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Assessment of Soil Erosion Risk Using GIS and Rusle: The Case of Meja Watershed, West Shewa, Ethiopia

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Abstract:- **Soil erosion resulting from steep slope cultivation and heavy deforestation is among the most difficult and incessant environmental problems in Meja watershed. Studies that characterize erosion rates that are crucial to improve land and water resources management are rarely done in this watershed. Thus the main aim of this study was to measure erosion rates and map erosion risk areas using GIS and Remote sensing techniques. The soil loss was estimated by using Revised Universal Soil Loss Equation (RUSLE) model. Sentinel2A satellite imagery with spatial resolution of 10 m and field survey was used to derive RUSLE's soil loss variables. The RUSLE parameters were analyzed and overlain using raster calculator in the geo-processing tools in ArcGIS environment to estimate erosion rates and map erosion risk. The result showed that soil losses ranged from 0 t/ha/year in plain areas to more than 100 t/ha/year in the steep slope areas of the watershed with an average soil loss of 25.14 t/ha/year. Priority classes II and III combined contribute 41.1% with a total soil loss of 45671.9 tons. Priority Class IV and V contributes the lowest percent (16.9% and 10.2% respectively) for the total soil loss. Most of the soil erosion affected areas were found to be situated in the cultivated steepest slope part of the watershed. Therefore, understanding the magnitude of soil erosion is very important to plan appropriate soil conservation strategy. Given the seriousness of soil erosion problem in the study area, the study recommends that planners should give due attention to priority areas with severe erosion rates and treat these area with appropriate soil and water conservation measures.**

***Keywords**:- Erosion Risk, GIS, RUSLE, Soil Loss, Sentinel, Meja*

I. INTRODUCTION

Water induced soil erosion resulting from anthropogenic factor is the most hazardous form of land degradation in the modern-day world. Around 16% of the land in Africa is degraded and soil erosion is of great concern in Sub-Saharan African countries [1]. Ethiopia is one of the countries with very high level of erosion which puts peoples' livelihoods under pressure [2]. About 14 million hectares of productive agricultural lands have been seriously eroded with a probable total soil loss of 2 billion m^3 of top soil per year [3]. Recent estimates of erosion on cultivated lands in the country indicated rates of 20 Mg ha^{-1} $year^{-1}$ while soil loss of 33 Mg ha^{-1} $year^{-1}$ was reported on formerly cultivated degraded lands [4]. Each year 1.9 up to 3.5 billion tons of top soil has been lost in the highlands of Ethiopia, which has been affecting the production capacity of the crop land [5][6]

Geographic information system technique is an effective tool for assessing soil erosion risk by integrating different soil erosion assessment models[7][8]. The RUSLE model can predict erosion potential on a cell-by-cell basis [9]. The use of RUSLE in a GIS environment has enabled application for large areas and satisfactory results have been reported [10][11], for delineation of erosion prone areas and prioritization of micro-watersheds for a targeted and cost-effective conservation planning purposes.

It is reported that the Blue Nile basin is seriously affected by land degradation, soil erosion, reservoir sedimentation, flooding and sediment transport [12]. Meja watershed is the head of Blue Nile basin where Meja river draining approximately south-north which is a tributary to Guder River. The watershed is heavily affected by water erosion as a result of steep slope cultivation and heavy deforestation [13]. As part of the Abay basin, Meja watershed is one of the areas that contributes a large amount of sediment to the basin.Despite the severity of soil erosion and its threatening impacts, studies that characterize erosion rates and erosion rsik areas using small watersheds that are crucial to improve land and water resources management are rarely done in thiswatershed. Therefore, this study was designed to quantify/estimate soil erosion and identify high erosion risk areas through intergrated application GIS-RS and RUSLE useful for future planning of soil and water conservation interventions.

II. MATERIALS AND METHODS

A. Study Area Descriprion

The study was conducted at Meja watershed in Jeldu district, in the southern part of upper Blue Nile Basin, Central Ethiopia. The watershed lies within9° 08' 30" to 9° 19' 30" N and 38° 00' 40" to 38° 9' 20" E (Figure 1). The watershed has an area of 12,304 ha. The watershed has an undulating terrain nature with altitude ranging from 2100 to 3200 meters above sea level. The temperature ranges from 17 to 22 ^{0}C. The average annual rainfall of the watershed ranges from 1311 mm up to 1755 mm. The Meja Riveris originates at high altitude just outside Jeldu district in the Dendi district [14].

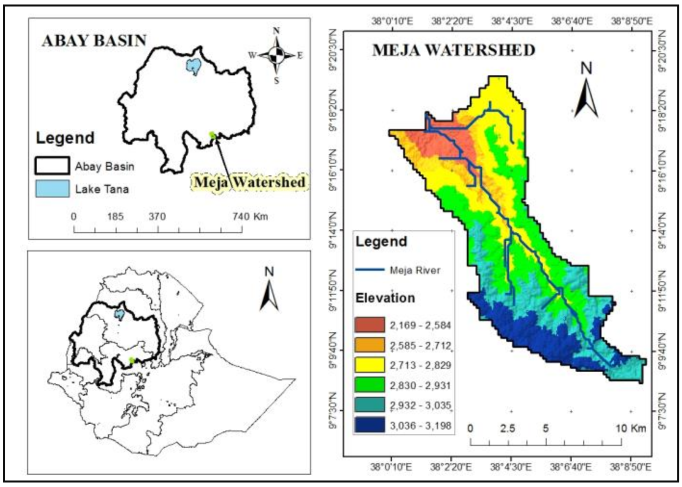

Figure 1: Map of the Study Area

B. Data Source and Collection

The data sources used for the study are climate, soil, Digital Elevation Model (DEM), satellite image and field survey. Long-term daily rainfall data was retrieved from National Meteorological Agency of Ethiopia (NMA) Rainfall Erosivity (R-factor) was derived from this data for the computation of the RUSLE model. Detail soil data of the study area with as scale of 1:100,000 was obtained from Water and Land Resource Center of Addis Ababa university [15]. The Shuttle Radar Topography Mission (SRTM) 30m resolution DEM was used (United States Geological Survey, 2013 for delineating the watershed boundary and classifying the slope, which was used to determine LS-factor in RUSLE model.

For the purpose of land use and land cover classification sentinel 2A satellite imagery was used. The satellite captures images of the surface at high revisit frequency with 13 spectral bands (10, 20 or 60 meters resolution) [16]. Sentinel-2A data available for download are processed to Level-1C which includes radiometric and geometric corrections along with ortho-rectification and spatial registration. The data covering the watershed area and having the minimum cloud cover (<10%) was chosen. The satellite imagery was acquired on January 1, 2018. The data set was at adequate quality for image classification. The image was used to derive the land use land cover map in order to generate Cover factor for the RUSLE model.

Field survey was conducted to understand the land use/land cover and soil erosion status of the study. Detail field data and observation was undertaken with the aid of GPS to investigate bio-physical conditions (land use/land cover, land form, and soil and water conservation practices). Ground truth was used to obtain accurate location point data for each land use/land cover class and for management practice (P) factor assessment.

C. Soil Loss Analysis

Revised Universal soil loss equation (RUSLE) in a raster GIS environment was employed in assessing the soil erosion risk and mapping. RUSLE is developed as an equation of the main factors controlling soil erosion, i.e., climate, soil characteristics, topography, land cover and land management practice. Arc GIS was used for the generation of R, K, LS, C and P layers. According to Renard and USDA-ARS the Revised Universal Soil Loss Equation (RUSLE) is expressed by equation 1[17][18]:

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

Where, A is the mean annual soil loss (tons ha^{-1} yr^{-1}); R is the erosivity factor (MJ mm ha-1 h-1 yr-1); K is erodibility index (tons ha^{-1} MJ-$^{-1}$mm-1); LS is the combination of slope length (L) and steepness (S) factor (dimensionless) C is the land use/cover factor (dimensionless; ranges between 0-1); and P is the management practice factor (dimensionless, ranging between 0-1).

Individual files was built for each factor in the RUSLE and combined by cell grid modeling procedures in GIS software environment to predict soil loss in the watershed (Figure 2)

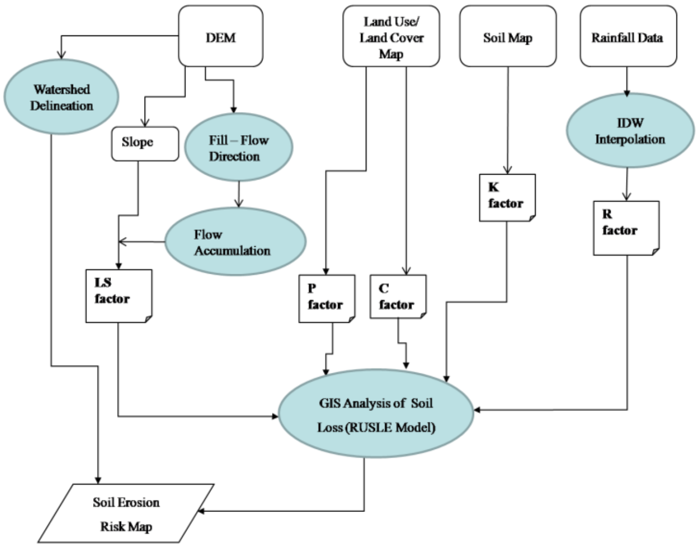

Figure 2: Flow Chart of General Methodology

D. Parameter estimation for RUSLE model

Rainfall erosivity factor (R)

The rainfall factor, an index unit, is a measure of the erosive force of a specific rainfall. R factor was estimated by taking the average of historic rainfall event (30 years). The R value was calculated based on equation 2 given by Hurni which is derived from a spatial regression analysis Hellden [19][20], for Ethiopian conditions.

$$R = -8.12 + (0.562 \times P) \qquad (2)$$

Where; R is the erosivity factor (MJ mm ha^{-1} h^{-1} y^{-1}),P is the mean annual rainfall in mm.

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The inverse distance weight of spatial interpolation technique in GIS software was used for assessing the spatial variability in the rainfall. Then R value was calculated from the rainfall map using 'Raster calculator' tool. The raster rainfall data of the study area was then converted to erosivity map of the study area using the regression equation.

Soil Erodibility Factor (K)

Soil erodibility factor (K) values reflect the rate of soil loss per rainfall-runoff erosivity (R) index. K factor for the soil in the watershed was determined based on its texture; Equation 3 was used for this study:

$$K = f_{csand} * f_{cl-si} * f_{orgc} * f_{hisand} \quad (3)$$

Where; K= t ha^{-1} MJ^{-1} mm^{-1}, f_{csand} is a factor that gives low soil erodibility factors for soils, f_{cl-si} is a factor that gives low soil erodibility factors for soils with high clay to silt ratios, f_{orgc} is a factor that reduces soil erodibility for soils with high sand contents. The factors are calculated using equation 5, 6 and 7;

$$f_{csand} = \left[\left(0.2 + 0.3 * \exp\left[-0.256 * m_s * \left(1 - \frac{m_{silt}}{100}\right)\right]\right)\right] \quad (4)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_s + m_{silt}}\right)^{0.3} \quad (5)$$

$$f_{orgc} = \left(1 - \frac{0.0256 * orgC}{orgC + \exp[3.72 - 2.95 * orgC]}\right) \quad (6)$$

$$f_{hisand} = \left(1 - \frac{0.7 * \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + \exp\left[-5.51 + 22.9 * \left(1 - \frac{m_s}{100}\right)\right]}\right) \quad (7)$$

Where m_s is the percent sand content (0.05-2.00 mm diameter particles), m_{silt} is the percent silt content (0.002-0.05 mm diameter particles), and orgC is the percent organic carbon content of the layer (%) [21].

Slope length and Slope steepness (LS)

The slope length and slope steepness (LS) factor illustrates the effect of topography on erosionIn this study, the flow accumulation and slope were used to calculate and map the LS-factor using equation 8 [22][23]

$$LS = (FA * \text{cell size}/22.1)^m * (0.065 + 0.045\, S + 0.0065 (S)^2) \quad (8)$$

Where FA is the flow accumulation, cell size is the resolution of the grid (i.e., 30 m), m is an exponent that depends on slope steepness and S is slope gradient in percent. To run the equation, mapping of m was undertaken by classifying the slope of the watershed according to the m values presented in Table 1.

Table 1: m Values of different slope classes

Slope class in percent (%)	m value
<1	0.2
1-3	0.3
3.001-5	0.4
>5	0.5

Source: (Wischmeier and Smith, 1978)

Crop Management factor (C)

In this study the satellite image was used to generate the land cover map. The land cover mapping steps includes: preprocessing, training sample collection, image classification and accuracy assessment (Figure 3).

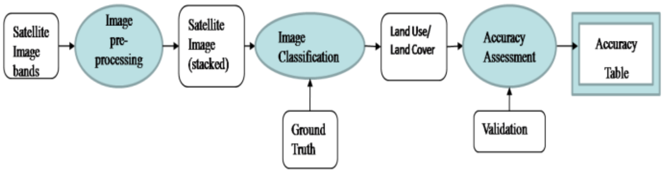

Figure 3: Land cover Mapping Procedure

The type of image pre-processing applied was image stacking. Two image composites were created using different bands: composite of bands 2, 3, 4 (RGB-true image) and composite of bands 3, 4, 8 (False Image). The false composite was used for land use and land cover classification. Training polygons were used for Maximum Likelihood Classification (references). A total of 178 training samples were used for land cover classification. Land cover classification scheme was used based on UNFCCC [24]. Confusion Matrices were used to assess classification accuracy. Outputs of the classification method were compared against ground truth data. Overall accuracy and kappa coefficient were computed.

Assessment of the type of land use-cover was made on each land unit and the corresponding land cover was assigned accordingly. There are different cover factor values suggested for different land cover types [25][26]. However, C values suggested for plantation forest[27][28], Hurni for degraded grass land [29], Bewket and Teferi for cultivated land [30] and Gansari and Ramesh for mixed settlement [31] was used in this study. These values are preferred since they are suitable and suggested for Ethiopian Highland conditions that is dominated by cultivated land and represents a good estimation of cover factor values. Then the C value was converted to raster by conversion tool method from polygon to raster.

Management Practice Factor (P-value)

For all the non-cultivated lands with no conservation practices a P-value of 1.0 was used (Morgan, 1995). For the agricultural lands the P-values corresponding to presence or absence of soil conservation practice and quality of conservation practice was estimated from 0 to1 (Kumar and Kushwaha, 2013). This P values were preferred since there exists different qualities of soil bunds and it is appropriate for this condition unlike other P values suggested by other authors (Hurni, 1985). The appropriate values for each grid cells have been assigned according to the land cover and soil conservation practices.

Estimation of Soil Erosion Rate of the study area

In order to estimate the soil erosion rate of the study watershed, all the six factors (R,K, LS, C and P) that had been identified using the previous method were converted in to a raster format then each layer were changed to the same cell size. Finally ArcGIS was used to overlain all factors. Then the product of these factors was recorded as the soil loss of the watershed area in ton/h/year.

E. Mapping the spatial variability of erosion and identify high risk areas

Erosion rates were reclassified in to six categories. Erosion rates from 0-12 t/ha/year, 12-25 t/ha/year, 25-50 t/ha/year, 50 -80 t/ha/year and >80 were categorized as Low, Moderate, high, very high and extremely high-risk areas respectively [35]. Accordingly, priority map was prepared. Following the reclassification, the kebele shape file was overlain and the area coverage soil loss for each kebele was calculated using zonal statistics tool in ARCGIS 10.2.1 software.

III. RESULT AND DISCUSSION

A. RESULTS

Rain fall erosivity factor

The average annual rainfall of eight meteorological stations was calculated (1986-2016) (Figure 4). The highest monthly mean rainfall was recorded from June to September, and the highest and lowest mean annual rainfall was observed at Jeldu and Dertu Liben stations respectively.

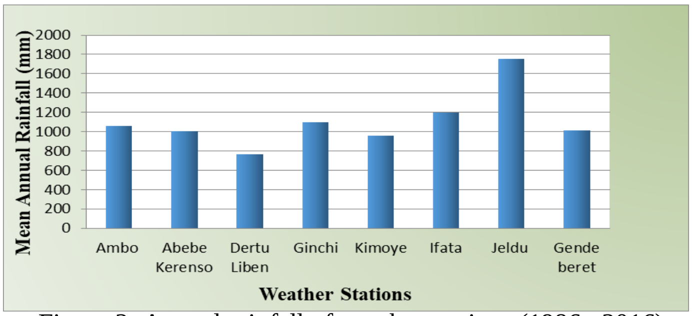

Figure 2: Annual rainfall of weather stations (1986 –2016)

The rainfall amount form these stations was interpolated to obtain the average annual rainfall amount of Meja watershed. According to the interpolation results, an average annual rainfall ranging from 1311 mm up to 1755 mm have been obtained (Figure 5). Accordingly, Erosivity value ranging from 729- 918 MJ mm ha/ ha/year (Figure 6).

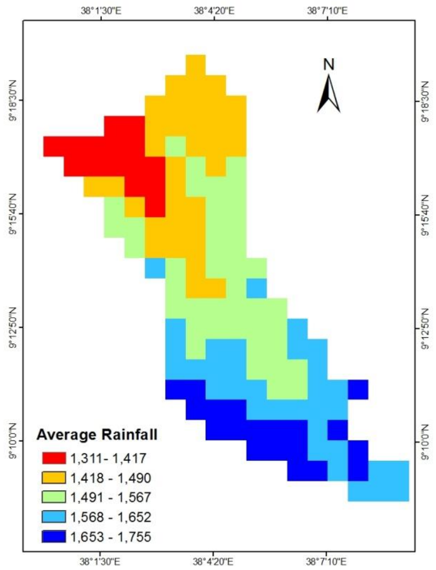

Figure 3: Average annual Rainfall

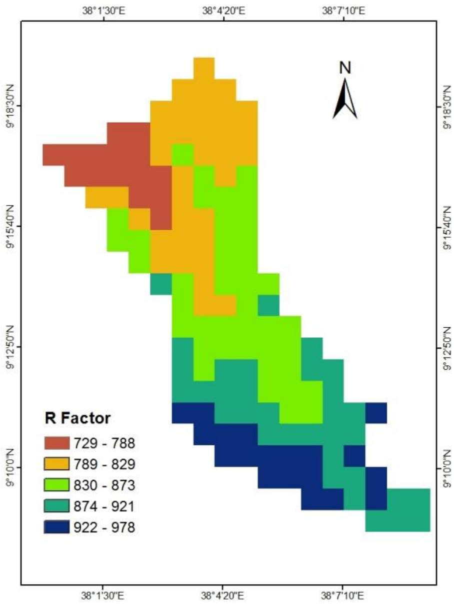

Figure 4: Erosivity factor of Meja Watershed

Soil erodibility factor

The most abundant soil type in the study area is Haplic Acrisol with 11,555 ha of area coverage followed by Eutric Leptosol with 438 ha of area coverage. The least soil area coverage are PellicVertisol and Rhodic Nitosols with an area coverage of 230 ha and 79 ha respectively (Figure 7). When expressed in percent, Haplic Acrisols are 93.93 % abundant while the other soil types all together are below 7%.

Table 2: Soil types, coverage and K value based on Willams (1995) (At 0-30 cm depth)

Soil Unit	Texture			Organic Carbon	f_{scand}	$f_{cl\text{-}si}$	f_{org}	f_{hisand}	K
	Sand	Silt	Clay						
HaplicAcrisols	68	26	6	3.65	0.2	0.94	0.97	0.965	0.18
EutricLeptosols	12	30	58	14.6	0.23	0.72	0.97	0.999	0.16
PellicVertisols	5	30	65	31	0.32	0.71	0.97	0.999	0.2
RhodicNitisols	53	32	15	4.43	0.2	0.89	0.97	0.998	0.17

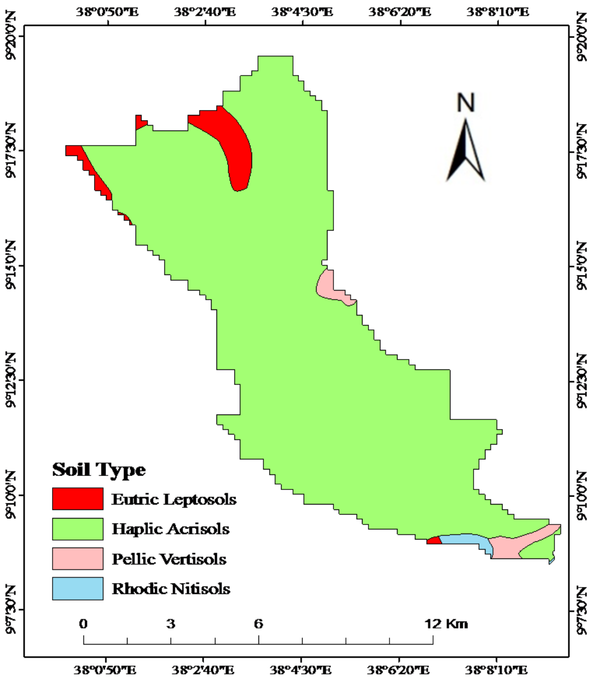

Figure 5: Soil type of Meja Watershed

The top most soil from (0-30 cm) depth have been considered and the highest k factor was found to be 0.2 (Pellic Vertisol) followed by Haplic Acrisols and Rhodic Nitisols with 0.18 and 0.17 values, respectively. Eutric Leptosoil has the k factor value of 0.16, which is the lowest from all the soil types present in the watershed (Table 2).

After assigning the k factor values (Table 2) to the corresponding soil types, K factor values were converted into a raster format with 30 m resolution.

Slope length and steepness factor

The watershed slope increase from North to South-East direction. The dominant slope class is moderately steep (15-30%) covering 38.1 % followed by Sloping (8-15%), which covers 25% (Figure 8). LS were performed by classifying the slope of the watershed according to the m values presented in Table 1. The m map indicated that values of m vary from 0.2 in the lower part of the watershed to 0.5 in the upper parts (Figure 9). LS was then calculated by the aid ofthe raster calculator tool using the formula of Equation 10. The resulting combined LS-factor map varied between 0 and 22.5 (Figure 10B).

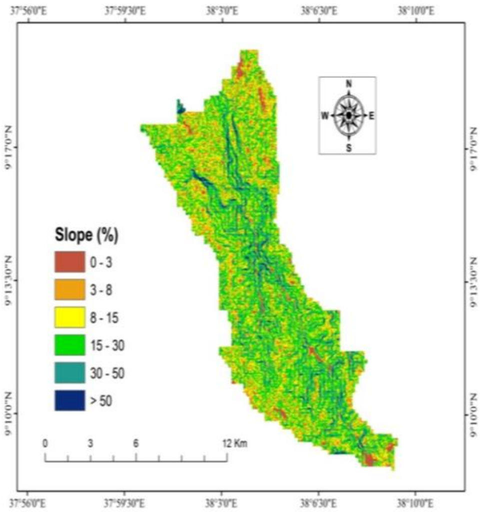

Figure 8: Slope of the watershed

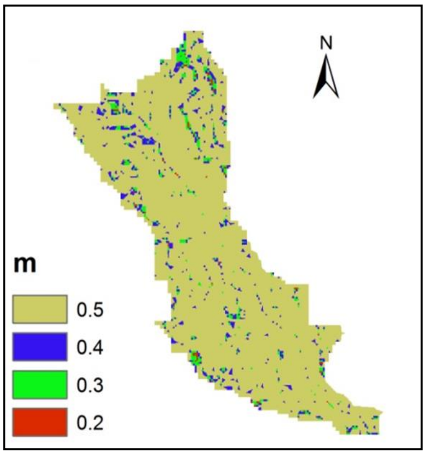

Figure 6: Map of m values

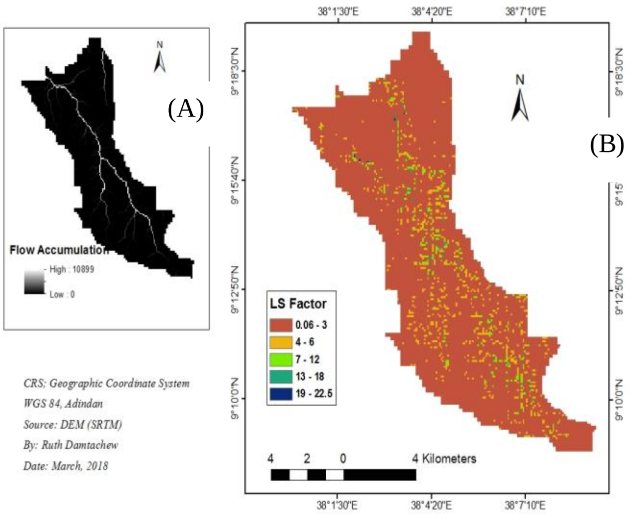

Figure 10: (A) Flow accumulation and (B) LS factor map

Crop management factor

The dominant land use type is cultivated land (57.4%) followed by settlement (20.5%) and plantation forest (16%) respectively. Most of the plantation forest is dominated by eucalyptus. The least dominant land use type is grassland with 6.1% of area coverage (Table 3).

Table 3: Land use/cover area coverage

Land use/cover	**Area Covered (Ha)**	**Percentage of area coverage (%)**
Grassland	752.5	6.1
Cultivated land	7062.8	57.4
Plantation Forest	1971.9	16.0
Settlement	2516.9	20.5
Total	12304	100

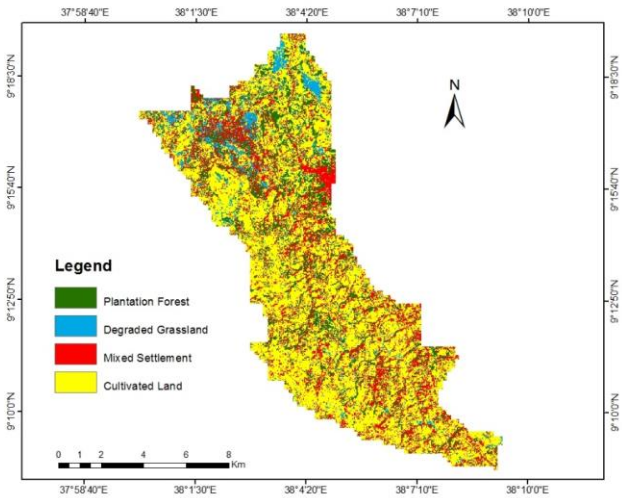

Figure 7: Land use/cover Map

Accuracy Assessment

The results indicate a good performance for both producer's and user's accuracy assessment. Producer's accuracy result shows that grassland and cultivated land were classified accurately among all with 100% and 93.5% respectively, then followed by settlement area and plantation forest classes which turned out to be 84.6% and 72.4% (Table 4). On the other hand, user's accuracy is very high for grassland (93.3%) followed by 91.3% for plantation forest, 88% for settlement and 82.7% for grassland. As it is shown in (Table 4), the supervised classification showed high reliability in correctly predicting classes with an overall classification accuracy of 87% and an overall kappa statistics of 0.82. The Kappa statistics shows that the image classification is highly accurate matching near to perfect to the ground data [36].

Table 4: Classification Accuracy Matrix

Class	**Reference Total**	**Classified Total**	***B. Number Correct***	**Producers Accuracy (%)**	**Users Accuracy (%)**
Settlement	26	25	22	84.6 %	88%
Plantation Forest	29	23	21	72.4 %	91.3%
Cultivated Land	46	52	43	93.5%	82.7%
Grassland	14	15	14	100%	93.3%
Totals	115	115	87		

Overall Classification Accuracy=87% and Over all Kappa Statistics= 0.82

As a result, cover factor values for each land use type have been assigned (Table 5) based on the values suggested by different authors [37][38][39][40][41].

Table 5: Cover management factor values of Meja watershed

Land use/cover	**C-factor**	**Reference**
Plantation Forest	0.001	Morgan (1985 and 2005); Amare et al. (2014)
Degraded Grassland	0.05	Hurni (1985); Abate (2011); Tadesse and Abebe (2014)
Cultivated land	0.15	Bewket and Teferi (2009); Tadesse and Abebe (2014)
Mixed Settlement	0.09	Gansari and Ramesh (2015)

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After assigning the C factor values (Table 5) to the corresponding land use and cover types, C factor values were converted into a raster format with 30 m resolution.

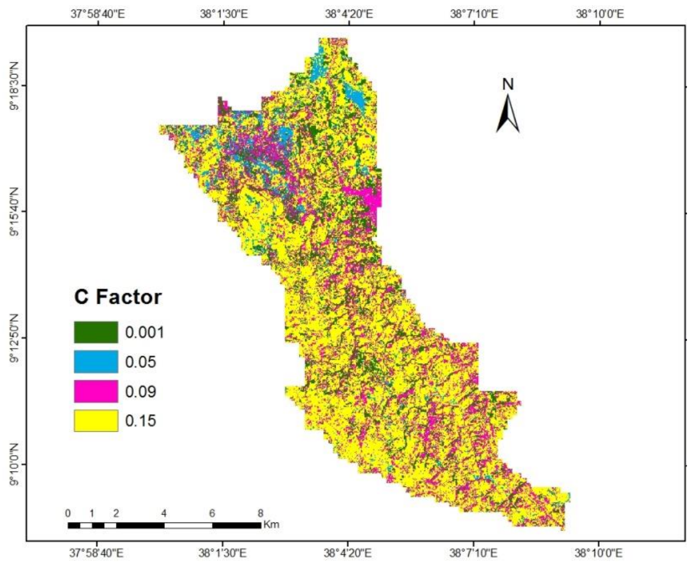

Figure 8: Cover factor map of Meja watershed

Management practice factor

For all agricultural lands with no conservation structure a p factor value of 0.9 had been assigned, while for agricultural lands with poor and moderate bund qualities, P factor values of 0.54 and 0.36 respectively have been assigned (Kumar and Kushwaha, 2013). For all non cultivated lands, P factor value of 1 had been assigned (Table 6 & Fig. 13).The assigned the P factor values (Table 6) to the corresponding land use and bund qualities were converted into a raster format with 30 m resolution Fig 13).

Table 6: P values assigned according to the land use and qualities of conservation structures

Land Use	**Qualities of Bund**	**P Factor**	**Reference**
Agricultural land 1	None	0.9	Kumar and Kushwaha (2013)
Agricultural land 2	Poor	0.54	Kumar and Kushwaha (2013)
Agricultural Land 3	Moderate	0.36	Kumar and Kushwaha (2013)
Grassland	-	1	Morgan (1995)
Plantation Forest	-	1	Morgan (1995)
Mixed settlement	-	1	Morgan (1995)

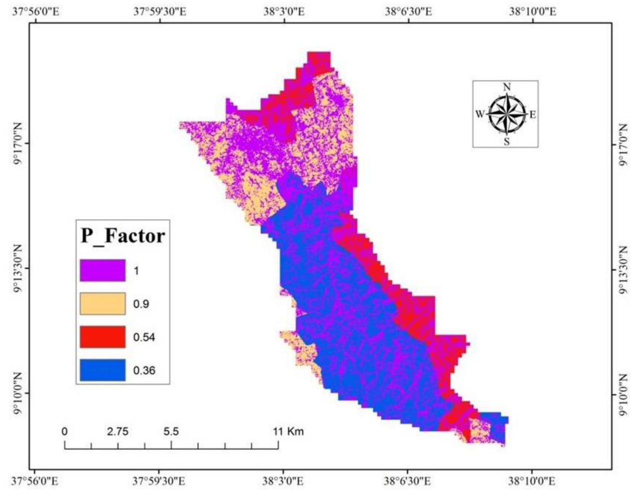

Figure 9: Management practice factor map of Meja Watershed

Estimation of Soil Loss and Erosion Risk areas

The annual soil erosion rates ranged from 0 t t/ha/year in plain areas to more than 100 t/ha/year in the undulating terrains of the watershed with a mean annual soil loss of 25.14 t/ha/year (Figure 14). The result shows that the entire watershed loses a total of about 107,787 tons of soil annually. In terms of exposure to the risk of erosion, set according to Bewket and Teferi [43] about 78.5 % of the watershed is characterized low soil erosion rate, which is 0–12 t/ha/year and these areas are considered low risk areas. The remaining areas are categorized as moderate risk areas (8.3%) with a rate of 12–25 t/ha/year, high risk areas (6.4%) with a rate of 25–50 t/ha/year, very high risk areas (3.6 %) with a rate of 50 –80 t/ha/year and extremely high affected areas (3.3%) with a rate of >80 t/ha/year (Table 7).

Table 7: Annual soil loss rates and severity classes with their conservation priority

Soil Loss (t/ha/year)	**Severity class**	**Priority**	**Area (Ha)**	**Percent of total area (%)**	**Annual soil loss (ton)**	**Annual soil loss (%)**
0-12	Low	V	9660	78.5	11379.3	10.2
12-25	Moderate	IV	1016	8.3	18832.8	16.9
25-50	High	III	787	6.4	26142.9	23.5
50-80	Very High	II	439	3.6	19529.0	17.6
>80	Extremely High	I	402	3.3	35337.9	31.8

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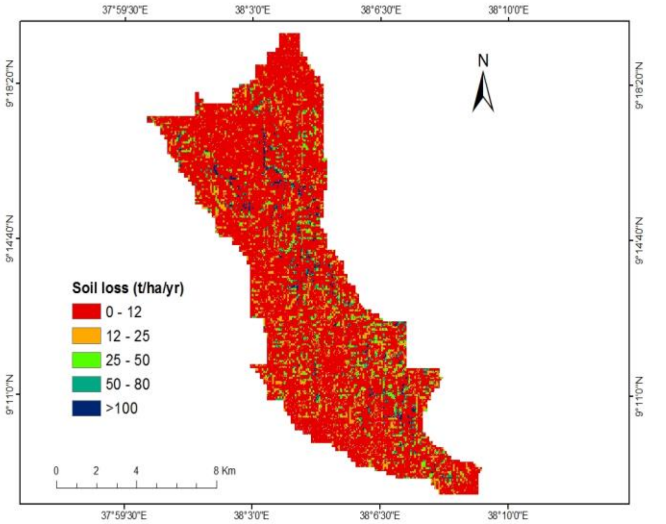

Figure 10: Soil erosion severity map of Meja watershed

Prioritization of Erosion Risk areas

Based on the estimated rates of erosion, Meja watershed is classified and ranked into five priority classes (Table 8 and Figure 15). The total area experiencing soil erosion rate above 12 t/ha/year is 2644 ha, which covers 21.6% of the entire watershed. However, this area accounts for 89.8 % (99842.8 tons) of the total soil loss. According to the result, priority class I covers only 3.3% of the entire watershed but it accounts about 31.8% (35337.9 tons) of the total soil loss. Whereas priority classes II and III combined cover only about 10% of the watershed but contributed 41.1% (45671.9 tons) of the soil loss. Priority Class V covers the percentage of area (78.5%) but it contributes the lowest percent (10.2%) for the total soil loss (Table 8).

Out of the 16 kebeles included in the watershed, all kebeles have more than 70% area of soil loss within the range of 0-12 t/ha/year. For evaluating the high areas of soil loss the sum of very severe soil loss range above 50 % was considered. Kebeles with high percentage areas of soil loss rate are Aintodele (4.2%), Galesa Kofitu (4.2 %), Chalnko (4.1%) and Seretidenku (3.7 %). Whereas other kebeles such as Harodagadaba, Bicho, Tulugura, Andesalegn, Tulugurji, Kologelan, Gosomikael, and chebiserba have coverage of less than 2%. Meanwhile, KetketeWeren Bulich and Gorolelisa have showed the least coverage (0%) (Table 9).Accordingly, a priority class has been assigned based on the mean annual soil loss rates and the severity classes (Figure 15).

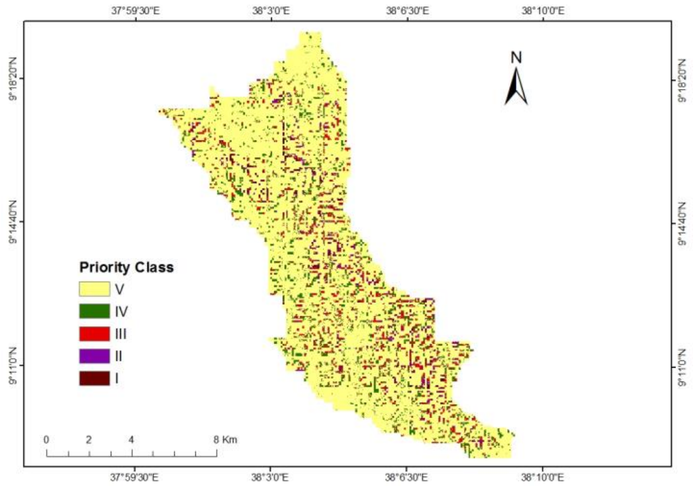

Figure 11: Prioritization map for soil and water conservation Planning

Table 8: Area of soil lost per kebele in the Watershed

Kebelle	Area coverage of soil loss (%)			
	Class I	Class II	Class III	Class IV
Chabiserba	92.1	4.7	2.0	1.2
Kologelan	91.6	4.4	2.2	1.1
Tulugurji	85.9	6.8	3.6	1.7
Aedensagelan	85.6	6.0	4.2	2.0
Tulugura	83.2	7.6	5.4	2.1
Sertidenku	74.0	10.1	9.4	3.7
Bicho	82.8	7.4	5.0	2.6
Chlanko	77.2	7.4	9.5	4.1
GalesaKofitu	73.1	13.3	8.7	4.2
KetiketeWerenBulich	100.0	0.0	0.0	0.0
Goralelisa	73.0	12.7	9.5	0.0
Herokakeli	89.0	5.1	4.2	1.3
Gojo Town	80.1	9.3	7.2	2.9
Herodagadaba	82.7	6.8	5.3	2.2
Aintodele	83.3	12.5	0.0	4.2
Goso Mikael	92.1	4.7	2.0	1.2

Where; Class I= 0 - 12, Class II=12-25, Class III=25-50, Class IV= >50 t ha−1 year−1

TABLE I. TABLE STYLES

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C. DISCUSSION

Rate and severity of soil erosion in Meja Watershed

The average soil loss rate estimated for the entire watershed was 25.14 t/ha/year, which is comparable to the average soil loss rate reported by Hurni [44] for the highlands (18 t/ha/year). The current result agrees with similar findings reported by Gashaw for Geleda watershed [45], North western highlands (23.7 t/ha/year), for the Wondo Genet watershed in the eastern highlands (26 t/ha/year) [46] and [47] for the Jabi Tehinan watershed in the northwestern highlands (30.4 t/ha/year).

The relatively higher average soil erosion rate estimated in the current studied watershed could be resulted from the topography, which is dominated by moderately steep (16-30%) and steep sloping (31-50%), It accounted 38% and 14 %, respectively. This is in line with other study who reported higher erosion rates in steeper slopes [48]. High erosion rates on steep slopes were also reported in other similar studies such as in Medego watershed where the slope ranged between 30 and 50% [49], and Abate reported erosion rate of more than 80 t ha−1 year−1 on steep slope areas in the Borena watershed [50]. In these studies higher erosion rates up to 80 t/ha/year have been reported in steep slope areas ranging from 30-100 %. It is also reported that highest soil loss rates reaching up to 200 t/ha/year have been recorded in very steep slope areas [51].

There are very high erosivity values reaching up to 978 that contribute to high amount of soil loss in Meja watershed. The type of land use also affects the soil loss rate in the watershed. Since the majority of the land use type is cultivated land (57%), this also contributes to the high amount of soil loss. It is confirmed that a very high soil erosion rate as a result of no land cover [52]. Ganasri and Ramesh also reported that erosion rates increased by 3.1% due to small increases in agricultural areas and decrease in forest areas [53]. The increase in soil loss rate may also be associated with the management practice, where poorly constructed soil bunds and absence of any conservation practice on cultivated areas may promote the increase in soil loss rate in the study area. In line with this finding it has been reported that increase in soil loss is highly attributed to the absence of effective soil and water conservation structure and agricultural activities such as ploughing, tillage and land preparation [54][55]. Some studies however, reported a rather elevated rate of erosion in different parts of the Ethiopian highlands.

For instance, Gelagay and Menale in Koga watershed of the Nile basin reported an average soil erosion rate of 47.4 t/ha/year [56]. An average soil loss rate of 45 t/ha/year was also found [57]. Molla and Sisheber also reported an average soil loss rate of 42 t/ha in Koga watershed, revealing a very high rate as high as 716 t/ha [58]. This is because the topography of the watershed is dominated by very steep slope areas and also associated with the land cover of the areas i.e. cultivated land being the dominant land use. Very high erosion rates unlike this study was also reported an average soil erosion rate of 93 t/ha/year in Blue Nile basin Chemoga watershed [59]. This was mainly due to the steep slopes and cultivation on these steep slope areas.

Prioritization of intervention areas based on the severity and high risks of soil erosion is very important. According to the result presented in (Table 8) the lowest areas contributed to the highest amount of soil loss in the watershed. In line with the findings of this study. For instance, it is found that priority class I (50 - 237 t/ha/year) covers only 0.83% of the entire watershed but it is responsible for 12.62% (19,822 tones) of the total soil loss [60]. Whereas priority classes II (30 -50 t/ha/year) and III (18 – 30 t/ha/year) combined cover about 6.49% of the watershed but contributed only 8.78% of the soil loss. Another study in Borena watershed conducted by Abate showed that areas experiencing very high to extremely severe soil loss accounted 29.85% but contributed 60.03% of the soil loss estimated in the studied watershed [61]. A study conducted in Wondo Genet watershed also revealed that 54.54% of the soil loss was contributed from 23.5% of the watershed area [62].

The areas that experienced from very high to extremely severe soil loss in Yangou watershed covers percent area of 25% but contributed 58.2% of the soil loss [63]. Studies in highlands of Ethiopia also indicates that areas having small coverage of severe and very severe soil loss contributed the highest amount for the estimated total soil loss amount [64][65]. These suggest the need for soil and water conservation measures that should be taken based on the given priority. There are different conservation measures suggested by different researchers for highland areas [66][67][68].

IV. CONCLUCION

The resulting soil erosion map produced by overlaying of grid maps of the six factors showed that the soil loss rate of the watershed ranged from 0 – more than 100 t/ha/year with a mean annual soil loss rate of 25.14 t/ha/year. Majority (78.5 %) of the watershed is characterizedas low soil erosion rate (0–12 t/ha/year). Moderate risk areas account for 8.3% with a rate of 12–25 t/ha/year. High risk areas cover 6.4% of the entire watershed area with a rate of 25–50 t/ha/year. The remaining areas are categorized as very high and extremely high risk areas covering 3.6 %and 3.3% of areal coverage. Areas having moderate to extremely high erosion rates are related to the steeper slopes and the land use. Moreover, Most of the watershed area is at low risk of erosion. But the small extremely high- and high-risk areas contribute the largest for the total soil loss. To facilitate the implementation and maintenance of soil conservation measures, the entire watershed has been organized into 5 priority areas. The watershed requires implementation and maintenance of different types of soil and water conservation measures for a sustainable land use. Even though participatory watershed development and different resource limitations may hinder the implementation of different structures, prioritizing the watershed risk areas may help to overcome such barriers. Prioritization entails the ranking of the areas within the watershed based on the amount of soil lost and suggesting the best fit soil and waters conservation strategy. Hence, undertaking soil conservation measures based on the given priority is desirable.

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