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# Effect of Land Use-Land Cover Change on Soil Erosion and Sediment Yield in Muger Sub-Basin, Upper Blue Nile Basin, Ethiopia

**Dawit Samuel Teshome [1,2,3], Mitiku Badasa Moisa [4], Dessalegn Obsi Gemeda [5] and Songcai You [1,*]**

1 Institute of Environment and Sustainable Development in Agriculture (IEDA), Chinese Academy of Agricultural Sciences (CAAS), Beijing 100081, China
2 Oromia Agricultural Research Institute, Bako Agricultural Research Center, Bako P.O. Box 03, Ethiopia
3 Graduate School of Chinese Academy of Agricultural Sciences, Beijing 100081, China
4 Faculty of Technology, Wollega University, Shambu P.O. Box 38, Ethiopia
5 College of Agriculture and Veterinary Medicine, Jimma University, Jimma P.O. Box 307, Ethiopia
* Correspondence: yousongcai@caas.cn

**Abstract:** Land use and land cover (LULC) change have intense implications on soil resources, that requires research attention and global collaboration to take urgent actions. The present study attempted to analyze the impact of LULC change on soil erosion and sedimentation in Muger Sub-basin, southwestern parts of Ethiopia. Landsat TM 1986, Landsat ETM+ 2003, and Landsat OLI/TIRS 2020 are used for LULC analysis. We used rainfall erosivity, soil erodibility, slope length and steepness, cover management, and conservation practices to calculate soil erosion and sedimentation between 1986 and 2020. In this study, the integration of revised universal soil loss equation (RUSLE) model and geographic information system (GIS) are used to analyze the impact of LULC change on soil erosion and sedimentation. The average soil loss rate is about 53.2 ton/ha/year in 1986 and increased to 63.6, and 64 ton/ha/year in 2003, 2020, respectively. Result revealed that about 2707.7 ha (33%), 3124.5 ha (38.1%) and 3197.4 ha (38.9%) were exposed to severe erosion in 1986, 2003 and 2020, respectively. The mean sediment yields of the study area is estimated to 7.8 ton/ha/year in 1986, and later increased to 10, and 10.2 ton/ha/year in 2003, and 2020, respectively. Results revealed that the steep slope areas with crop land experience considerable soil loss, with mean soil loss increasing over all study period. Thus, urgent policy on the wise use of natural resources is essential not optional to reduce the current soil loss and sedimentation in Muger Sub-basin.

**Keywords:** RUSLE model; mean annual soil loss; soil erosion; sediment yield; Muger sub-basin

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## 1. Introduction

Soil erosion caused by land degradation is one of the world's most serious environmental problems [1,2]. Over 75 billion tons of soil lost by erosion every year at global level [3,4]. These losses of soil have a significant impact on natural resource conservation as well as agricultural production [4–6]. Substantial studies have shown that soil loss and sedimentation have an impact on soil degradation, agricultural yield productivity, and increased nutrient accumulation in water bodies, i.e., eutrophication [6–8]. Frequent land use and land cover (LULC) change and unwise use of natural resources aggravate soil erosion and sedimentation [4–6,9,10]. Between 2001 and 2012, the LULC change contributes about 2.5% for the global soil mean loss [4,6]. Soil erosion can significantly contributes to the problems of food insecurity of agricultural based economy of developing countries like Africa, Asia and Latin America [11–13]. In comparison to Asia and Latin America, Africa is highly exposed to soil erosion [12,14].

The problem of soil erosion and sedimentation driven by LULC and other underlying factors like climate change has been a topic of concern over highland countries like

Ethiopia. The cumulative impacts of rapid population growth and unwise use of resources contributes for the increasing trends of soil erosion and sedimentation in Ethiopia. Forest encroachment to agricultural land is most likely the major factors that contributes for the current environmental problems in the country [15,16]. Study conducted in the Blue Nile Basin confirmed that rapid population growth contributed to LULC change which in turn to erosion risk and hazardous [8]. The increasing trend of human population boosting space demand for agricultural land and other economic activities. The total population of Ethiopia is about 114.96 million (Estimated as December 2020) with a growth rate of 2.57% [17]. Un imbalance between human needs and high demand for cultivated land contributes for the current environmental challenges of Ethiopia. About 85% of the total export earning, and 50% of the gross domestic product of Ethiopia is covered by agriculture [6,18].

According to [19], substantial areas around the Ethiopian highlands have been severely eroded, which requires multi-sectoral collaboration to recover. These issues are the cumulative effects of unwise use of land resources and the rapid population growth [8,20]. Severe land degradation and soil erosion has been documented over the central highland regions of Ethiopia [21,22]. Substantial studies show that the Ethiopian highlands are losing 200 to 300 tons of soil per hectare per year [6,23,24]. In Ethiopia, the presences of heavy rainfall, less vegetation cover, and high topography are contributing to the severity of soil loss and sedimentation. Likewise, deforestation, rapid urbanization, cultivation on steep slope, and overgrazing were another contributing factors for severity of soil loss and sedimentation in the country [6,24,25]. Soil erosion and sedimentation can significantly reduce agricultural yields, which enhances the conversion of forest ecosystems to agricultural land [21,26].

The declining of forest ecosystem will likely intensify climate extreme such as drought and flood. Research finding indicated a strong linkage between land degradation and climate extremes. Previous studies show that Ethiopia had severe and frequent drought and famine over the past decades [20,27]. Ref. [28] in the wettest parts of Ethiopia also detected the presences of extreme and severe drought and floods over the past several decades. The occurrence of climate extremes can significantly affect soil properties that may exposed to severe erosion. Soil erosion due to LULC change and other anthropogenic factors in southwestern parts of Ethiopia. Several studies have been performed to assess the effects of LULC changes on soil erosion and sedimentation [20,29,30], but the status of soil loss and yield sediment in the Muger Sub-basin is unknown. To design appropriate intervention strategies, investigating the impact of LULC change on soil erosion and yield sedimentation are essential not optional. As a result, soil loss assessment is a pre-requisite actions to design soil and water conservation measures [20,31–34].

Several scholars have been used revised universal soil loss equation (RUSLE) model by integrating with geographic information system (GIS) to quantify the amount of soil loss in different parts of the world [1,35–37]. Substantial studies have been used this model due to its compatibility with GIS and applicability to quantify the net and mean soil loss under different ecosystems types and management situations [1,20,32,34,38,39]. The RUSLE model is more adaptable, simple to apply, and works with GIS technology [37,40]. We selected the RUSLE because it is successful in highland areas and more operational in estimating annual soil loss with less field data [41–44].

Although the impacts of LULC change on soil loss and sedimentation have been studied, the southwestern parts of Ethiopia did not get research attention and little is known about the Muger Sub-basin. The rapid conversion of forest cover and other land cover classes to cultivated land worsen soil erosion and sedimentation. In spite of this facts, there is a knowledge gap on the quantity of soil loss and sedimentation in the study area.

## 2. Materials and Methods

### 2.1. Study Area Descriptions

The Muger Sub-basin is located in Oromia regional state, Ethiopia. The absolute location of the study area is between 9° 05′18.7′′–10°01′21.7′′ N latitude and 37°44′29.77′′–39°01′6.7′′ E longitude. Topography of the study area varies between 930 and 3530 meter above sea level (Figure 1). The study area covers about 8188 km$^2$. The study area temperature is warm to hot. The mean maximum temperature is between 16 and 31.5 °C, while the mean minimum temperature varied from 3 to 16.5 °C [45,46]. The annual rainfall around Muger Sub-basin is between 833 and 1326 mm. Leptosols and Luvisols are the most dominant soil types in Muger Sub-basin. Other common soils occurring in the study area includes Cambisols, Nitosols, and Rigosols [45,46].

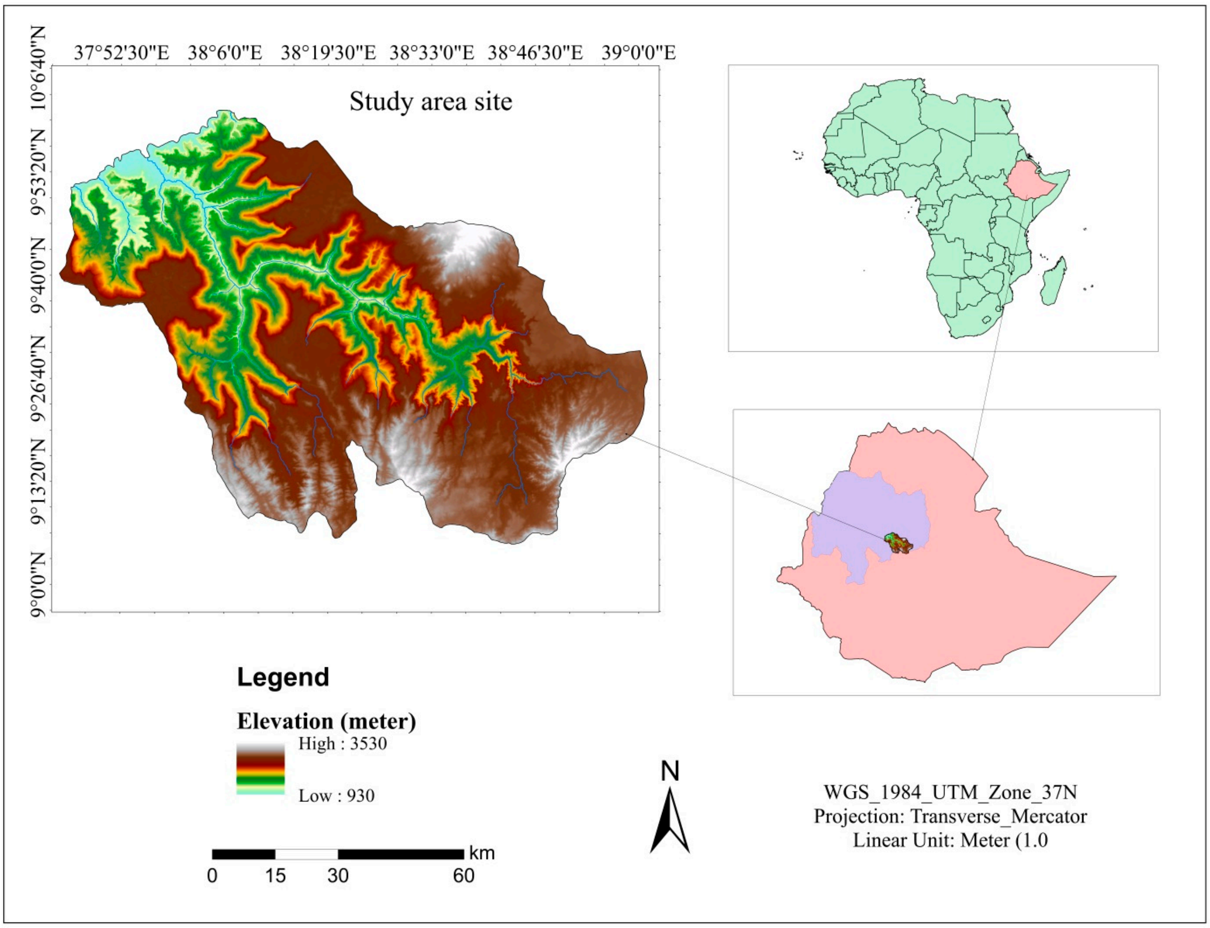


**Figure 1.** Map of the study area.

According to [46] the Muger sub basin is characterized as three main climate classification: lowland, middle land, and highland. Due to diversified climate types, varies types of crops are cultivated in this area [19]. In 2007, the Muger Sub-basin has a total population of 1,827,639 [47,48]. The population projection for 2017, and 2020 was about 2,381,946 and 2,523,089, respectively [48,49].

## *2.2. Land Use and Land Cover*

According to [45], of the different land-use in Muger Sub-basin, agro-pastoral and agriculture are the major ones. Pastoral land is also observed in some part of the basin. Eight major LULC types namely: cultivated land, shrub land, forest land, settlement, bare land, water body, grassland, and wetland are identified [48] and utilized for this study (Figure 2).

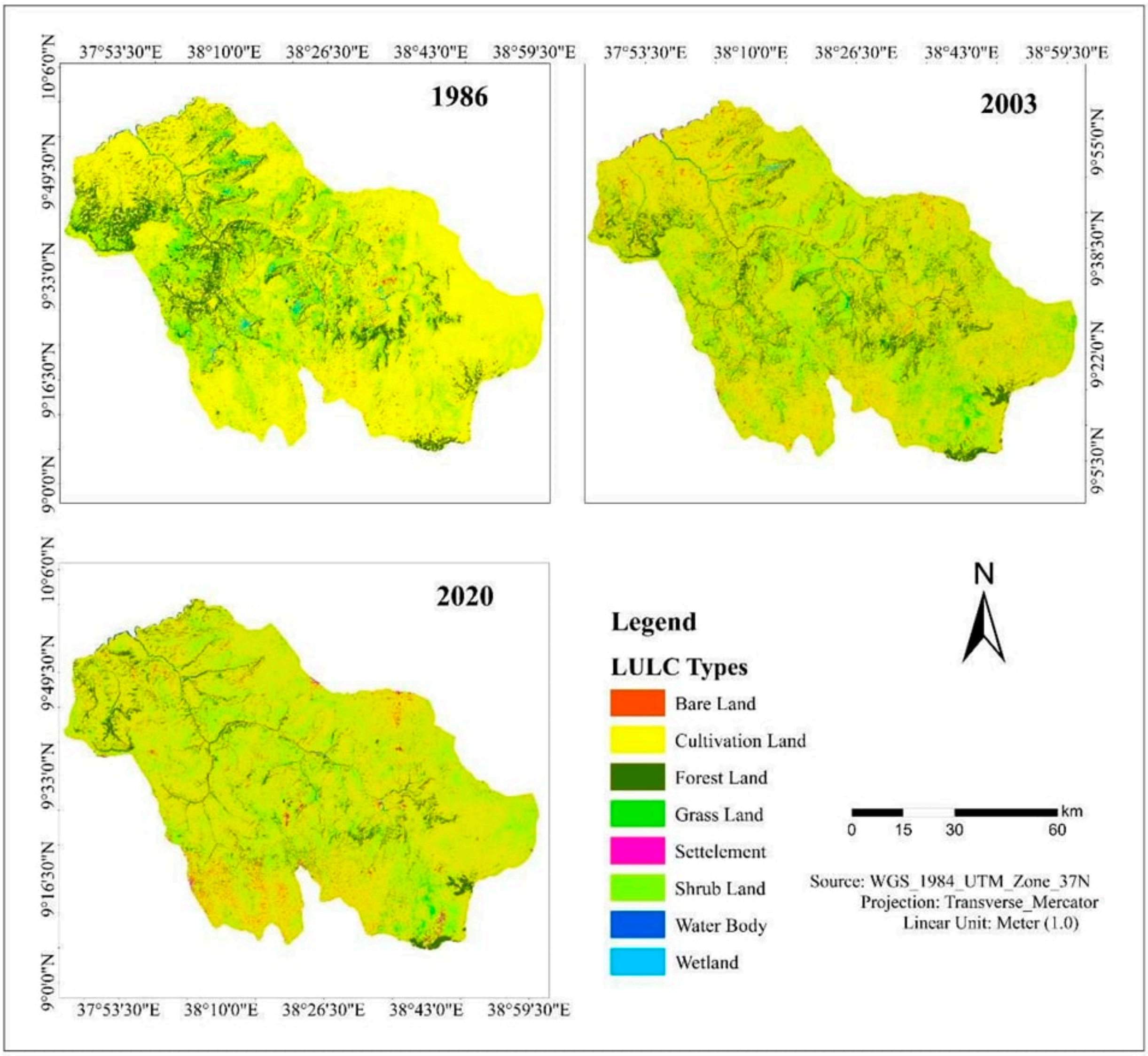


**Figure 2.** LULC map of Muger Sub-basin in 1986, 2003, and 2020 adapted from [48].

### *2.3. Data Sources and Types*

The present study used four geographic datasets from various sources: rainfall data, Landsat imagery, Digital Elevation Model (DEM), and digital soil map from Food and Agriculture Organization (Table 1). We obtained rainfall data of 35 years (1986–2020) of 18 stations in and around Muger Sub-basin from Ethiopian National Meteorological Agency (NMA) (Table 2). In the present study, the LULC analysis is taken from the previous land cover map we have done for the LULC analysis, three map for 1986, 2003 and 2020 [48]. Teshome et al. [48] used three Landsat images (i.e., TM Landsat-5 for 1986, ETM+ Landsat-7 for 2003, and OLI-TIRS Landsat-8 for 2020 LULC analysis in Muger Sub-basin). The DEM obtained from Ethiopian Ministry of Water, Irrigation and Energy (MoWIE) with 30 m spatial resolution was used to delineate the Sub-basin, to develop elevation, and to generate the slope of the Sub-basin.

**Table 1.** Data types and sources.

| Data Category | Sources | Purpose | Period/Resolution |
|---|---|---|---|
| DEM | The shuttle radar topographic mapping obtained from the MoWIE Ethiopia | To generate drainage network, flow length, and LS factor | 30 m |
| Landsat images | Derived from Landsat images (Landsat-5, Landst-7, and Landsat 8) [48] | For LULC types and C, and P-factor | 30 m (1986, 2003, and 2020) |
| Soil data | MoWIE, Ethiopia | To map soil types and to generate the soil erodibility (K) factor | 1:250,000 |
| Rainfall data | NMA | To extract the R-factor from the mean annual rainfall data | 1986–2020 |

**Table 2.** The mean annual rainfall (mm) and the R-factor.

| Stations | Location | | | Mean Annual Rainfall (mm) (1986–2020) | R-Factor MJ mm $ha^{-1}$ $h^{-1}$ $year^{-1}$ |
|---|---|---|---|---|---|
| | Latitude (°N) | Longitude (°E) | Elevation (m) | | |
| Addis Ababa Obs | 9.02 | 38.75 | 2386 | 1213.24 | 673.72 |
| Kachise | 9.61 | 37.86 | 2557 | 1847.11 | 1029.96 |
| Fiche | 9.77 | 38.73 | 2784 | 1156.95 | 642.08 |
| Debre Berhan | 9.63 | 39.50 | 2750 | 928.52 | 513.71 |
| Gohatsion | 10.00 | 38.24 | 2507 | 1203.34 | 668.16 |
| Gebere guracha | 9.82 | 38.42 | 2560 | 1337.10 | 743.33 |
| Degem | 9.82 | 38.63 | 3086 | 1120.82 | 621.78 |
| Debre Tsige | 9.64 | 38.83 | 2640 | 883.55 | 488.43 |
| Fital | 9.62 | 38.65 | 2566 | 978.66 | 541.89 |
| Muke Turi | 9.62 | 38.65 | 2649 | 979.29 | 542.24 |
| Derba | 9.43 | 38.65 | 2385 | 1154.67 | 640.81 |
| Chancho | 9.30 | 38.74 | 2632 | 1536.33 | 855.30 |
| Sululta | 9.18 | 38.73 | 2610 | 1202.92 | 667.92 |
| Muger | 9.45 | 38.34 | 2553 | 1371.37 | 762.59 |
| Enchini | 9.32 | 38.37 | 2687 | 1231.11 | 683.76 |
| Shekute | 9.37 | 38.04 | 2581 | 1448.90 | 806.16 |
| Harodoyo | 9.56 | 37.96 | 2532 | 1478.80 | 822.96 |
| Jeldu | 9.25 | 38.08 | 2952 | 1524.05 | 848.40 |

### *2.4. Soil Loss Estimation Based on RUSLE Model*

The revised universal soil loss equation (RUSLE) model has the capacity to calculate the amount of soil loss over particular area or region [42]. This model considers a real situation at watershed level [42,50]. The RUSLE is easy to use under data deficient and applicable at different scale [6,20,33,42,51–55]. Five key parameters namely: rainfall erosivity, soil erodibility, slope length and steepness, cover management, and conservation practices were required to calculate soil loss and sedimentation using RUSLE model as indicated in Equation (1). The overall methodology used for annual soil loss estimation is demonstrated in Figure 3.

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

where A is the average soil loss (ton/ha/year);

R is rainfall runoff erosivity factor (MJ mm ha/year);
K is soil erodibility factor (ton/ha MJ mm/year);
LS is slope length and steepness factor;
C is land cover and management factor, and
P is conservation practice factors.

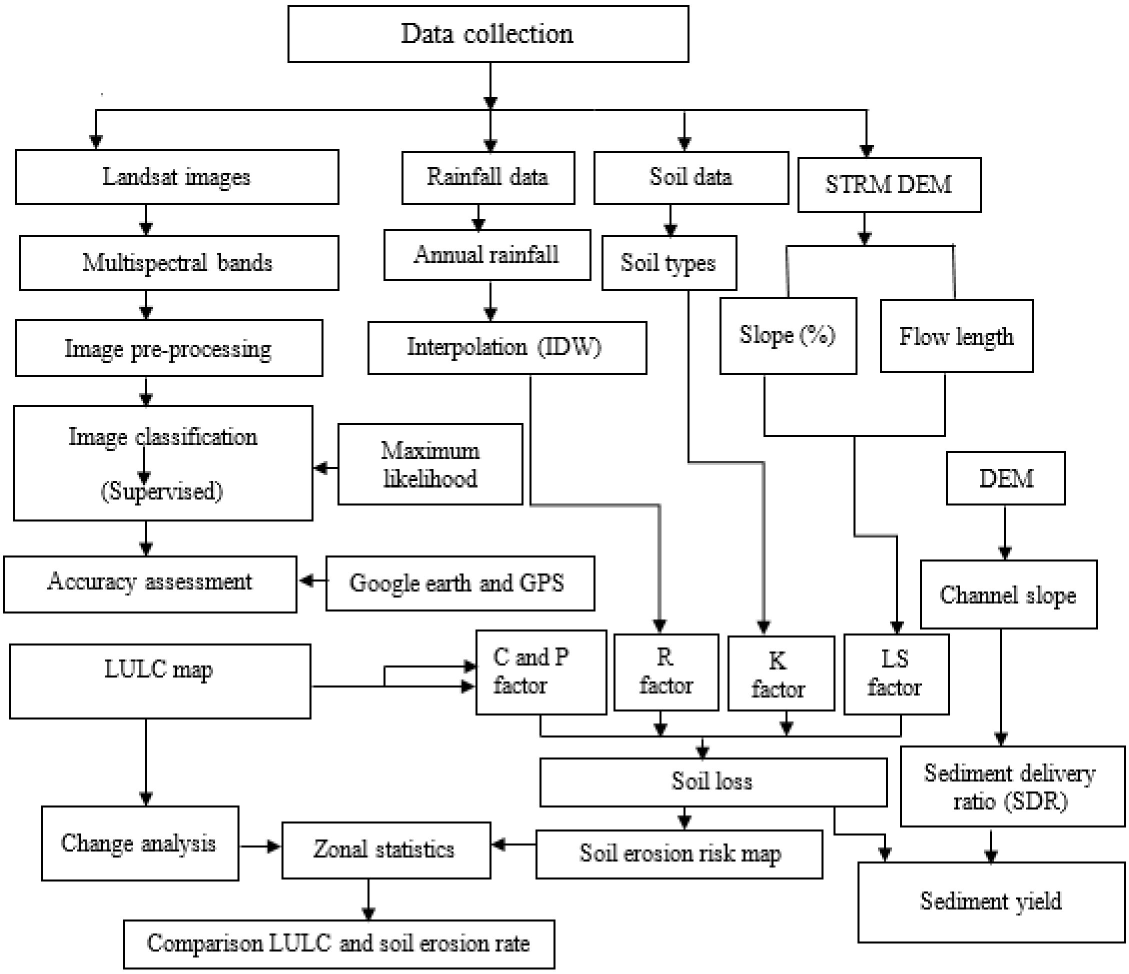


**Figure 3.** Methodological framework of the study.

### 2.4.1. Rainfall Erosivity (R) Factor

R-factor shows the relationship between rainfall kinetic energy and soil nature [56]. Rainfall erosivity of a particular area is influenced by intensity and distribution of rainfall [37,57], from the two factors, intensity is the most important factor in influencing erosion severity [12]. The R-factor is calculated as recommended by [58] to the Ethiopian conditions (Equation (2)). Rainfall data from 18 stations around the Muger sub-basin are collected from Ethiopia's National Meteorological Agency (NMA) from 1986 to 2020 (Table 2). The estimated R factor was converted into a 30-m resolution using the inverse distance weight (IDW) method (Figure 4).

$$R = -8.12 + (0.562 * P) \quad (2)$$

where R is the rainfall erosivity factor and P is the mean annual rainfall (mm).

### 2.4.2. Soil Erodibility (K) Factor

The K-factor indicates the capacity of soil particles to resist the influence of soil detaching after rainfall [56]. This factor indicates the degree of exposure and sensitivity to soil erosion [38]. However, in case of deficient on soil data soil color can be used as the base for K-factor determination [15,59]. The K-factor is assigned based on soil color and types, and clipped with Ethiopian digital soil map (Figure 5a). The K value were given based on soil color and scientific literatures on Ethiopian highland (Table 3).

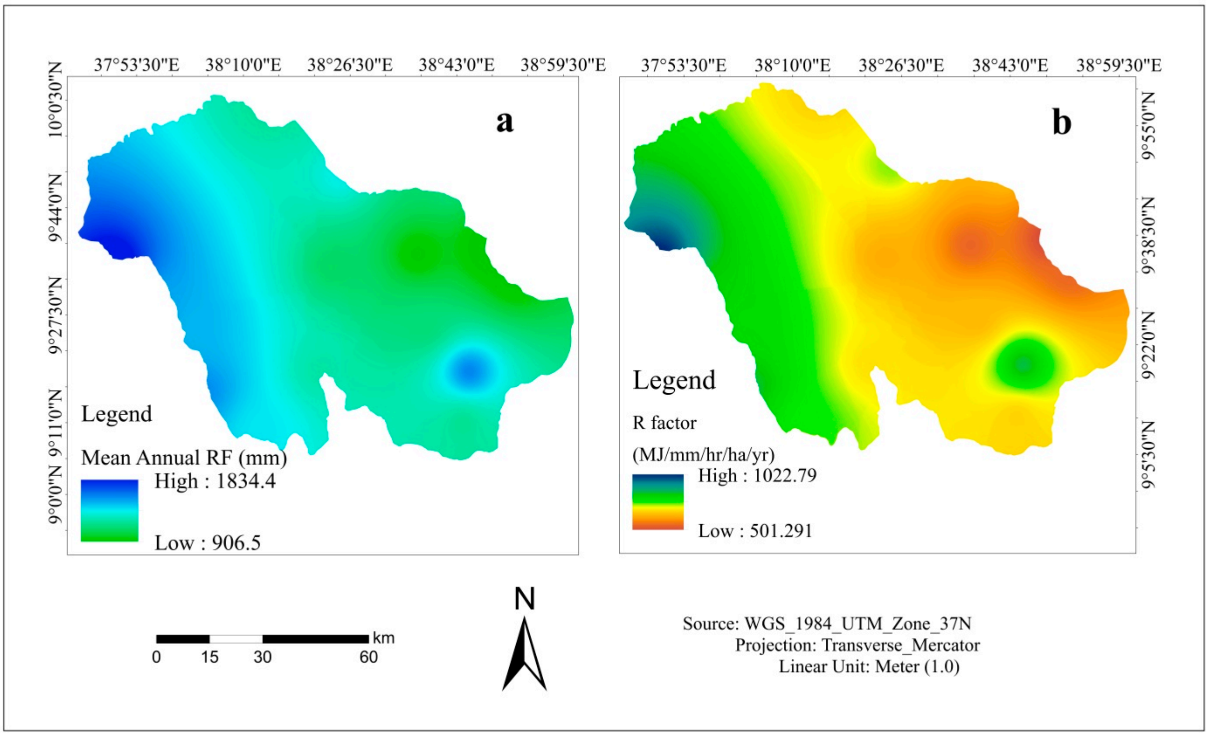


**Figure 4.** Mean annual Rainfall (mm) (**a**) and Rainfall erosivity (R) factor (**b**) of the Muger sub-basin.

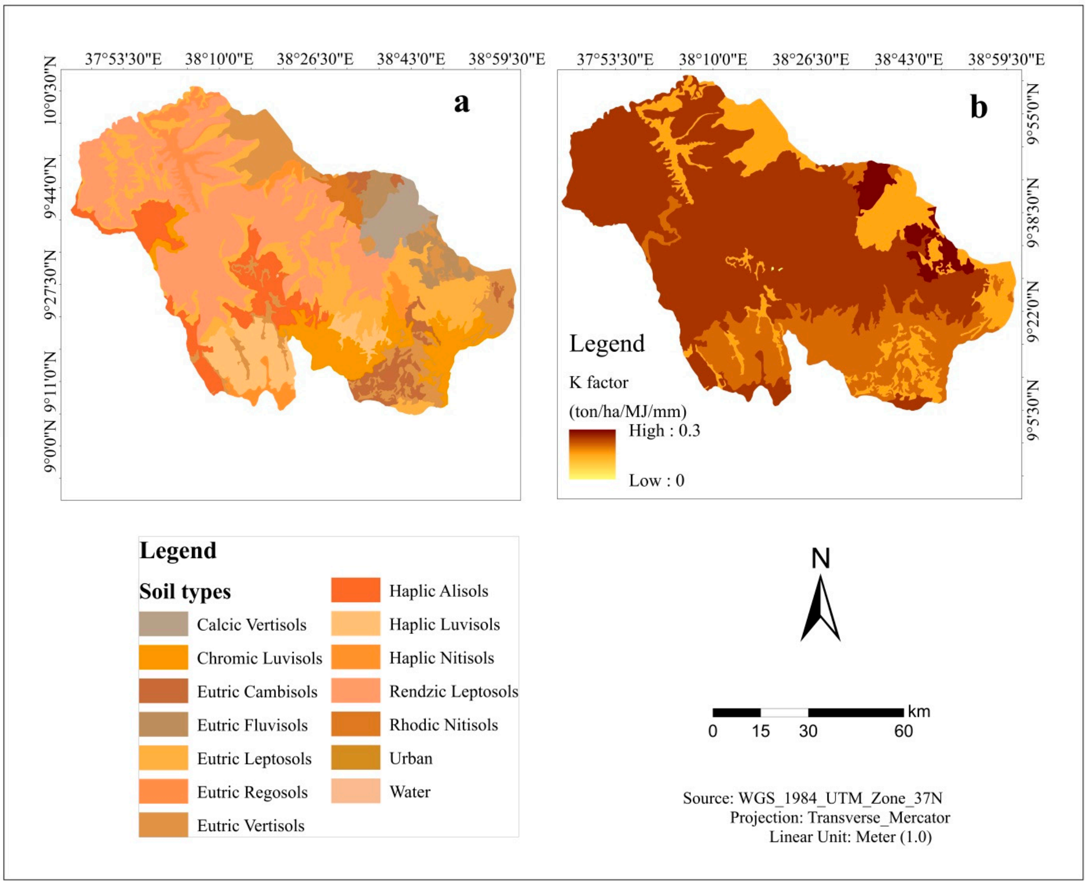


**Figure 5.** Map of soil types (**a**) and Soil erodibility (K) factor (**b**).

**Table 3.** Soil types, color, coverage and its K-factor.

| Soil Types | Soil Color | K-Factor | Area (ha) | Percentage (%) | References |
|---|---|---|---|---|---|
| Calcic Vertisols | Black | 0.15 | 29,407.92 | 3.59 | [20,51] |
| Chromic Luvisols | Brown | 0.2 | 68,522.20 | 8.37 | [20,51] |
| Eutric Cambisols | Brown | 0.2 | 29,829.01 | 3.64 | [10,51] |
| Eutric Fluvisols | Yellow | 0.3 | 27,378.35 | 3.34 | [20,51] |
| Eutric Leptosols | Red | 0.25 | 149,753.05 | 18.29 | [34,51] |
| Eutric Regosols | Brown | 0.2 | 21,513.83 | 2.63 | [20,34,51] |
| Eutric Vertisols | Black | 0.15 | 93,894.68 | 11.47 | [20,34,39,51] |
| Haplic Alisols | Red | 0.25 | 65,453.09 | 7.99 | [15,20,51] |
| Haplic Luvisols | Brown | 0.2 | 52,497.27 | 6.41 | [16,20,34,51] |
| Haplic Nitisols | Red | 0.25 | 21,213.26 | 2.59 | [14,39,51] |
| Rendzic Leptosols | Red | 0.25 | 247,882.08 | 30.27 | [34,51] |
| Rhodic Nitisols | Red | 0.25 | 11,322.20 | 1.38 | [34,51] |
| Urban, mining, etc | - | 0 | 75.10 | 0.01 | [60] |
| Water bodies | - | 0 | 68.92 | 0.01 | [30,60] |

2.4.3. Slope Length and Steepness (LS) Factor

Water erosion is more severe on steeper and longer slopes, while less common on gentler and shorter slopes [56,57,61]. The LS-factor is estimated from DEM with a 30-meter resolution from the slope (Figure 6) as used by [62,63]. The standard slope length 22.1 m and slope steepness of 9% [42,64] and expressed as Equation (3).

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

where λ is flow length, and S is slope in percent.

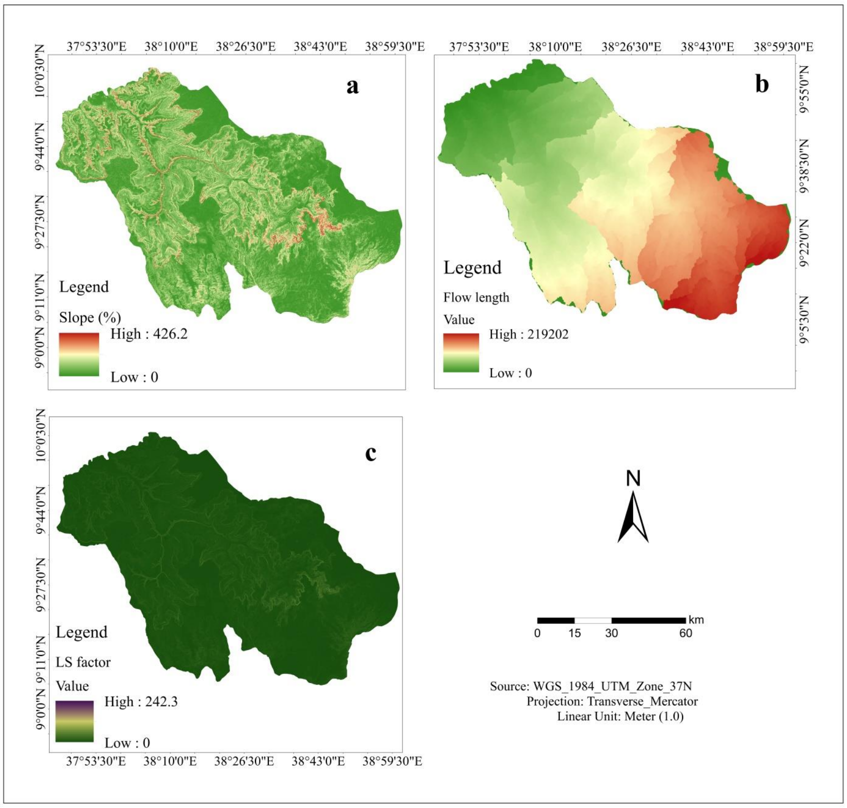


**Figure 6.** Map of slope in percent (**a**); flow length (**b**) and Slope Length-steepness (LS) factor (**c**) of the Muger sub-basin.

2.4.4. Land Cover and Management (C) Factor

Soil erosion by water is more common in locations where vegetation is limited, while lower around high vegetation cover [61]. The C-values (Table 4) were allocated for different LULC class based on scientific literature [10,15,16,30,34,51,65]. Cultivated land, forest land, grassland, settlement, and shrub land C-factor values were compiled from [16,34], for water bodies and wetland were adapted from [15,51,66] and for bare land was adapted from [10,30,65]. The C factor maps of 1986, 2003 and 2020 is illustrated in (Figure 7).

**Table 4.** The LULC types in Muger sub-basin and the corresponding C and P factors.

| LULC Types | 1986 | | 2003 | | 2020 | | C-Factor | P-Factor |
|---|---|---|---|---|---|---|---|---|
| | Area (ha) | % | Area (ha) | % | Area (ha) | % | | |
| Bare Land | 9413.19 | 1.15 | 8601.39 | 1.05 | 4654.5 | 0.57 | 0.05 | 0.8 |
| Cultivation land | 563,823 | 68.86 | 592,957 | 72.42 | 576,806 | 70.44 | 0.15 | 0.9 |
| Forest land | 96,475.9 | 11.78 | 76,634.6 | 9.36 | 48,326.3 | 5.90 | 0.001 | 0.7 |
| Grassland | 12,482.9 | 1.52 | 28,152.5 | 3.44 | 3362.4 | 0.41 | 0.01 | 0.8 |
| Settlement | 262.89 | 0.03 | 6182.91 | 0.76 | 12,563.5 | 1.53 | 0.004 | 0.9 |
| Shrub land | 117,792 | 14.39 | 92,954.9 | 11.35 | 165,935 | 20.27 | 0.014 | 0.8 |
| Water body | 2764.56 | 0.34 | 2066.04 | 0.25 | 4613.58 | 0.56 | 0.00 | 0.0 |
| Wetland | 15,809.5 | 1.93 | 11,274.6 | 1.38 | 2562.66 | 0.31 | 0.05 | 0.8 |
| Total | 818,823.9 | 100 | 818,823.9 | 100 | 818,823.9 | 100 | | |

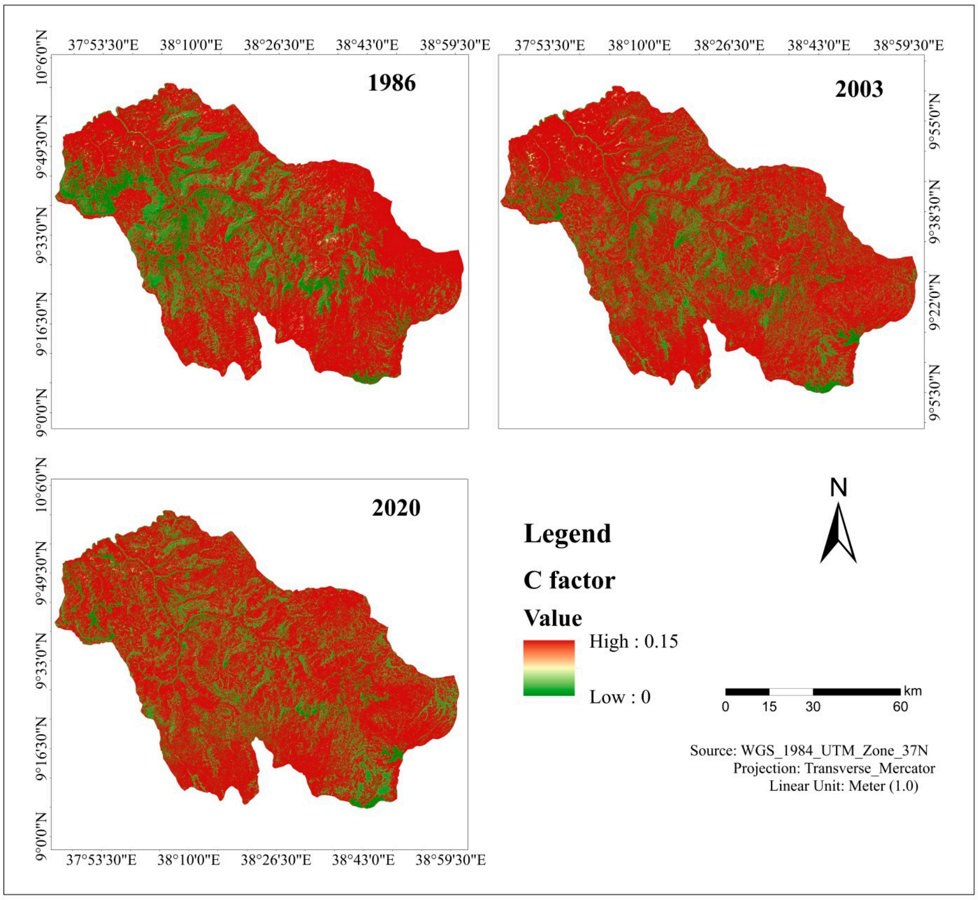


**Figure 7.** C-factor maps of the study sub-basin for 1986, 2003, and 2020.

2.4.5. Support Practice (P) Factor

The P value ranges from 0 to 1, where values closer to 0 shows better conservation activities, while values near to 1 indicating poor conservation [1,42,67]. The *p* value is calculated based on the slope gradient and conservation practices [15,20,34,51]. The P-factor value for each LULC class is adapted from literature [8,30,66,68,69]. The P factor maps of 1986, 2003 and 2020 is indicated in (Figure 8).

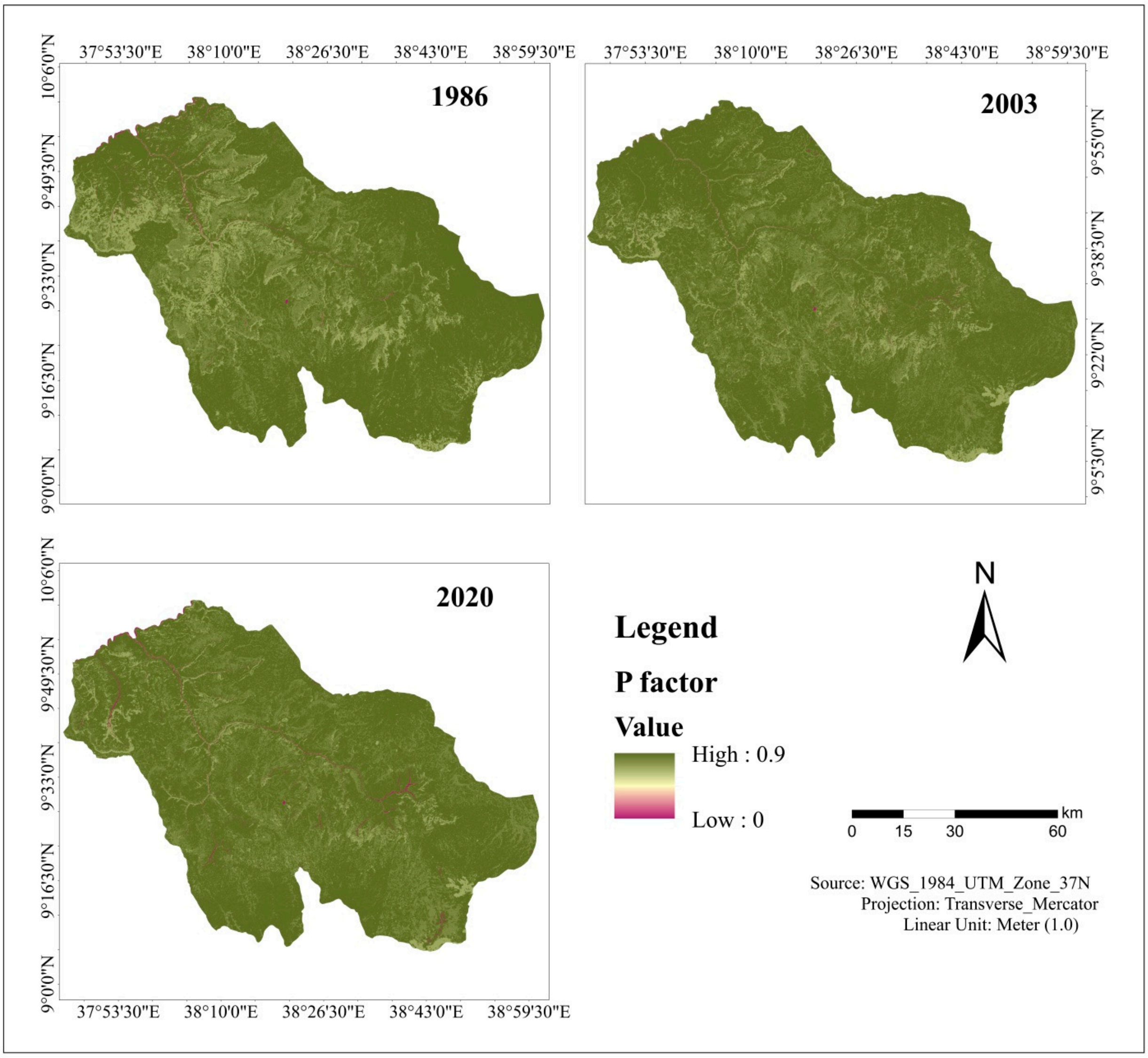


**Figure 8.** P-factor map of the study sub-basin for 1986, 2003, and 2020.

### *2.5. Estimation of the Sediment Delivery Ratio (SDR)*

Sediment delivery ratio (SDR) is calculated by using different parameters such as; channel slope, stream density, LULC, sediment source, and rainfall-runoff [70]. The work followed a method proposed [71] (Equation (4)). The SDR equation have been widely used fin the northwestern parts of Ethiopia, with reasonable forecast results [20,30,72]. The SDR is also utilized in other countries; Irga watershed in Jharkhand, India [73,74]; Kalu Ganga basin, Sri Lanka [74,75], and in Sebeya watershed in Congo river, Congo [55]. In this study, SDR was determined by adopted the model developed by [71] using Equation (4).

$$\text{SDR} = 0.627 * (\text{SLP})^{0.403} \text{ where SLP} = \frac{\Delta\text{Ch}}{\text{Lc}} \quad (4)$$

where SLP is stream slope expressed in percent;

$\Delta$Ch is the channel divide and outlet;

$L_c$ is the distance between the same two points parallel to the mean channel.

Hec GeoHMS was used to compute the stream slopes after mapping the flow direction, accumulation, and drainage network [54]. SDR was finally computed in the raster calculator tool in GIS environment using Equation (5).

$$SDR = 0.627 * (SLP)^{0.403} \quad (5)$$

*2.6. Estimation of Sediment Yield (SY)*

Sediment yield is a function of sediment delivery ratio and gross erosion [55]. Three SY raster grids were calculated for the years 1986, 2003, and 2020, assuming that LULC changes have an impact on sedimentation [55]. The SY value for the three-time period is calculated using Equation (6).

$$SY = SDR * A \quad (6)$$

where SY denotes sediment yield ((t/ha)/year); SDR is sediment delivery ration, and A is annual mean soil loss ((t/ha)/year).

## 3. Results and Discussion

*3.1. Land Use Land Cover Change*

According to [48], the results show that cultivated land, shrub land, forest land, settlement, bare land, water body, grassland, and wetland are major LULC in Muger Sub-basin. Overall classification accuracy was found to be 85.45, 88.51, and 89.39% for the year 1886, 2003, and 2020, respectively. The Kappa statistics were 0.79, 0.83, and 0.83 for the 1986, 2003, and 2020, respectively. Cultivated land was the dominant LULC types which covers 68.88%, 72.42% and 70.44% in 1986, 2003, and 2020, respectively (Table 5 and Figure 2). Substantial studies on Ethiopia have also found that cultivated land is the major LULC with an increasing trend caused by rapid population growth and increasing demand for cultivated land [10,48,76–78].

**Table 5.** LULC change the percentage and rate of change in the Muger sub-basin between 1986, 2003, and 2020 adapted from [48].

| LULC Types | 1986 | | 2003 | | 2020 | | Percentage Change (%) | | | Rate of Change in ha/year | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area (ha) | % | Area (ha) | % | Area (ha) | % | 1986–2003 | 2003–2020 | 1986–2020 | 1986–2003 | 2003–2020 | 1986–2020 |
| Bare Land | 9413.19 | 1.15 | 8601.39 | 1.05 | 4654.5 | 0.57 | −8.62 | −45.89 | −50.55 | −47.75 | −232.17 | −139.96 |
| Cultivation Land | 563,823 | 68.86 | 592,957 | 72.42 | 576,806 | 70.44 | 5.17 | −2.72 | 2.30 | 1713.76 | −950.06 | 381.85 |
| Forest Land | 96,475.9 | 11.78 | 76,634.6 | 9.36 | 48,326.3 | 5.90 | −20.57 | −36.94 | −49.91 | −1167.14 | −1665.19 | −1416.16 |
| Grass Land | 12,482.9 | 1.52 | 28,152.5 | 3.44 | 3362.4 | 0.41 | 125.53 | −88.06 | −73.06 | 921.74 | −1458.24 | −268.25 |
| Settlement Area | 262.89 | 0.03 | 6182.91 | 0.76 | 12,563.5 | 1.53 | 2251.90 | 103.20 | 4679.00 | 348.24 | 375.33 | 361.78 |
| Shrub Land | 117,792 | 14.39 | 92,954.9 | 11.35 | 165,935 | 20.27 | −21.09 | 78.51 | 40.87 | −1461.01 | 4292.95 | 1415.97 |
| Water Body | 2764.56 | 0.34 | 2066.04 | 0.25 | 4613.58 | 0.56 | −25.27 | 123.31 | 66.88 | −41.09 | 149.86 | 54.38 |
| Wetland | 15,809.5 | 1.93 | 11,274.6 | 1.38 | 2562.66 | 0.31 | −28.68 | −77.27 | −83.79 | −266.76 | −512.47 | −389.61 |
| Total | 818,823.9 | 100 | 818,823.9 | 100 | 818,823.9 | 100 | −8.62 | −45.89 | −50.55 | −47.75 | −232.17 | −139.96 |

Results show that agricultural land experiencing an increasing trend over the study period at the expense of forest, grassland and wetland. This finding is in line with the work obtained by [34], which report an increasing trend of agricultural land and settlement area in the northwestern parts of Ethiopia. Results revealed that agricultural/cultivated land increased by 381.85 ha/year. This finding is consistent with the report of various scholars [20,49,76,77,79].

### *3.2. Soil Loss Estimation Using RUSLE Model*

The annual soil loss is calculated using RUSLE model. This model considers five major factors and superimposing each factor to commute the average annual soil loss rate, which can determine high erosion risk area for further interventions.

#### 3.2.1. Rainfall Erosivity (R) Factor

There is a significant variation of rainfall erosivity factors in the Muger Sub-basin (Figure 4a). The lowest erosivity value is detected at Debre Tsige station with the value of 458.43 MJ mm ha$^{-1}$ h$^{-1}$ year$^{-1}$ in the north east, while the highest value is detected at Kachise station with erosivity value of 1029.96 MJ mm ha$^{-1}$ h$^{-1}$ year$^{-1}$ in the north west part of the Sub-basin. This finding is a slightly higher than the findings of [10] who found the value of 1022.79 MJ mm ha$^{-1}$ h$^{-1}$ year$^{-1}$ in western part of Ethiopia.

#### 3.2.2. Soil Erodibility (K) Factor

In the present study, the K-factor is estimated as suggested by [58] for Ethiopian highlands. To calculate the K-factor value of the Muger Sub-basin we considered soil color and types (Table 2). Rendzic Leptosols (Red), Eutric Leptosols (Red), Eutric Vertisols (Black), Chromic Luvisols (Brown) and Haplic Alisols (Red) were the major soil types in the study area. The Rendzic Leptosols and Eutric Leptosols (Red) are the two dominant soils in the Sub-basin. The erodibility factor values varied between 0 to 0.3 (Figure 5a).

Substantial studies proved that both water bodies and urban have no estimated erodibility value [30,60,80]. Thus, these two land cover classes assigned zero K value. The map revealed that Eutric Fluvisols with Erodibility value of 0.3 and for Rendzic Leptosols and Eutric Leptosols with erodibility with a value 0.25, while Calcic Vertisols and Eutric Vertisols Calcic Vertisols assigned 0.15 (Figure 5b). These values are found to be with the range suggested by [20,81].

#### 3.2.3. Slope Length and Steepness (LS) Factor

The slope of the Muger sub-basin varied between 0 and 426.2% (76.8$^0$) (Figure 6a). The study area is characterized with steps, fragmented hills, and gentle slopes. Steep slopes with high risk of erosion are characterized by higher LS factor values. This finding is consistent with findings from other tropical studies [20,33,38].

#### 3.2.4. Land Cover and Management (C) Factor

In the study area cultivated land is a dominant LULC during the study period. In the present study, the corresponding C values of each cover management is obtained from scientific literature (Table 4). The C-factor values for the three-time period varied from 0 to 0.15 (Figure 7). These findings are comparable with the work of [10,82] who found that the C factor from 0.001 to 0.18 in western part of Ethiopia.

#### 3.2.5. Support Practice (P) Factor

The P-factor shows the role of erosion mitigation strategies to minimize soil loss [56]. The P-factor value varied between zero and one, where values near to zero indicates better conservation practices with minimum erosion, while values approaching to one indicates low conservation practices (Figure 8).

### *3.3. Soil Erosion Rate under Different LULC Change*

The calculated soil erosion rate is categorized into five major severity classes namely: very slight, slight, moderate, severe, and very severe following previous studies [8,39,78]. The annual soil loss in the Muger Sub-basin varied from 0 to 867.3 ton/ha/year, 0 to 905.7 ton/ha/year and 0 to 958.2 ton/ha/year in 1986, 2003 and 2020, respectively. Other study by [29] found the annual soil loss around lake Hawassa lake in south-central part of Ethiopia found 0 to 605.26 ton/ha/year. The average annual soil loss for the Sub-basin is about 53.2 ton/ha/year, 63.6 ton/ha/year and 64.8 ton/ha/year in 1986, 2003 and 2020, respectively (Table 6; Figure 9).

**Table 6.** Soil loss (ton/ha/year) in 1986, 2003, and 2020.

| Year | Min | Max | Mean |
|---|---|---|---|
| 1986 | 0 | 867.3 | 53.2 |
| 2003 | 0 | 905.7 | 63.6 |
| 2020 | 0 | 958.2 | 64.8 |

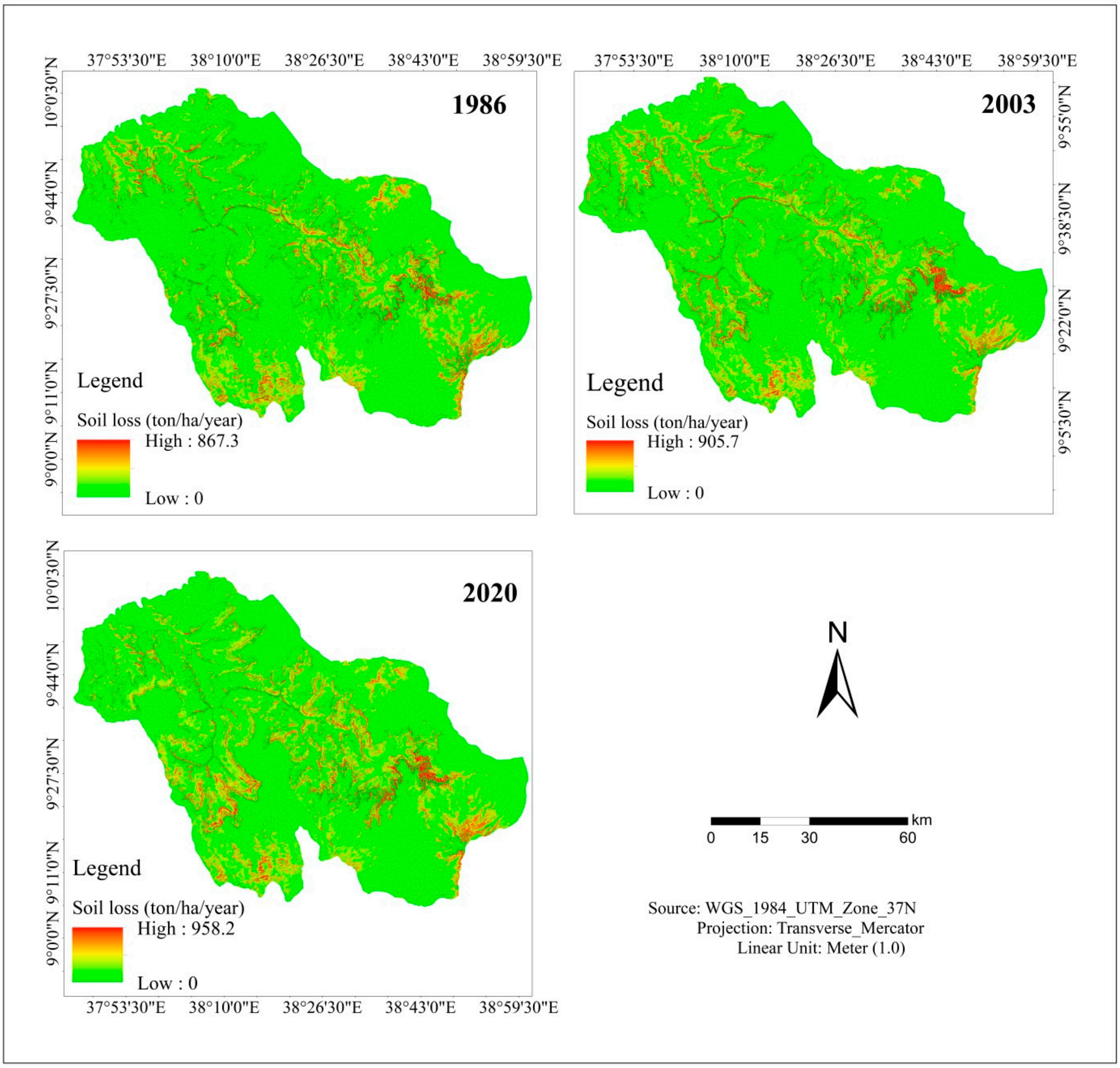


**Figure 9.** Soil erosion severity of Muger Sub-basin in 1986, 2003, and 2020.

From the total area, about 33, 38.1, and 38.9% is exposed to very severe erosion risk in the year 1986, 2003, and 2020, respectively (Table 7; Figure 10). In the year 1986, about 25.5% is exposed to very slight soil erosion. In 2003, about 24.9% of the study area is categorized under very slight, 14.6% slight, 11.2% moderate, 11.2% sever, and 38.1% very severe soil erosion risk. By the year 2020, about 23.9% is categorized as very slight soil erosion risk, which lower than the results of 1986, and 2003. About 56% and 60% of the Sub-basin experienced moderate and very sever soil erosion in 1986 and 2020, respectively.

**Table 7.** Erosion severity classes and area of soil loss in the Muger Sub-basin.

| Severity Class | | 1986 | | 2003 | | 2020 | |
|---|---|---|---|---|---|---|---|
| | Soil Erosion Rate (ton/ha/year) | Area (km$^2$) | % | Area (km$^2$) | % | Area (km$^2$) | % |
| Very slight | 0–5 | 2089 | 25.5 | 2037.2 | 24.9 | 1950.5 | 23.9 |
| Slight | 5–15 | 1485.3 | 18.2 | 1190.1 | 14.6 | 1269.5 | 15.5 |
| Moderate | 15–30 | 1066 | 13.0 | 919.5 | 11.2 | 844.2 | 10.3 |
| Severe | 30–50 | 840 | 10.3 | 916.7 | 11.2 | 926.4 | 11.3 |
| Very severe | >50 | 2707.7 | 33.0 | 3124.5 | 38.1 | 3197.4 | 38.9 |
| Total | | 8188 | 100.0 | 8188 | 100 | 8188 | 100 |

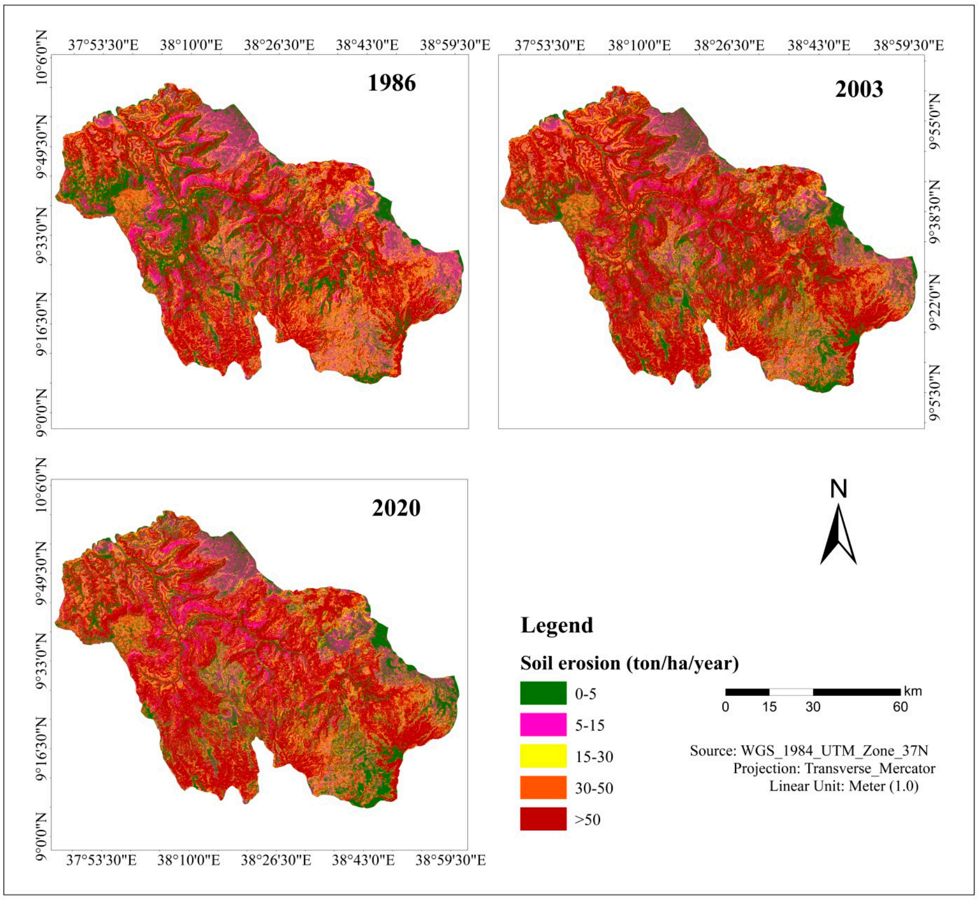


**Figure 10.** Muger Sub-basin spatial distribution of soil loss in 1986, 2003, and 2020.

It is not difficult to speculate that the rate of soil erosion decreased significantly between 1986 and 2003 due to the expansion of cultivated land and declining of forest cover in the study area as due to rapid population growth and increased demand for more food supply. In addition to agricultural land expansions, very little efforts were made to protect the soil for erosion, however, after 2003 onwards governments have encouraged the use of soil and water conservation measures to minimize the severity of soil loss.

### 3.4. Impact of LULC Change on Soil Erosion

The estimated annual soil loss across different LULC classes in 1986, 2003, and 2020 is presented (Table 8). Among all LULC, cultivated land is experiencing an increasing trend in soil loss, i.e., the soil loss is increased from 74.3 ton/ha/year in the year 1986 to 83.7 ton/ha/year and 87.6 ton/ha/year, 2003 and 2020, respectively. Substantial studies have been reported that LULC change and type significantly influence soil erosion [4,6,83]. After cultivated land, Shrubs land experienced the highest soil loss.

**Table 8.** Mean soil loss rate across different LULC classes in the Muger Sub-basin.

| LULC Types | 1986 | 2003 | 2020 |
|---|---|---|---|
| | Mean Soil Loss (ton/ha/year) | Mean Soil Loss (ton/ha/year) | Mean Soil Loss (ton/ha/year) |
| Bare land | 25.9 | 26.4 | 28.1 |
| Cultivated land | 74.3 | 83.7 | 87.6 |
| Forest land | 1.1 | 1.1 | 1.2 |
| Grassland | 1.0 | 2.3 | 3.2 |
| Settlement | 1.9 | 1.9 | 2.9 |
| Shrub land | 7.2 | 8.0 | 10.6 |
| Water body | 0.0 | 0.0 | 0.0 |
| Wetland | 2.8 | 4.3 | 4.5 |

### *3.5. Sediment Yield Estimation*

The result of sediment delivery ratio (SDR) in the Sub-basin varied between 0 to 0.54 (54%), which indicates only 46% were re-deposited in the Sub-basin and the others transported in the form of runoff, which later converted to sediment yield (Figure 11). Our findings is more or less comparable with the work of [30,72]. The results of the annual sediment yield ranges from 0 to 195.3 ton/ha/year, 0 to 293.2 ton/ha/year, 0 to 334.5 ton/ha/year in in 1986, 2003 and 2020, respectively. The mean sediment yields in the Sub-basin increased from 7.8 in 1986 to 10 and 10.2 ton/ha/year, in the year 2003, and 2020, respectively (Table 9, Figure 12). This finding is comparable with the work reported by [20], which varied between 6.7, and 9.6 ton/ha/year. Other study also reported between 14.8 and 22.1 ton/ha/year [14].

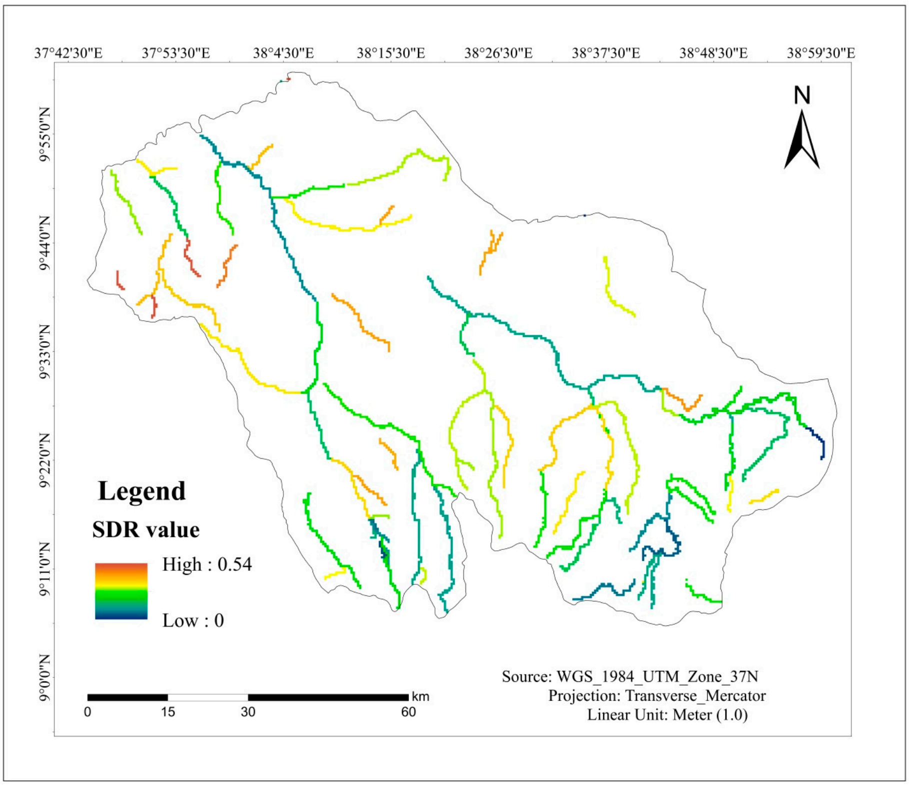


**Figure 11.** Map of sediment delivery ratio (SDR) the Muger Sub-basin.

**Table 9.** Soil sediment (ton/ha/year) result during 1986, 2003, and 2020.

| LULC Types | 1986 | 2003 | 2020 |
|---|---|---|---|
| Mean | 7.8 | 10 | 10.2 |
| Max | 195.3 | 293.2 | 334.5 |
| Min | 0 | 0 | 0 |
| SD | 16.2 | 18.5 | 21.5 |

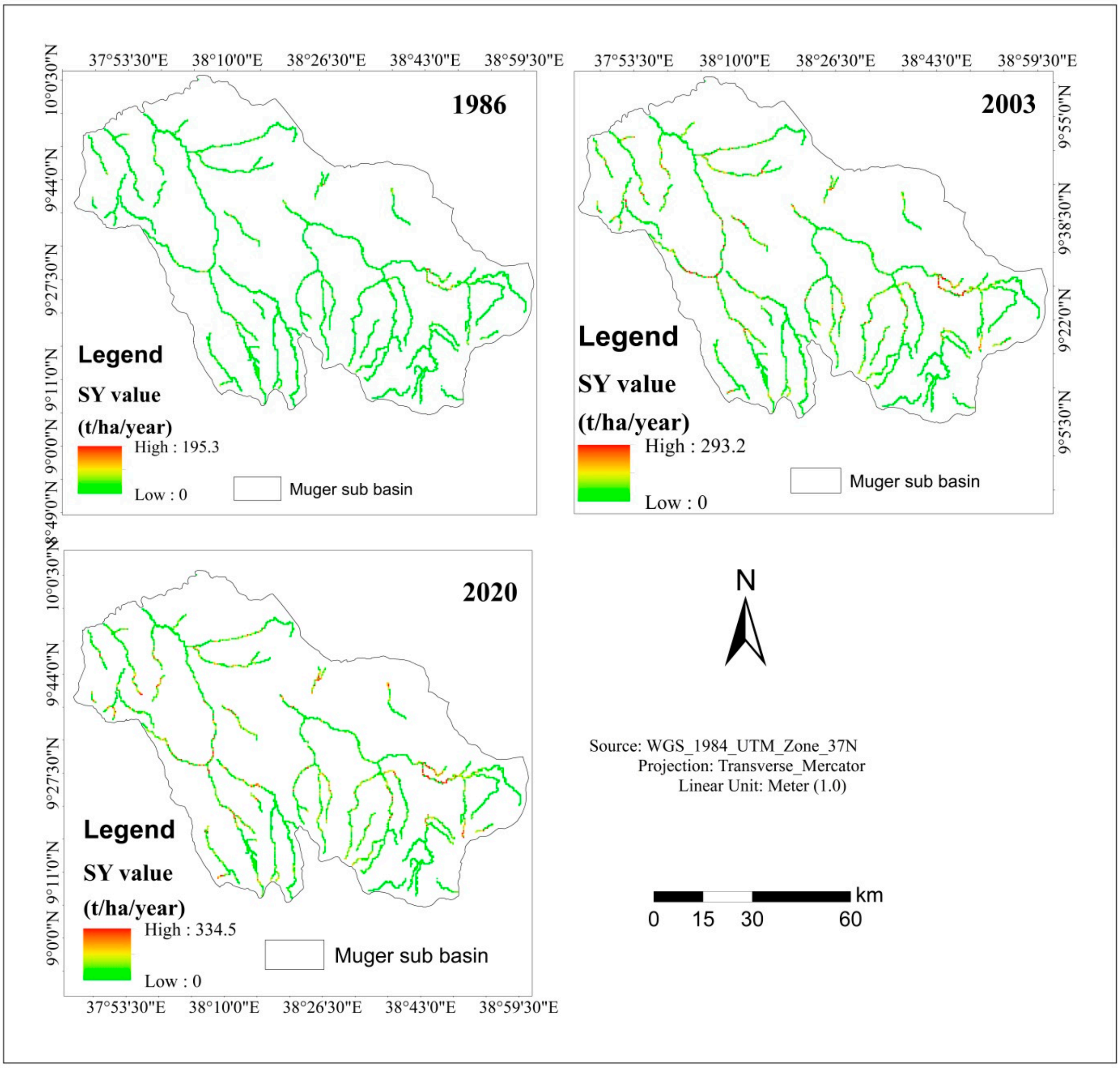


**Figure 12.** Sediment yield in 1986, 2003 and 2020.

## 4. Conclusions

In this study, we analyzed the effects of changes in LULC on soil erosion and sediment yield for the period 1986 to 2020. During the period 1986–2003, bare land lost in total in total of 4758.69 ha equivalent to annual decrease of 139.96 ha/year. While cultivated land increased in total 12,983 ha, with an average increment by 381.85 ha per year, forest land lost in total in total of 48,149.6 ha equivalent to annual decrease of 1416.16 ha/year, grassland lost in total in total of 9120.5 ha equivalent to annual decrease of 268.25 ha/year, settlement area increased in total 12,300.61 ha equivalent to 361.78 ha/year, shrubs land increased in total 48,143 ha equivalent to 1415.97 ha/year, water body increased in total

1849.02 ha equivalent to 54.38 ha/year and wetland lost in total 13,246.8 ha equivalent to 389.61 ha/year annual decreasing rate.

The mean annual soil loss varies greatly between LULC. The findings revealed that soil loss from cultivated land was higher than in other LULC classes. About 56% and 60% of the sub basin suffered from moderate to very sever soil erosion in 1986 and 2020 respectively, and only remaining part of the sub basin had under the very slight and slight soil erosion categories. The rapid conversion of forest cover to cultivated land resulted in a significant rate of soil erosion. Thus, high volume of silt can be easily transferred to downstream in the form of erosion. The results revealed that increasing trends towards cultivated land and decreasing conservation practices were the main reasons for soil erosion and sediment yield in the study area. Thus, there is an urgent need of conservation strategies to minimize the problem of soil erosion and sedimentation. Specifically, afforestation and re-afforestation programs are crucial to reduce environ-mental risk in general and soil erosion and sediment yield loss in particular. Soil erosion and sediment yield loss prevention requires collaboration of multi-sectors. Thus, all concerned stokeholds including the local people should work hand in hand to minimize the negative effects of soil loss and sediment loss on the environment. Moreover, further research with fine spatial resolution satellite images is required to enforce policy makes towards soil and water conservation strategies in the study area and beyond.

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