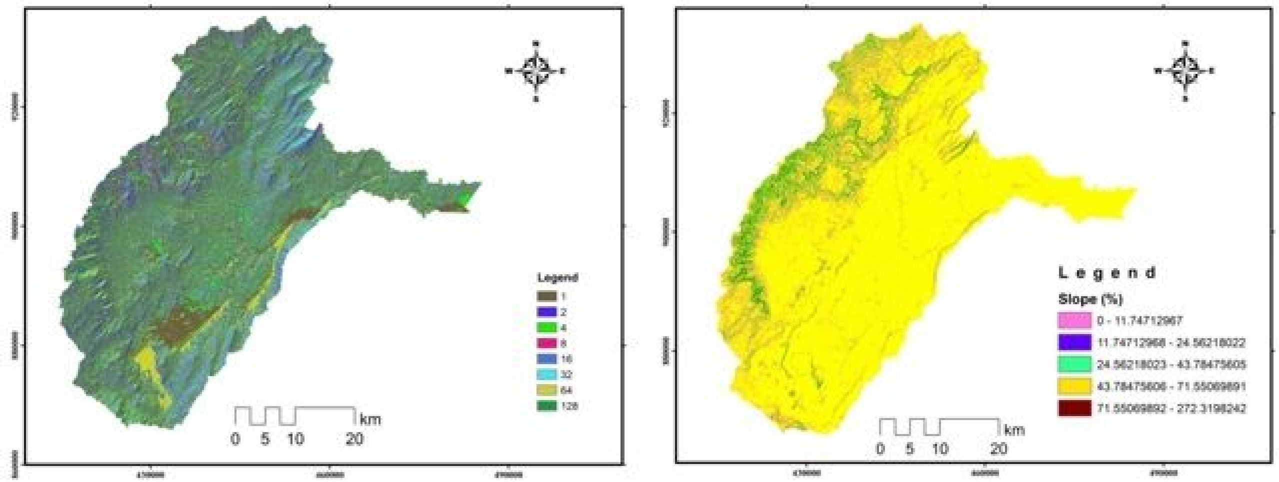

Figure 9

Flow length & Slope map of Meki watershed

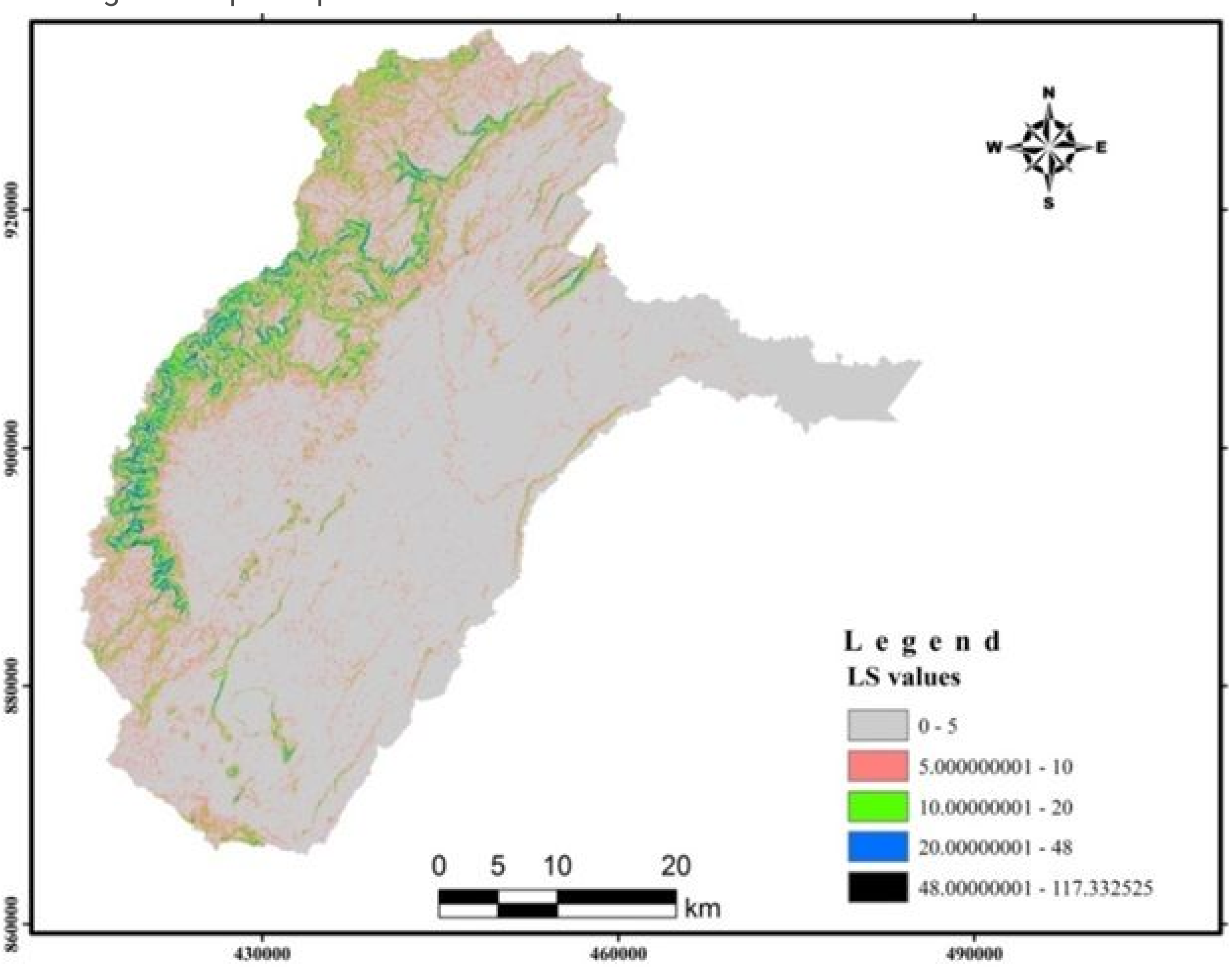

Figure 10

Topographic (LS) map of Meki watershed

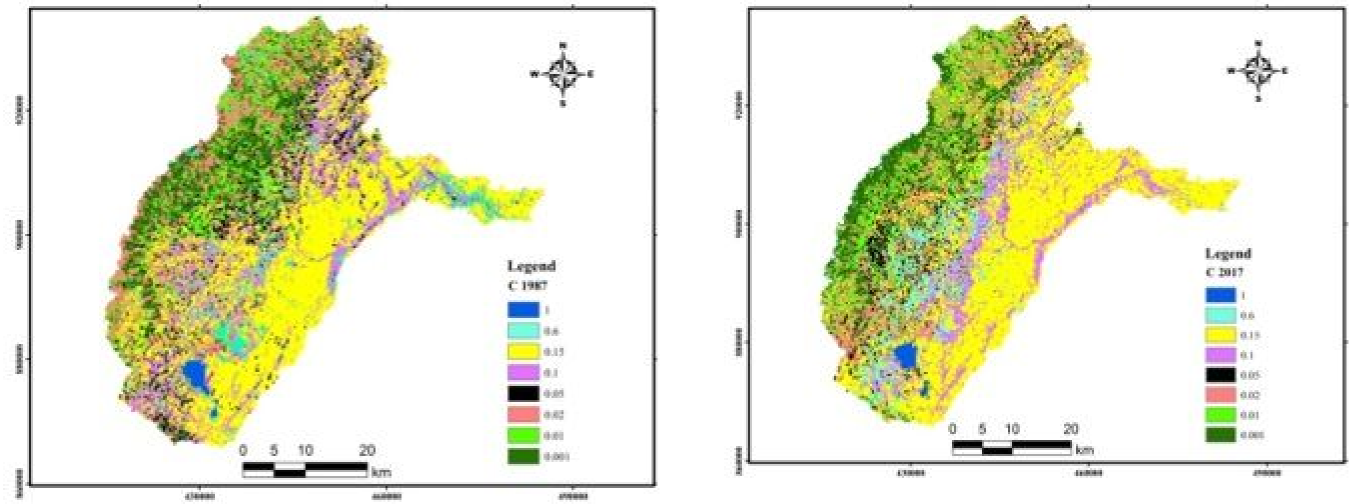

Figure 11

Land cover factor map of Meki watershed in 1987 & 2017

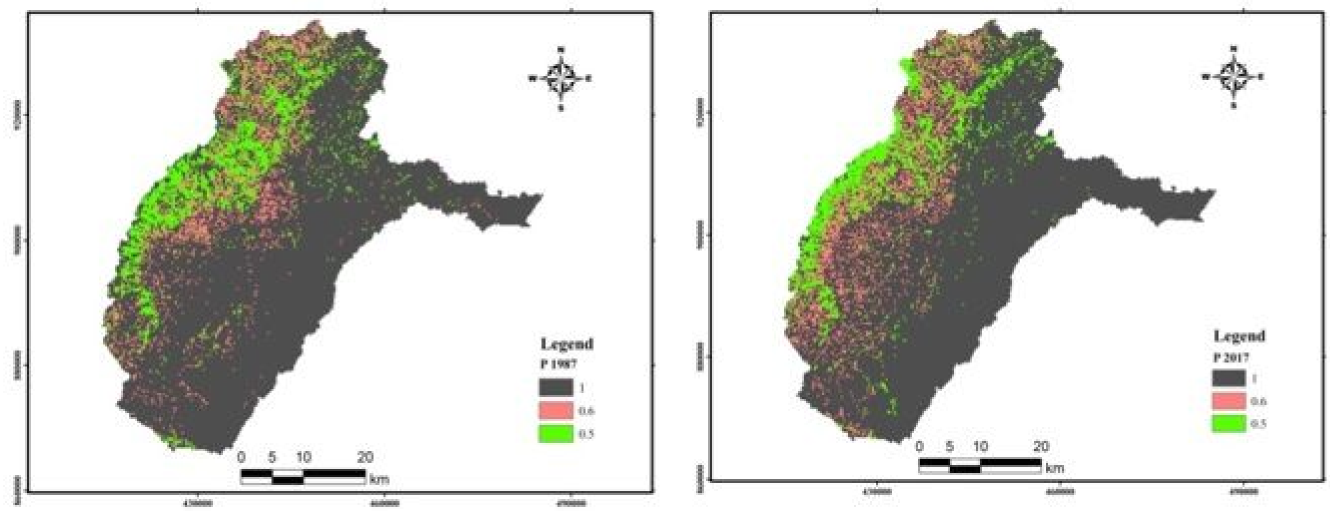

Figure 12

Management factor map of Meki watershed in 1987 & 2017

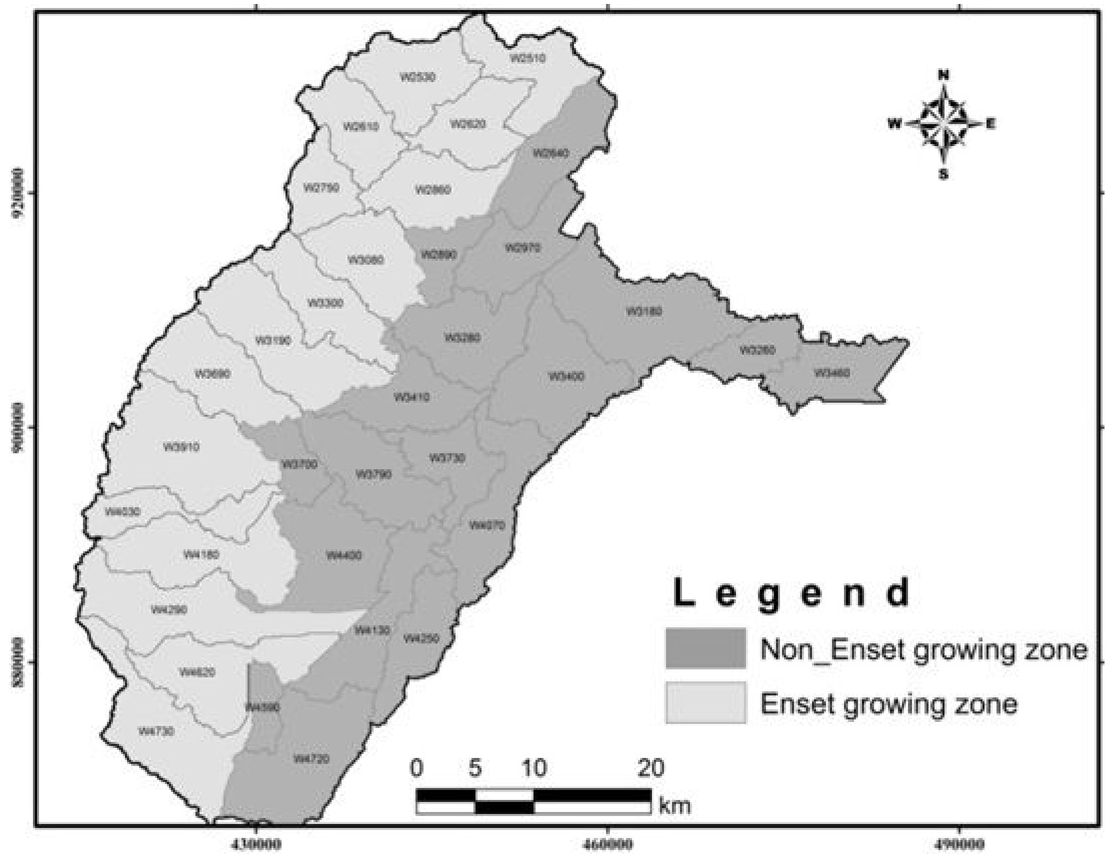

Figure 13

Sub-watersheds and major zones in Meki river watershed

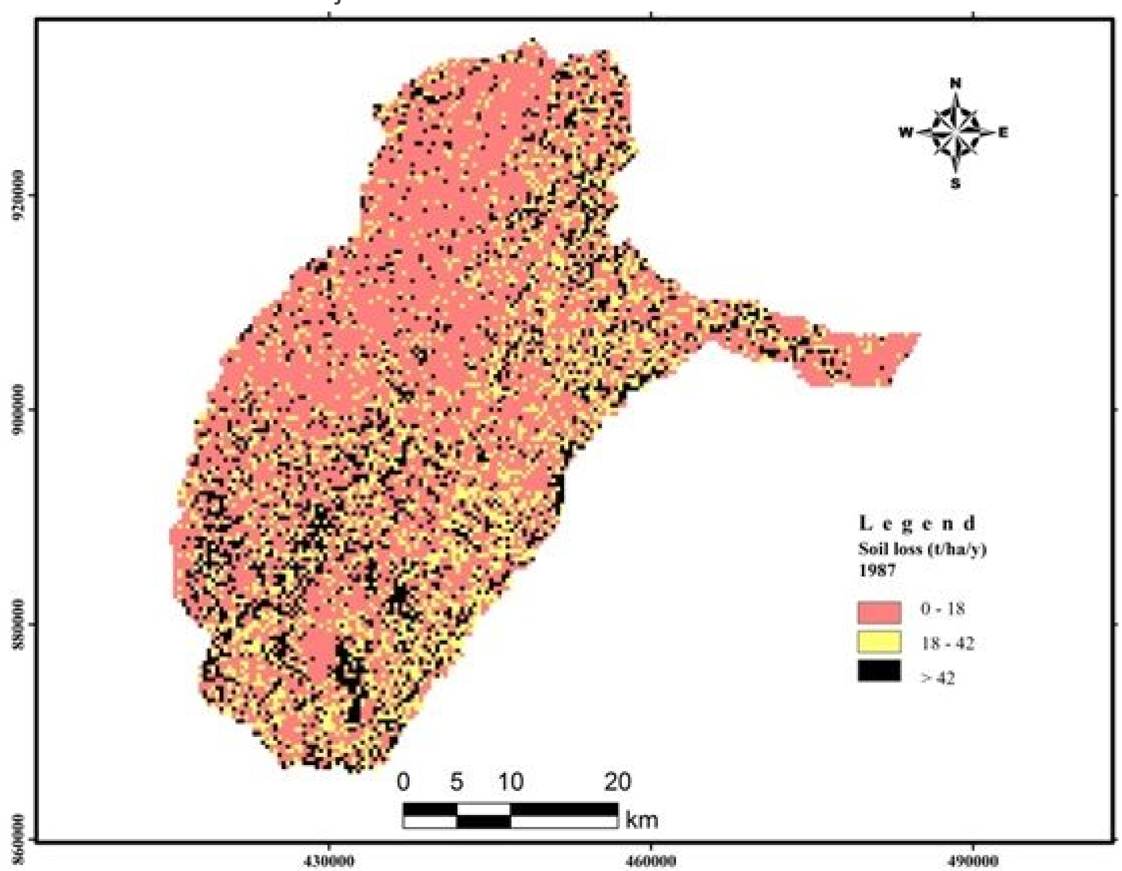

Figure 14

Soil loss (tone/ha/year) in 1987

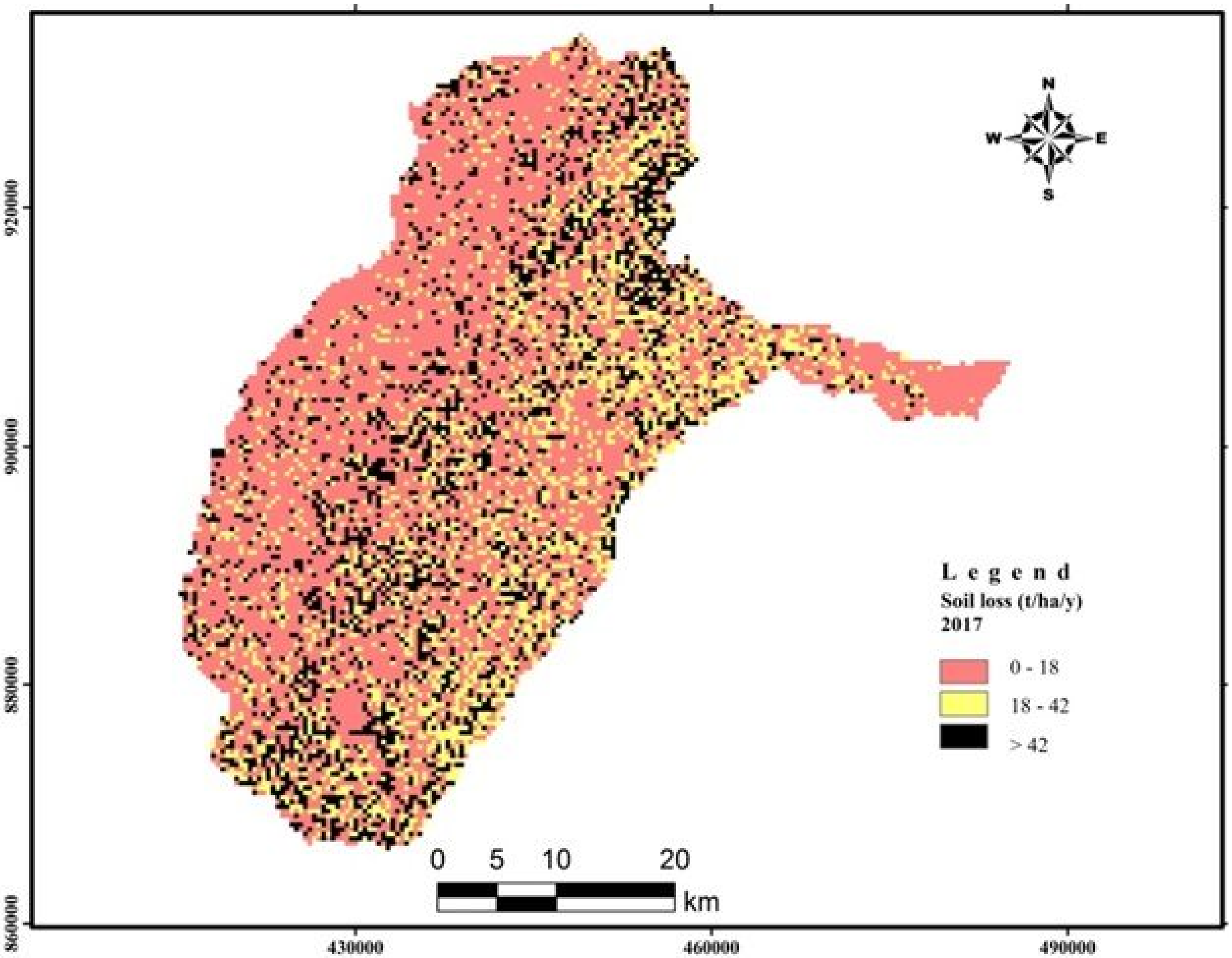

Figure 15

Soil loss (tone/ha/year) in 2017

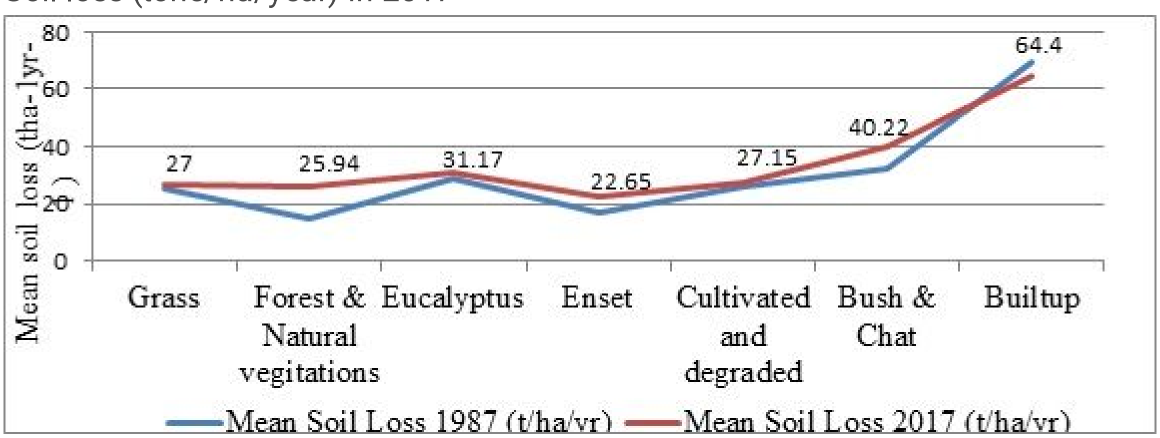

Figure 16

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

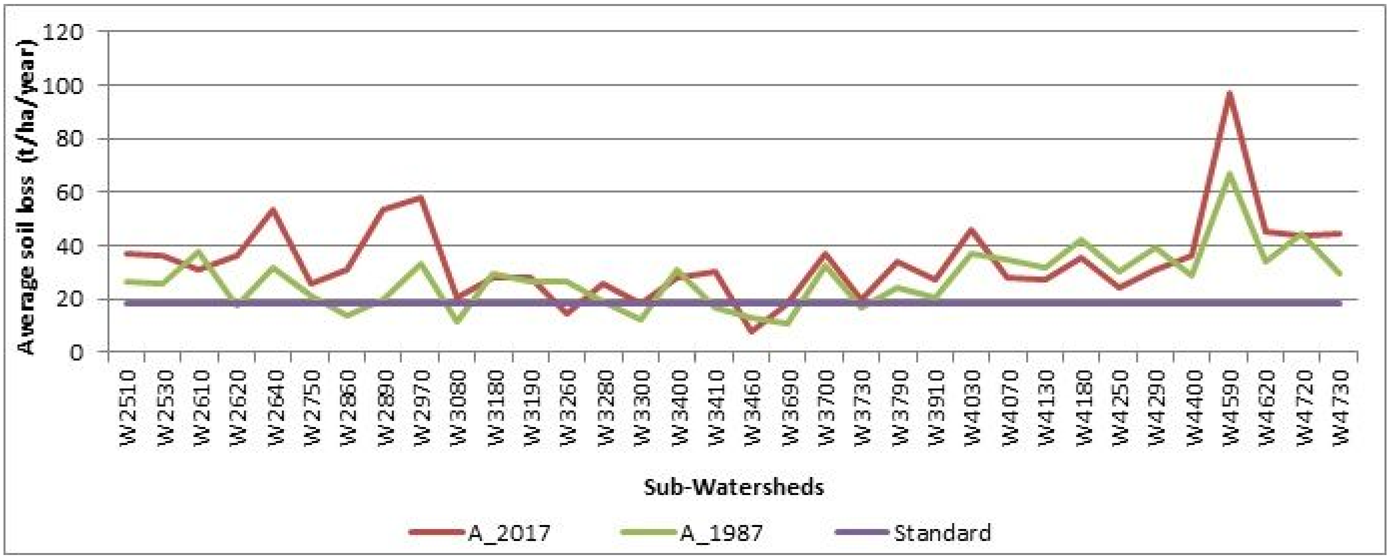

Figure 17

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

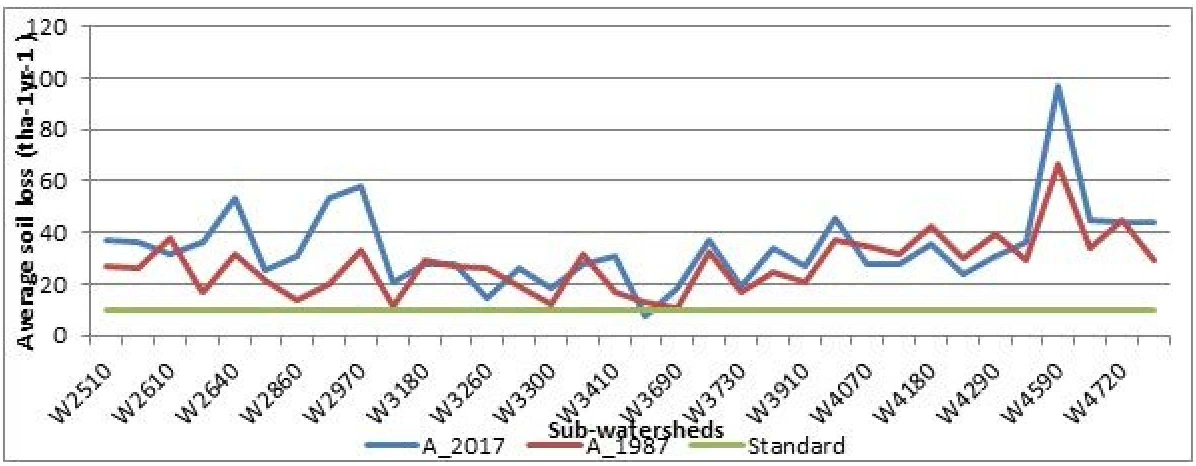

Figure 18

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

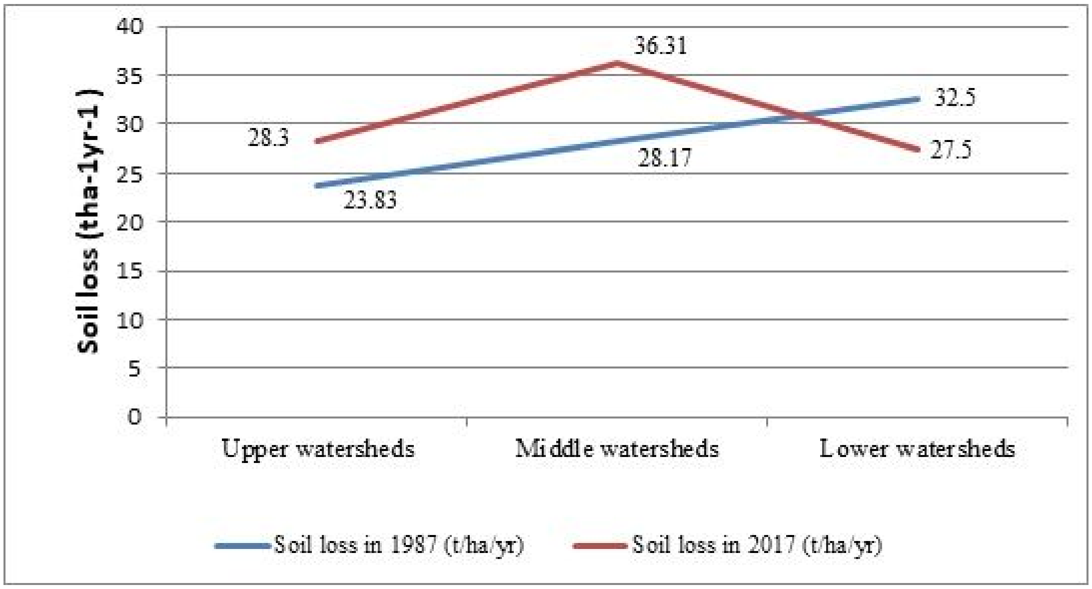

Figure 19

Zone based soil loss in Meki river watershed

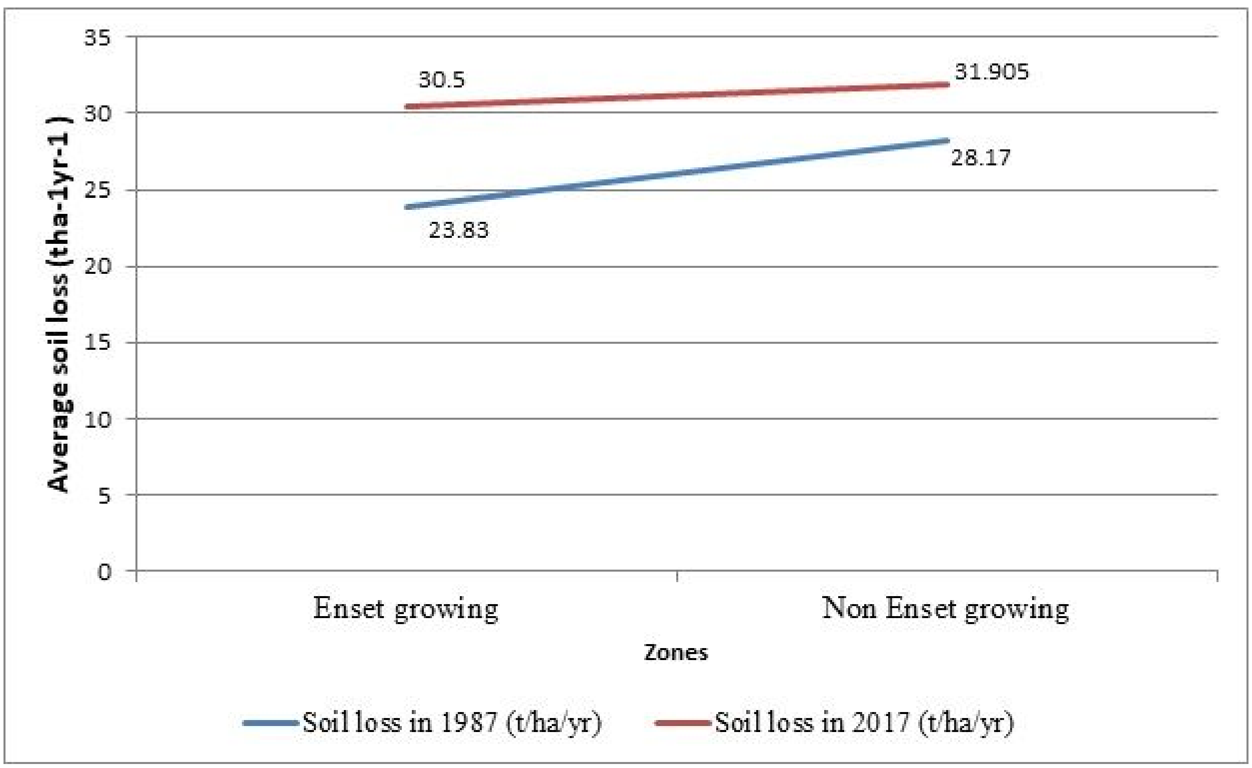

Figure 20

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

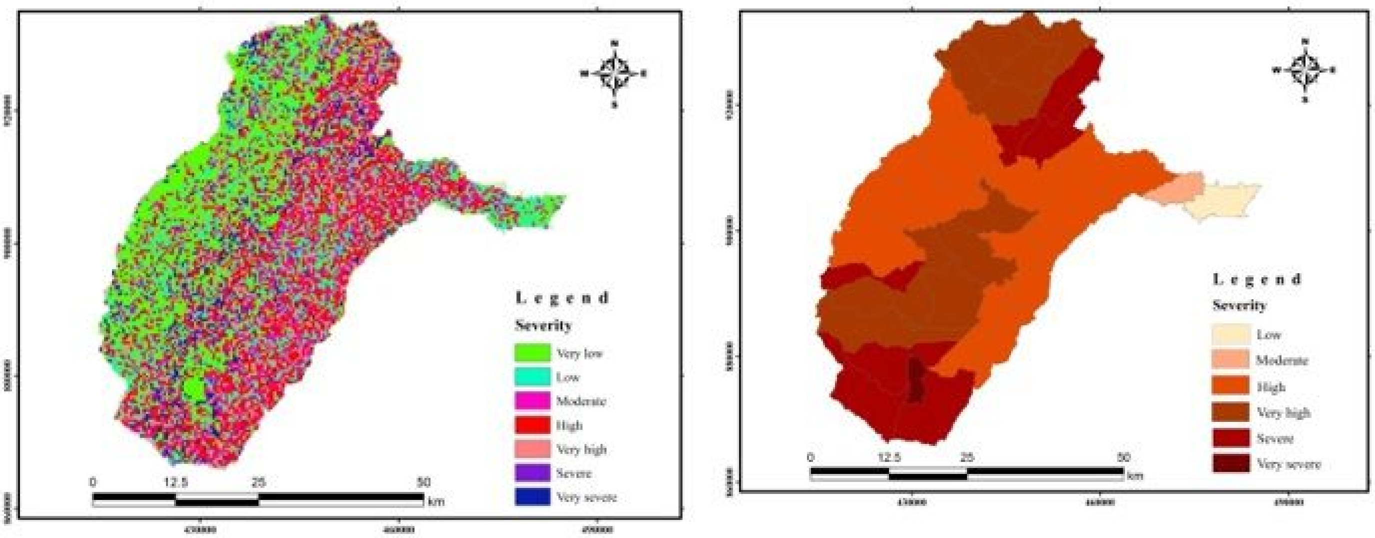

Figure 21

Spatial distribution of severity and its priority class