

Assessment of Spatial Soil Erosion Using RUSLE Model Integration with GIS and RS Tools: The Case of Gilgel Gibe-I Catchment, South West Ethiopia

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Abstract: Water-induced soil erosion is one of the serious environmental, agricultural, and socioeconomic problems in Ethiopian highlands. Accurate information on the rates of soil erosion helps environment protection and socio-economic development efforts of the nation. The objective of this research was to estimate annual soil loss, sediment yield, and map erosion risk areas of Gilgel Gibe-I (GG-I) catchment via integrating Revised Universal Soil Loss Equation (RUSLE) model with Geographical Information System (GIS) and Remote Sensing (RS) technologies. The model inputs variables; rainfall erosivity (R), soil erodibility (K), topographic (LS), land cover (C) and land management (P) were derived from meteorological stations, Ethio-soil map, and satellite image of the catchment. The annual soil loss ($t^{-1}ha^{-1}yr$) was estimated using pixel-by-pixel ArcGIS map overlays to ensure the accuracy of RUSLE output. The model output revealed on average 12.52 ($t^{-1}ha^{-1}yr$) soils was lost from GG-I catchment through sheet and rill erosion. The rates of soil loss were varying in the catchment, 59.8% of the catchment exposed to low rate ($<5 t^{-1}ha^{-1}yr$), 12.2% to moderate rate (5-12 $t^{-1}ha^{-1}yr$), 11.7% to high rate (12-30 $t^{-1}ha^{-1}yr$), and 6.6% to severe ($>30 t^{-1}ha^{-1}yr$). The annual sediment yield capacity of the catchment was 2.54 $t^{-1}ha$ and delivery ration estimated 0.203% transported to outlet of the catchment-GGI hydropower dam. To combat the problems of GG-I hydropower dam siltation, land degradation, and low agricultural productivity an integrated natural resource management intervention is required throughout the catchment particularly in high and severe erosion risk areas.

Keywords: Soil Erosion, RUSLE, Erosion Molding, Soil Erosion Severity, Gilgel-Gibe, Siltation, Catchment, Watershed

1. Introduction

Soil erosion is natural processes occur in geological periods, under which the rates of soil loss and soil formation are equivalent. Human actions accelerate the natural processes of erosion and erosion becomes global environmental, social, and economic problem [13, 40]. The accelerated erosion removes topsoil from a point on the earth's surface and deposits elsewhere [47]. Over 56% of ice-free land surfaces has affected with water erosion [19]. The problem of soil erosion is

becoming worst in developing countries due to improper land use, deforestation, over grazing, continues cultivation, and poor natural resource management (e.g., vegetation, soil, water) coupled with ever growing population [1]. Moderate to severe erosion has affected 80-85% of the global agricultural lands [44, 46] In Ethiopia, the annual soil loss via erosion is reported over 1.5 billion tons that can contribute to 1.5 million tons of grain production [34, 53]. Due to sheet and rill erosion, 100-200 million tons of soils are lost annual from the highlands of Ethiopia [52]. The national average annual amount of loss is 12 ($t^{-1}ha$) [25, 42, 20]. To halt soil erosion

effects on the environment, society, and economy watershed based natural resource management intervention has become priority agenda in Ethiopia [6, 3].

Soil material detached and transported from a catchment is deposit into dam (reservoir) in the forms of bed and suspended load [15] depending on sediment discharged through a river outlet of catchment within specific time [2]. Sedimentation of dams adversely affects the lifetime of reservoir, quality of water, and increase dam operation cost for removal of sediment [30, 15]. Sedimentation affects socioeconomic development of the downstream area via closing stream and irrigation channels, decrease water quality of domestic use, interruption of stream flow, raise conveyance maintenance, and agriculture and fisher activities [37, 4, 3]. Sedimentation is one of the major challenges to hydropower dams (e.g., GG-I, Koka etc.) in Ethiopia. A community based watershed management program strategy has used to minimize the problem of dam siltation, low agricultural productivity and food insecurity [27].

Researchers have developed different predictive models to estimate the amounts of soil loss and identify erosion risky areas for management interventions for maximum impact on soil erosion problems [51]. The Revised Universal Soil Loss Equation (RULSE) model is one of the versatile empirical models that consider the complex biophysical factors (e.g., slope gradient, lengths etc.). Due to this, the model is applicable to different land uses (e.g., rangeland, forestland, cropland, disturbed sites), topographic conditions (e.g. steep slopes) and widely used to estimate average annual soil loss [45, 39]. This model has adopted and validated for Ethiopian highland condition and extensively used to estimate soil loss caused by sheet and rill erosion [7]. Further, integrating RULSE model with GIS and RS tools provides an accurate prediction of annual soil loss at different scales, show erosion spatial distribution, and produce erosion risk maps [58, 21]. This integration makes soil erosion estimation and its spatial distribution feasible with reasonable costs and better accuracy at larger scale [56]. A clear understanding of soil erosion factors, and areas exposed to erosion guides natural resource management strategies within the framework of integrated watershed management to minimize the effects of soil erosion [5]. Hence, quantitative information on soil erosion risk and its spatial distribution assists policy makers, decision makers, experts, and farmers concerning runoff, erosion and soil management to prioritize areas for immediate natural resources management interventions [20, 7]. Limited quantitative information is available on the rates soil erosion and sediment yield in GG-I catchment. The Gilgel Gibe I hydroelectric power plant has an installed with total reservoir capacity 917,000,000 m³, produce 184 MW electricity, and supply power to over 123,200 households [38]. This dam highly threatened by siltation and nutrient enrichment due to soil erosion problems [14]. The aim of this research was to estimate soil loss, sediment yield and identify erosion risk areas in GG-I hydropower catchment through integrating RUSLE (Revised Universal Soil Loss Equation) model with GIS (Geographic Information System) and RS

(Remote Sensing) technologies. Since quantitative information on soil erosion is vital to improve community understanding on erosion problems (e.g., causes, impacts, severity, and factors), and for develop suitable soil and water conservation strategies to improve overall condition of the catchment and lifespan of the dam.

2. Materials and Methods

2.1. Description of the Catchment

Gilgel Gibe-I is the sub-catchment of Omon-Gibe basin, covers 431427 ha land, and situated within the altitude ranges of 1450 to 3272 meter above sea level (m.a.s.l). It is located in the southwest of Ethiopia about 260 km away from Addis Ababa-the capital city of Ethiopia (Figure 1). Geographical, the catchment is located between 7° 22' 72"-7° 34' 84" latitude N and between 37° 21' 05"-37° 28' 80" longitude E. Most of the GG-I catchment area is found in south of Jimma Zone-Oromia Region and some parts in Yem special Woreda (District)-Southern Nations Nationalities and Peoples Region. Parts of the catchment found in Jimma Zone are situated in different Woreda; Dedo, Kersa, Omonada, Tiro-Afeta, Sokoru, and Seka-Chekorsa, Limu-Kosa, and Shebe-Sombo.

The catchment embraces topographic features ranges rugged terrain to flat plain areas. Physiographically the catchment is occupied by local tectono-volcanic system that is active since the mid of Cenozoic era in western and southwestern parts of Ethiopia [11]. Dominate geological materials of the catchment are felsic volcanic rocks, pyroclastic rocks, and intercalated basalt flows with an isolated quaternary volcanics, lacustrine deposits, and alluvial sediments exposure [10]. Further, nitisol and other associated soil groups are the main soil types of the upper and middle slope class of the catchment in association with planosols and vertisols in the lower riverbanks [55]. The catchment receives an average annual rainfall ranges 1400-1800 mm and temperature of 15-19°C. The seasonal rainfall distribution pattern is bi-modal with the maximum during summer and minimum in the winter, influenced by the inter-tropical convergence zone [12].

2.2. Sources and Methods of Data Collection

In this study, both primary and secondary data were gathered and used. Primary data were collected through field survey and ground control point (GCP) observation (170 observations) using Global Positioning System (GPS). The GCP provides actual information on land use, land cover, topography and soil of catchment, assists supervised image classification, and used to validate the results of classified images. Secondary data obtained from satellite image, Digital Elevation Model (DEM), Ethio-GIS, and metrological data. Landsat digital images obtained from United State Geographical Survey (USGS) seamless server were used for land cover classification following supervised classification in ERDAS software (Table 1). The image analysis and categorization was carried out using false color composite technique.

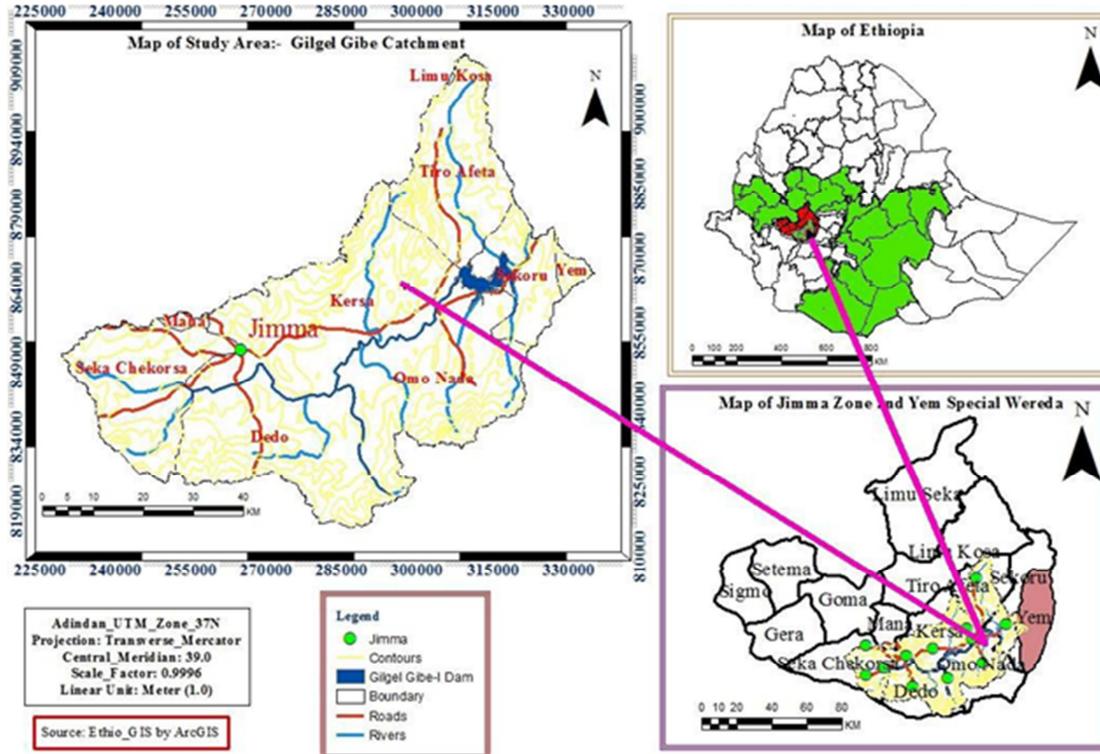


Figure 1. A map showing the location of Gilgel Gibe-I catchment in southwestern Ethiopia.

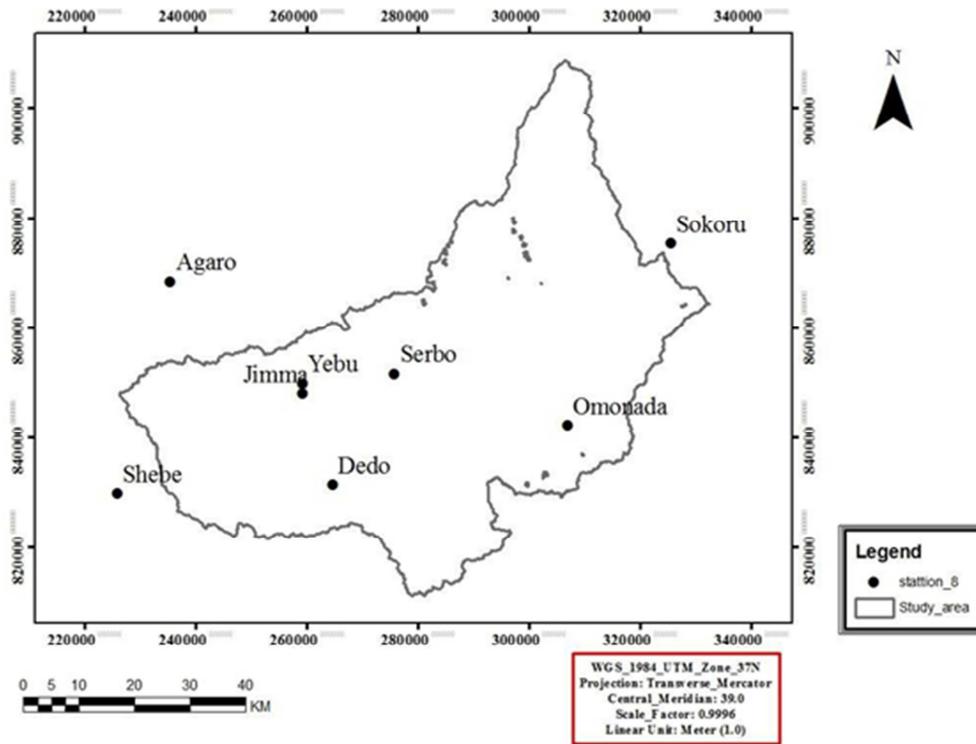


Figure 2. A map showing the locations of metrological stations within and around the catchment used for this study.

Table 1. Description on Landsat image used for the study.

Satellite ID	Sensor ID	Path/row Ac	quisition date	Resolution (m)	Cloud (%)	Band
Landsat-8	OLI-TIRS	169/054	01/01/2017	30	0.00	1-8
		169/055	01/01/2017	30	0.00	1-8
		170/054	08/01/2017	30	0.00	1-8

After classification the images were converted to raster using the raster function of Arc GIS 10.5 to produce C factor map of the catchment, based on C value of each cover types. The Raster Digital Elevation Model (DEM) with 30× 30m resolution obtained from Global Land Cover Facility was used to obtain information on topography factor-slope length, gradient, shape, and form that determine the energy and direction of runoff flow. The 16 years (2000-2015) rainfall data recorded at eight meteorological stations situated inside and near to the catchment (Figure 2) obtained from National Metrological Agency were used for rainfall erosivity. Final, Ethio-GIS database was used to re-classify soils in the study catchment. The ERDAS 2010 software was used to mosaicing and georeferencing the topographic map and ArcGIS 10.5 used to digitalize the topographic maps and to implement RULSE factors.

2.3. Data Analysis

2.3.1. Soil Loss Estimation

The Revised Universal Soil Loss Equation (RULSE) model integrated with GIS and RS tools was used to estimate long-time average annual soil erosion caused by sheet and rill erosion in the catchment. RULSE has simple structure and empirical model developed by [45]. The basic structure of RULSE is identical with ULSE however; improvements of determining factors are made for RUSLE. [42] Verify RUSLE model applicability for Ethiopian highlands. This model is broadly for soil loss estimation in Ethiopia [24]. However, RUSLE model is less applicable in rugged and undulated terrains, not consider runoff flow (convergence and divergence), estimate soil loss at large scale, and ineffectively consider slope length and gradient factors [59]. Hence, this study used advanced LS estimation method to overcome the above-mentioned limitations. The complex interaction between topography, geology, vegetation, land use, climate, soil, and human development activities determines degree of soil erosion and sediment yield of catchment [49]. The RULSE model integration with GIS and

RS tools treat these complex interactions and compute erosion accurately. In RUSLE rainfall erosivity, soil erodibility, slope length, slope steepness, cover management, and support practices factors are main input variables to estimate soil loss [57]. Mathematical the model is describes as follow Eq. (1);

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

Where: A is annual soil loss ($t^{-1}ha^{-1}yr$), R is rainfall erosivity factor ($MJ\ mm\ ha^{-1}\ ha^{-1}\ yr^{-1}$), K is soil erodibility factor ($t\ ha^{-1}\ MJ^{-1}\ mm^{-1}$), LS is Slope length and steepness factor (dimensionless), C is land cover management factor (dimensionless), P is supportive conservation practices (dimensionless).

RULSE model hypothesis sediment content flow governs the detachment and deposition of soil particles. The carrying capacity of sediment flow limits soil erosion; when sediment loads reaches the carrying capacity detachment is not occurring. Sedimentation occurs when the withdraw portion of hydrograph flows rate decreases [28]. The recent computer technology makes RULSE simpler and uses physically meaningful input values obtained from DEM. DEM is one of one of the vital inputs required for soil erosion that is created with stereoscopic optical and microwave (SAR) remote sensing data analysis [28]. The RULSE model was applied using GIS and RS tools as indicated in Figure 3. The estimation and mapping of spatial distribution of soil loss in the catchment was done via discretization of RULSE parameters (R, K, LS, C, and P) maps of identical geographic coordinates to grid with 30 m x 30 m cell sizes. Then these layers were overlaid and multiplied pixel-by-pixel following Eq. (1) and the raster calculator geo-processing tool in ArcGIS 10.5. The cell-by-cell base erosion estimation is effective to recognize spatial patterns of erosion at large scale [50]. Final, the quantitative model output of average annual soil loss ($t^{-1}ha$) was classified into four categories using [18] < 5 low, 5-12 medium, 12-30 high, and > 30 sever erosion.

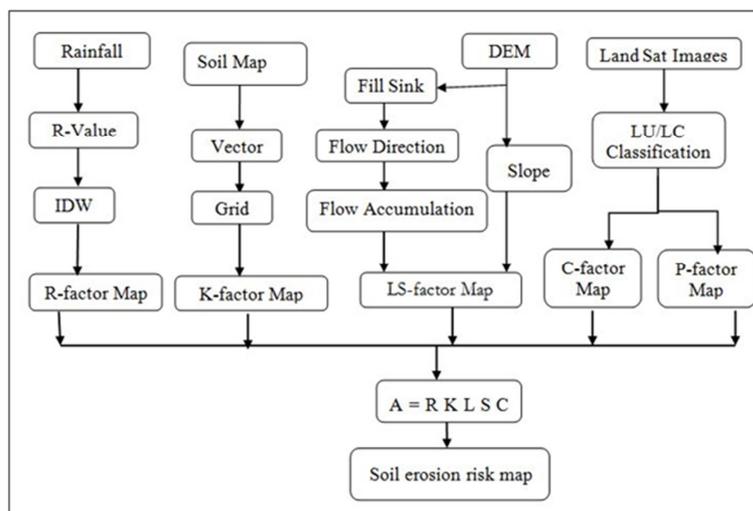


Figure 3. Conceptual framework used for estimation of soil loss via integrating RUSLE and GIS.

(i). Rainfall Erosivity Factor (R)

The R factor is product of total kinetic energy (KE) of rainfall and the maximum rainfall intensity (I) of 30 minutes [57]. It expresses the potential ability of rainfall to cause soil erosion with raindrop detaching power and contributing to runoff [37]. When rainfall KE and I data are absent, R factor can be calculated using different techniques [25, 32]. In Ethiopia, these data are absent and R factor of the study catchment computed using formula suggested by [25] for Ethiopia Eq. (4).

$$R = -8.12 + (0.562P) \tag{2}$$

Where: P is mean annual rainfall (mm yr⁻¹)

The mean annual rainfall of sixteen years (2000-2015) recorded in eight metrological stations situated inside and around the catchment. Some of the missed rainfall data were filled through interpolating the available data of nearest meteorological stations. R factors were spatial presented on map using Inverse Distance Weighted (IDW) interpolation technique in ArcGIS 10.5 and converted into raster surface with cell size of 30 x 30 m resolution.

(ii). Soil Erodibility Factor (K)

Soil erodibility is the inherent resistance of soil particles for detachment and transportation with rainfall [57]. It refers to the ability of soil to resist for detachment and

transportation via erosive agent [37], and indicate soil loss rate per rainfall erosivity index. This factor is empirical determined for a particular soil category. The K factor of the study catchment soil is unknown. Thus, K factor of the catchment was derived from the soil type via extracting from soil map of Ethiopia [17] and Ethio-GIS database. K factor map of the catchment was generated via changing digital soil map shape file in to grid file (raster) with cell size of 30 x 30m resolutions using ArcGIS 10.5.

(iii). Topographic Factors (LS)

LS factor is ratio of soil loss per unit of land area slope to 22.13m long of uniform 9% Slope under same conditions [57]. L refers distance between source and culmination of erosion process; culmination takes place when Slope length decrease and deposition process starts, or concentration flow into rill or channel [57]. For small-scale conservation planning, field measurement of Slope length and gradient is applicable. The actual field measurement is infeasible for large-scale erosion modeling, and this study applied computer program generated for RUSLE based grid of LS factors using GIS. LS factor was calculated using unit stream power erosion and deposition (USPED) method as described by [29]. This method uses raster calculation between flow accumulation and Slope of the watershed [29] and effectively reduces the effects of heterogeneous topographic attributes [57, 36].

Table 2. K, C and P factor values corresponds to the study catchment condition.

Parameters description	Values
Soil types	K-value (Nguyen, 2011; Hurni at al., 2015)
Vertisols	0.01-0.20
Fluvisols	0.15-0.30
Nitisols	0.20-0.30
Cambisols	0.15-0.25
Acrisols	0.10 – 0.34

Land use/land cover type C-factor	(Wischmeier and Smith, 1978; Hurni, 1985a; Eweg and van Lammeren, 1996)
Forest	0.01
Shrub land	0.01
Cultivated land (teff)	0.25
Bare land	0.05
Urban built up area	0.05
Cultivated land	0.15
Wetland	0.01
Water body	0.00
Grazing land	0.01

Land use at different	Slope (%)	P-factor	(Wischmeier and Smith, 1978)
Cultivated land	0–5	0.1	
Cultivated land	5–10	0.12	
Cultivated land	10–20	0.14	
Cultivated land	20–30	0.19	
Cultivated land	30-50	0.25	
Cultivated land	50-100	0.33	
Non-cultivated	All Slope class	1.00	

The flow direction and accumulation was calculated from DEM dataset of catchment delineation tool using ArcGIS 10.5 after producing sinks free DEM [29, 1]. The following

formula was used for LS factor calculation to produce the LS map of the catchment Eq. (5).

$$LS = \text{Power}(\text{flow accumulation} * \text{cell resolution} / 22.1, 0.4) * \text{Power}(\sin(\text{slope} * 0.01745) / 0.09, 1.4) * 1.4 \quad (3)$$

Where: flow accumulation is raster based total accumulated flow to each cell, Cell resolution is the length of cell side.

(iv). Land cover Management Factor (C)

The C factor indicates the effectiveness of crop (vegetation) management practices in preventing soil erosion. C factor is the ratio of soil loss from certain land cover type to soil loss from bare land or continuous fallow land under same rainfall, and values exist between zero and one-zero refers well protected while one bare land [57]. This factor is easily changed and considered in conservation planning. Land cover of the catchment was classified using Landsat image obtained from USGS. The classification was carried out following supervised classification technique in ERDAS software assisted with 170-ground control point observation. The classified images were converted to raster using Arc GIS 10.5 raster function to produce C factor map of the catchment, based on C value each cover type (Table 2).

(v). Supportive Practices Factor (P)

It refers to the effects of surface conditions (e.g., contour, strip cropping, and terraces) on erosion through regulating flow path and hydraulic force [15]. P factor is the ratio of soil loss from conserved soil (with different conservation practices) to soil loss from straight row cultivation running up and down slope [29]. Direct observation of each land plot to determine land uses types and farming system at large scale is time consuming, cost, and labors thus P value can be derived from digital satellite image classification [43]. Hence, land use/cover types of the study catchment were re-classified as cultivated and non-cultivated areas under different slope category and the subsequent P factor value of the catchment was obtained from secondary data on land use type that match with the catchment conditions to produce P factor map (Table 2).

2.3.2. Sediment Yield (SY) and Delivery Ration (SDR)

Estimation

Sediment yield (SY) refers to the total volume of sediment evacuated, and transported from upper catchment area and deposited into outlet per a year. It is the amount of sediment loaded into the end of slope length and outlet of catchment [23]. SY provides information on the net result of soil erosion and deposition processes within a catchment, effectiveness conservation practice and sediment delivery in catchment. The factors control erosion (e.g., topography, soil properties, climate, vegetation cover, catchment morphology, drainage

network, and land use) also determines sediment delivery and yield of catchment [23]. Annual sediment yield ($t^{-1}ha$) of the study catchment was estimated using [57] formula Eq. (2).

$$SY = SDR * SE \quad (4)$$

Where: SDR is sediment delivery ratio Eq. (3) of the catchment while SE is annual soil loss of the catchment ($t^{-1}ha^{-1}yr$).

$$SDR = 0.51A^{-0.11} \quad (5)$$

Where: A is area of catchment (km^2)

Sediment Delivery Ratio (SDR) is a fraction of gross erosion transported from a given area in a given time interval to outflow of watershed [31]. It indicates the integrated capability of catchment to sort and to transport eroded soil materials, and allows the detection of critical sediment source and delivery areas for site-specific management interventions [33].

2.4. Accuracy Assessment

Since RULSE input variables come from different sources, accuracy assessment is vital to provide quality information for end users. Thus, error matrix analysis is important to GIS and RS based RULSE models to know the accuracy data products. The confusion/error matrix consists of rows and columns; rows represent the classification values and the column represents facts from the field. The diagonal line of the matrix represents the number of correctly classified pixels. The overall accuracy obtained from ratio of number of all pixels correctly classified to the total number of pixels in the matrix. Producer's accuracy refers error of omission (exclusion) index is the ratio of correctly classified pixels in a class to sum of the values of the column of the same class. User's accuracy also refers error of commission (inclusion) index calculated by dividing the total number of correctly classified pixels in a class by the sum of the values of the rows of the same class. The Kappa coefficient expresses the proportionate reduction in error generated by a classification process, compared with the error of a completely random classification [9]. The Kappa statistic incorporates the off-diagonal elements of the error matrices or classification errors and represents agreement obtained after removing the proportion. The kappa coefficient lies typically between 0 and 1, where 1 indicates absolute agreement, and is often multiplied by 100 to give percentage measure of classification accuracy.

$$K = \frac{N \sum_{i=1}^r x_{ii} - \sum_{i=1}^r (x_{i+} + x_{+i}) / N^2}{N - \sum_{i=1}^r (x_{i+} + x_{+i})} \quad (6)$$

Where: r is the number of rows in the matrix; x_{ii} is the total number of correct LULC classes in rows i and column i, x_{i+} is the total of row i (right of the matrix), x_{+i} is the totals of column i (bottom of the matrix); N is the total number of ground control points.

3. Results and Discussion

3.1. Accuracy Assessment

The confusion matrix and kappa coefficients analysis

indicated, the input variables used in RUSLE for soil loss estimation were accuracy. The result showed overall image classification accuracy was 83.53% and Kappa statistics 0.81

(Table 3). This indicates the total accuracy of remotely sensed image classification is accurate and reliable for soil erosion application.

Table 3. Accuracy assessment maps produced from remotely sensed images.

Classes	Producer's accuracy (%)	Omission error (%)	User's accuracy (%)	Commission error (%)
Agriculture	64.1	35.9	86.2	13.8
Grass Land	80	20	87.5	12.5
Shrub land	87	13	74.1	25.9
Forest	84	16	80.8	19.2
Urban built up	100	0	85.7	14.3
Water body	100	0	100	0
Wet land	100	0	75	25
Bare land	100	0	81.8	18.2

3.2. Soil Erosion Estimation

3.2.1. Rainfall Erosivity Factor (R)

The rainfall analysis revealed the average amount of rainfall received in the catchment was ranges 1408 to 1750.47 mm with the corresponding erosivity factor 783.16-975.65 (Figure

4). The highest erosivity value (>900) was observed in Seka-Chekorisa, Shebe, Jimma town, Yebu and Omonada areas whereas relatively the lowest erosivity (<800) exists at Seribo, Dedo, and Sekoru. In terms of erosive, 30% of the catchment receives high erosive rainfall while 65% receive medium and the rest 5% low erosive rainfall (Table 4).

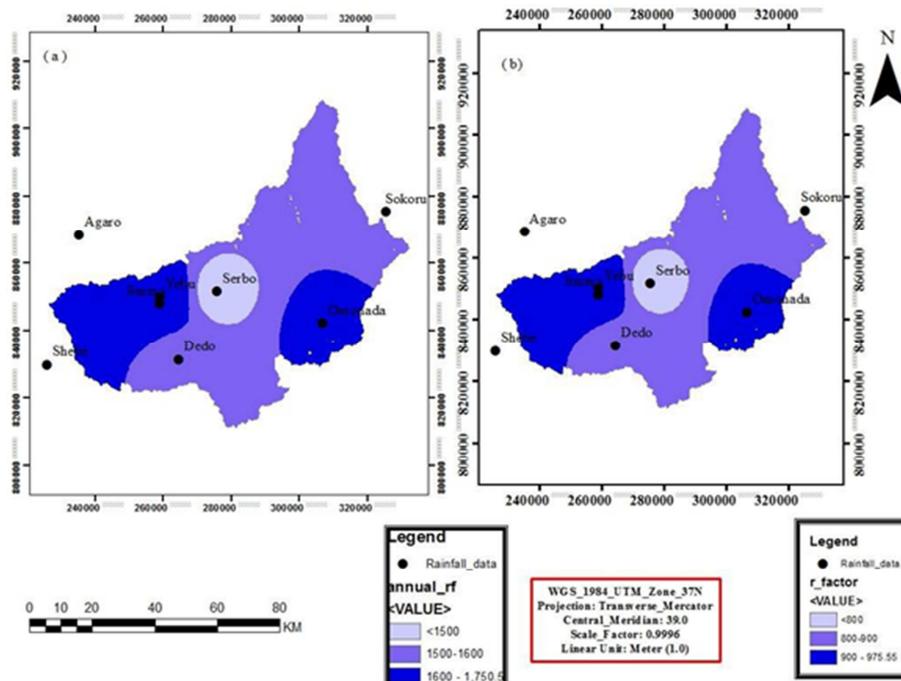


Figure 4. Map showing mean annual rainfall (a) and rainfall erosivity factor value (b) of the catchment.

The areas that receive highly erosive rain were situated high altitude, steep Slope areas and dominated with Nitisols. This implies parts of the catchment that receives erosive rain were associated with other factor (LS and R) that facilitates

high erosion. Thus, these parts of the catchment needs proper surface cover to prevent the direct contact of erosive raindrop with soil surface and minimize soil detachment caused by raindrop actions.

Table 4. Rainfall erosivity, soil erodibility and topographic factors values of the catchment.

R-factor value	Area (%)	K-factor value	Area (%)	LS-factor value	Area (%)
783.16 – 800.00	5	0.15	21	0 – 10	74
800.00 – 900.00	65	0.20	46	10 – 30	19
900.00 – 975.65	30	0.25	33	30 – 11482.5	7

3.2.2. Soil Erodibility Factor (K)

Based on the digital soil map of Ethiopia, five soil

groups Acrisols, Cambisols, Fluvisols, Nitisols and Vertisols (Figure 5(a)) were recognized in the catchment

that have three distinctive erodibility classes (Figure 5(b)). Acrisols and Fluvisols have highest K factor value (0.25) occupied 46% of the catchment areas followed by

Cambisols and Nitisols with K value 0.2 that cover 33% and Vertisols with K value 0.15 occupied 21% the catchment (Table 4).

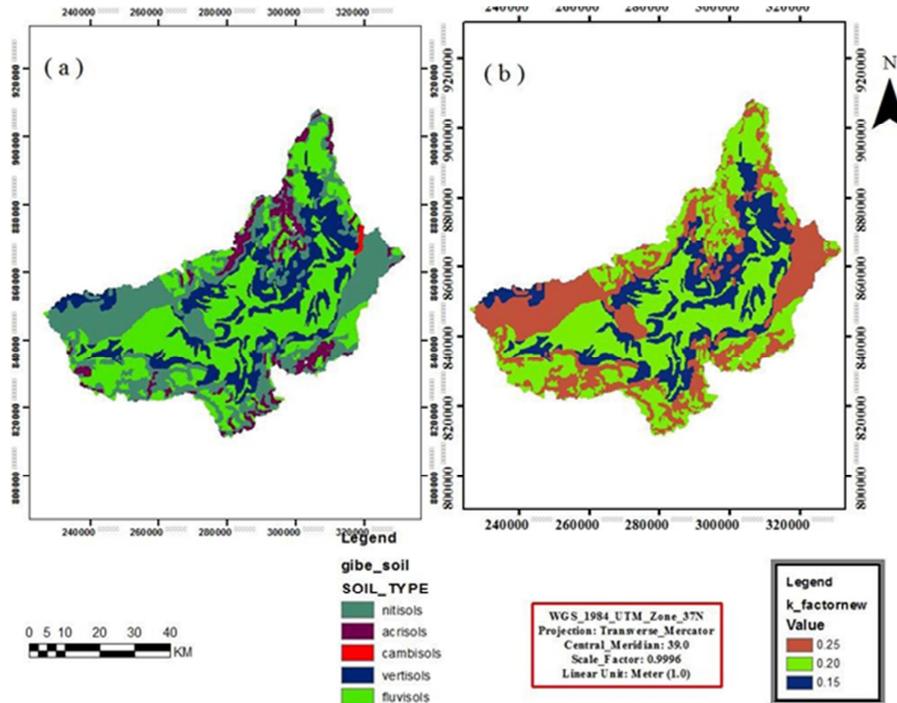


Figure 5. Map showing the soil types (a) and their respective erodibility (K) factor values (b) of the catchment.

This show, most soils in the catchment were susceptible for erosion and situated in highly erosive rain ranges, and sloppy areas. Soils with low erodibility factor, Vertisols was found in low altitude areas (flat lands, and pocket areas) whereas the other soil types were distributed over the catchment. Thus, soils of the catchment were highly vulnerable to erosion and needs proper management intervention (surface covers, physical structures etc.) to prevent soil erosion. Acrisols, Nitisols, Cambisols and other soil associated with Nitisols found in Ethiopian highlands are highly vulnerable to erosion [8]. These soils have been used for crop production for long period in Ethiopia, which makes the soil more susceptible to erosion.

3.2.3. Slope Length and Steepness (LS) Factor

The study catchment exists between an altitude range of 1450 to 3272 m.a.s.l (Figure 6(a)) with complicated topographic features, and varying Slope degree 0-66.14 (Figure 6(b)). Accordingly, the LS factor value varies from 0 to 11482.5; about 7% of the catchment areas laid within higher LS factor values (Figure 6(c); Table 4). The higher value indicates the utmost probability for faster run-off energy and powerful rainwater flow rates that cause severe erosion problem. Soil loss increases as Slope length increases because of greater accumulation of runoff on the longer Slopes increases soil detachment and sediment transportation capacity.

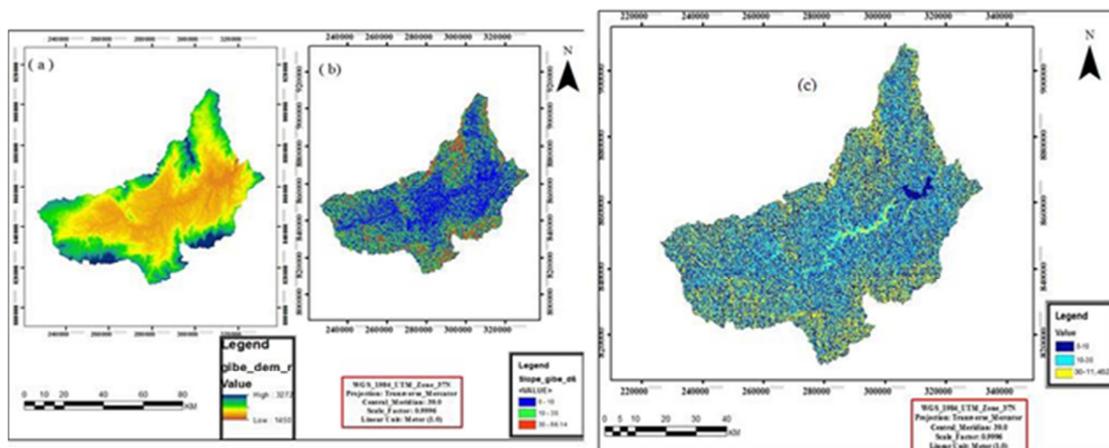


Figure 6. Maps showing altitudes (a), slope degree (b), and LS factor value (c) of the study catchment.

3.2.4. Cover and Management (C) Factor

The satellite image analysis revealed the catchment has eight major land uses types (Figure 7(a)) with different C factor value (Figure 7(b)).

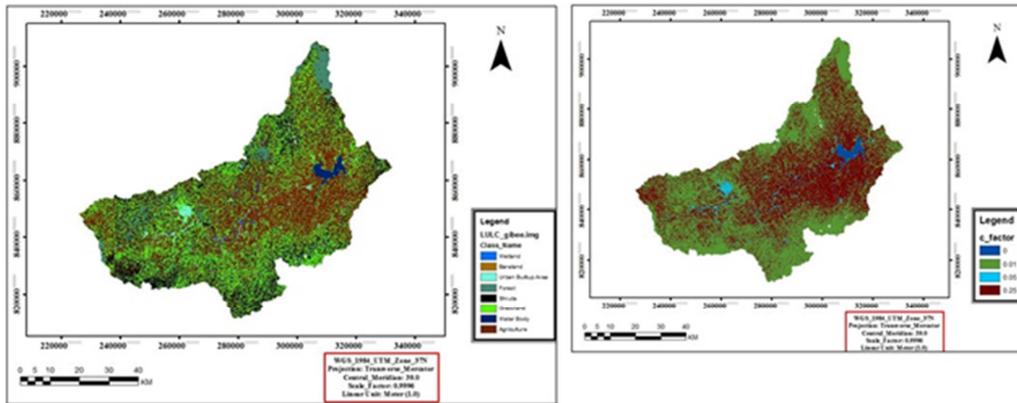


Figure 7. Map showing land cover management and C factor values of the catchment.

About 39.74% of the catchment area was subjected to agriculture, which has the highest C factor values (0.25), 2.62% area bare with C value of 0.05, and 56.59% covered with

vegetation with C value 0.01 (Table 5). This show, part of the catchment subjected to cultivation and bare lands were less resistant to soil erosion and contributing for erosion rates.

Table 5. Land cover and land use type factor values with their respective area coverage of the catchment.

Land cover	C-value	Area (%)	Land use at diverse Slope (%)	P-value	Area (%)
Water body	0.0	1.05	Agriculture land at 0-5	0.10	9
Shrub, grass, forest	0.01	56.59	Agriculture land at 5-10	0.12	15
Built-up and bare land	0.05	2.62	Agriculture land at 10-20	0.14	14
Agriculture land	0.25	39.74	Agriculture land at 20-30	0.19	2
			Agriculture land at 30 – 50	0.25	0.99
			Agriculture land at 50-100	0.33	0.01
			Non-agriculture at any Slope	1.00	59

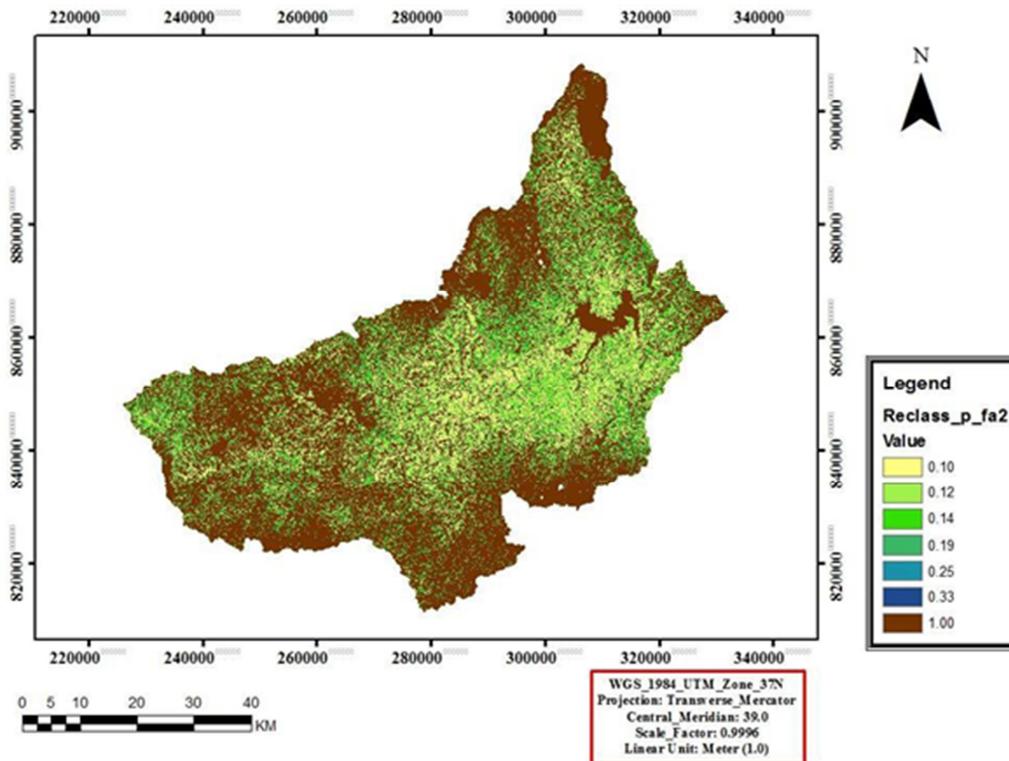


Figure 8. Map showing the P factor values of the catchment.

3.2.5. Supportive Conservation Practices Factor (P)

About 59% of the catchment was not used for agricultural activities due to various factors like physical limitation (Table 5). The land belongs to this category has the highest P factor value (Figure 8). Whereas, 41% of catchment areas found in different slope degrees were subjected cultivation practices have 0.1 – 0.33 P factor values. The agricultural practices at high slope degree accelerate soil erosion rates for the raising P and C factor values.

3.2.6. Annual Soil Loss and Sediment Yield

The model output showed the average annual soil loss in the catchment was 12.52 t¹ha. The problem soil erosion is widespread throughout catchment, ranges low to severe rates

(Table 6; Figure 9). Catchment areas affected with low rate erosion was occupied 47%, both moderate and high erosion rate accounted 15%, and severe erosion rate covered 23% (Table 6). In most part of Gilgel Gibe-I catchment (> 60%), the rate of soil loss was below tolerable soil loss rate. Tolerable soil loss rates of Ethiopian highland is 2-22 (t¹ha¹yr), that sustain the current productivity level [18]. High to severe rates of soil erosion happen due to the presence of highly erodible soils, erosive rain, topographic condition, continues cultivation, and insufficient supportive conservation practices. The presence of forest patch (includes coffee shade tree), grassland, and croplands in flat areas contributes for rates of erosion in some parts of the catchment.

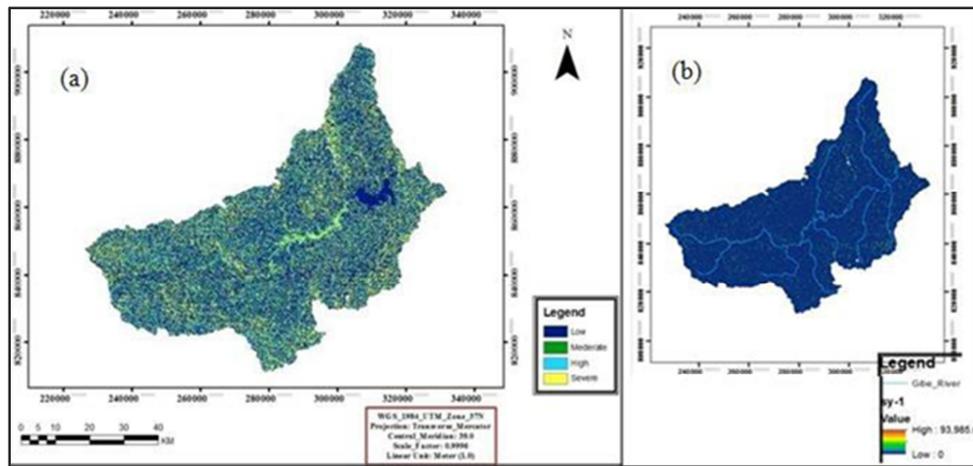


Figure 9. Map showing the annual soil loss rate of the catchment.

Severity of soil erosion influenced by lacks of supportive practices, presence of less erosion resistant soils (e.g., Nitosols), undulating topography, and poor land cover [22]. Further, low soil erosion occurs to areas dominated with flat to gentle slope, high erosion resistant (e.g., Vertisols), and good vegetation covers [16]. [37] Reported sloppy areas cultivation without sufficient conservation practices increases the rates of soil erosion through raising the velocity and volume of surface runoff. This show risk areas of the catchment requires integrated soil and water

conservation interventions to restore environment conditions, support maximum productivity and siltation of water bodies including of Gilgel Gibe I (GG-I) dam. [35] stated high soil loss area should get soil conservation priorities. In Ethiopia, the use of various conservation measures such as contour tillage, area closure, terrace, stream bank stabilization, forest development, grass strip, and riverbank stabilization meaningfully reduce the risks of erosion [22] and improve soil physical, chemical and nutrient status [54].

Table 6. Soil erosion rates in Gilgel Gibe-I catchment.

Ranges of soil loss (t ha ¹ yr ⁻¹)	Soil erosion risk	Conservation priority	Area (%)
0-5	Low	4	47
5-12	Medium	3	15
12-30	High	2	15
> 30	Sever	1	23

The annual sediment yield capacity of the catchment was estimated 2.54 t¹ha. The sediment delivery ration (SDR) of the catchment was estimated 0.203; this shows 0.203% of the soil loss in Gilgel-Gibe I hydropower catchment estimated using RUSLE integration with GIS and RS was transported to outlet of the catchment-GG-I hydropower dam. This indicates the existence of huge amount of sediment deposition in GG-I hydropower dam that could

adversely affect its performance, lifespan, and operational cost. The contribution of sediment load to GG-I dam reported in this study is lower than [14]. This is due to difference in sources of sediments considered in the study- the present study considered rill and sheet erosion when the former considered sediments deposited into the dam regardless of sediment sources (rill, sheet, gully, and riverbank erosion).

4. Conclusions and Recommendation

The integrated use of RUSLE and GIS tools becomes popular to determine soil loss ratio and sediment yield at large scales, and generates precise information on watershed management decision-making processes. The present study revealed the average amounts of soil loss from Gilgel Gibe-I (GG-I) catchment $12.52 \text{ t ha}^{-1}\text{yr}^{-1}$. However, the rates of soil loss vary in catchment areas; 47% areas affected with low ($< 5 \text{ t ha}^{-1}\text{yr}^{-1}$), 15% with medium ($4\text{--}12 \text{ t ha}^{-1}\text{yr}^{-1}$), 15% high ($12\text{--}30 \text{ t ha}^{-1}\text{yr}^{-1}$) and 23% with severe ($>30 \text{ t ha}^{-1}\text{yr}^{-1}$). The annual sediment production capacity of the catchment is $2.54 \text{ t}^{-1}\text{ha}$ and about 0.203% of delivered to the catchment outlet. This indicates the problems of high soil erosion associated with rugged topography, poor land cover and management, erosive rainfall and highly erodible soil natures is the biggest challenge for the sustainability of GG-I dam. Therefore, integrated natural resource management strategies should be developed together with stakeholders and executed in priority areas of catchment to minimize siltation impacts on GG-I dam, and land degradation effect on environment and socioeconomic development efforts. Limitation of this research, as the RUSLE model is developed to estimate soil loss due to sheet and rill erosion the finding (annual soil loss, sediment yield and delivery) of this study is not shows the overall soil loss and sediment yield problems of GG-I catchment. Therefore, future researches should consider riverbank and gully erosion induced soil loss and sediment yield. Further, the present research is not project hydrological and metrological data of the catchment for soil loss estimation thus future study should consider this gaps.

5. Public Interest

Most of the Ethiopian highland croplands, grazing lands, and grass lands are affected by water induced soil erosion. Because of erosion, huge amount of soil is lost from these lands, environmental degradation, poor agricultural productivity, and food insecurity has become major development challenge of the nation. This research paper provides information on the annual soil loss and sediment deposition in Gilgel Gibe-I hydropower dam, which is one of the major source of electric in Ethiopia. The findings of this study help decision makers and other stakeholders in designing appropriate catchment management plane to reduce the problems of soil erosion and improve social and environmental wellbeing of the people within the catchment area as well as in downstream areas.

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Competing Interests

The authors would like to declare that there is competing interests.

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