The overshadow of the human evolvement process in the dynamics of soil drift of an agricultural watershed in the Nilgiri Hills, India

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Abstract: The Nilgiri Biosphere, being one of the critical catchments, a small agricultural watershed of Udhagamandalam has been analysed to show the need to improve the agriculture by reducing the soil erosion. For this study, the land use and land cover classification was undertaken using Landsat images to highlight the changes that have occurred between 1981 and 2019. The Revised Universal Soil Loss Equation (RUSLE) method and the Geographic Information System (GIS) was used in this study to determine the soil erosion vulnerability of Sillahalla watershed in the Nilgiri Hills in Tamilnadu. This study will help to promote the economic development of the watershed with proper agricultural planning and erosion management. This study focuses on the estimation of the average annual soil loss and to classify the spatial distribution of the soil loss as a map with the RUSLE method and GIS. To estimate the average annual soil loss of the study area, GIS layers of the RUSLE factors like rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C) and conservation practice (P) were computed in a raster data format. The total soil loss and average annual soil loss of the study area for 1981–1990,1991–2000, 2001–2010, 2011–2019 were found to be 0.2, 0.254, 0.3, 0.35 million t/year and 31.33, 37.78, 46.7, 51.89 t/ha/year, respectively. The soil erosion rate is classified into different classes as per the FAO guidelines and this severity classification map was prepared to identify the vulnerable areas.

Keywords: hilly terrain; land use land cover; RUSLE; soil erosion; soil erosion severity classification; sustainable agriculture

Land is a scarce resource; thus the assay of the land cover will help in assessing the human evolvement, which predicts the situation of the agricultural sustainability. In the process of human evolvement, many changes have occurred to the land cover which have resulted in an increase in the soil erosion, thereby causing a loss of soil fertility, posing a threat for agricultural production. In recent years, in a study carried out by Millward and Mersey (1999), soil erosion has increasingly been recognised as a hazard that is more serious in mountain areas. Soil erosion was found to occur more in the agricultural land in the Himalayan region, India by Jasorotia and Singh (2006). Sharma (2010), by integrating terrain and vegetation indices

in the Maithon reservoir catchment, at an elevation from 120 to 1360 m in the Jharkhand state of India, found the area to have a high erosion potential. A study carried out by Imamoglu & Dengiz (2016) in the Alaca catchment, which is located in the Central Black Sea region of Turkey, characterised by mountains, was susceptible to more erosion from 1960 to 2014. A soil erosion risk study that was carried out at a monthly temporal resolution in Swiss grasslands by Schmidt et al. (2019) showed that the mean monthly soil loss in the summer is 48 times higher than in the winter, which adds up the annual soil loss, hence, highlighting the importance of erosion and its problems in a sloppy terrain. When such lands are not given any

importance, it reduces the agricultural production, which brings about an economical setback and also makes the land worthless. In the future, land use should be made to fall within a flawless limit, so that the human demands be met without compromising sustainability, and to make all resources as well as agriculture to be sustainable. The aim of this study was to find out the soil loss transformation that has occurred through the decades, so that in a further study it would be helpful in making a detailed study and propose new conservation measures. To make this justifiable, it is imperative to accomplish such a study and make the globe safe and imperishable. A small agricultural watershed in the Nilgiri hills was selected to illustrate the study.

Study area. The Nilgiri Biosphere Reserve was the first biosphere reserve in India established in the year 1986. It is located in the Western Ghats and includes two of the ten bio-geographical provinces of India. The total area of the Nilgiri Biosphere Reserve is 5 520 km^2. It is located between 76°–77°15'E and 11°15'–12°15'N. The Nilgiri Biosphere is one of the critical catchment areas of peninsular India. Many of the major tributaries of the river Cauvery, like

the Bhavani, Moyar, Kabini, and other rivers like the Chaliyar, Punampuzha, etc. have their source and catchment within the reserve's boundaries. The Sillahalla watershed is one of the milli - watersheds (1 000 to 10 000 ha) in the Nilgiri's southern forest portion. It covers a total extent of 100 km^2, it is numbered as 13 (among other watersheds of the Nilgiri District) which is comprised of three divisions 13A, 13B and 13C. It lies between the latitudes 11°25'0''N and 11°20'0''N and longitudes 76°38'0''E and 76°44'0''E. The minimum and maximum altitude of the Sillahalla watershed is 1 860 and 2 640 m above the mean sea level (Figure 1). The landslide frequency is increasing due to increased instability caused by human activities which destroys houses and causes communication problems whenever heavy rains occur in the local mountains. In the past, the landslides mostly occurred in uninhabited areas, but nowadays landslides occur in the areas with settlements, this is because the housing sites have been developed on unstable slopes and people have built up those areas without realising the proneness to landslides (Jayanthi et al. 2016). The area has also been affected by a recent flood in August 2019 in
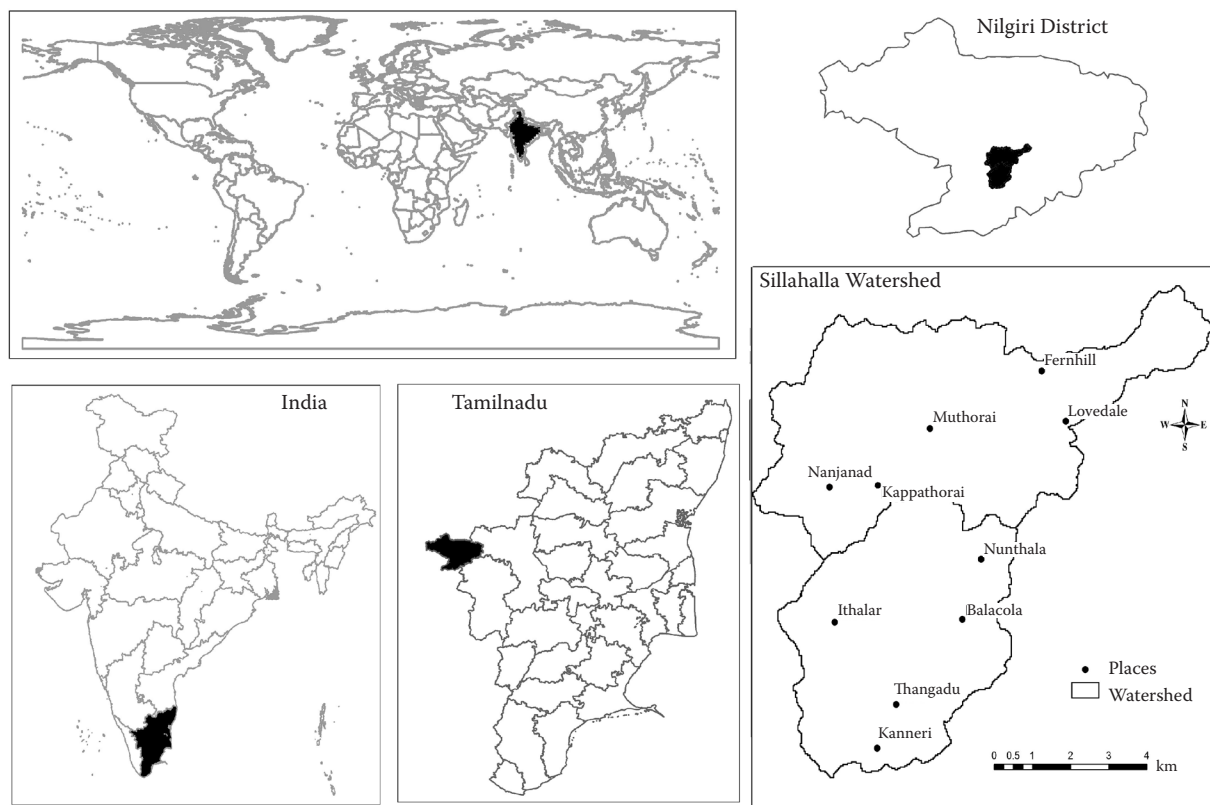

Figure 1. Base maps of the study area

Avalanche which is less than 20 km from the hill station Ooty. Hence, the Sillahalla watershed has undergone gradual devastations and more soil loss has occurred over the years because of human development which has impacted the ecological change.

MATERIAL AND METHODS

This study utilised the land use map from The Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) for the decades 1981–1990, 1991–2000, 2001–2010 (Roy et al. 2016) that was generated with satellite remote sensing data, like IRS IC – LISS III (1994–1995) and Resource sat I (2004–2005) imagery, multi-temporal Landsat 2005 MSS, TM, and ETM + data. Landsat 8 was launched in 2013 and was projected to WGS84 datum surface (UTM 44N projection) at a sub-pixel level; and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Global Digital Elevation Model (GDEM) were utilised to generate land use/land cover maps for the decade 2011–2019. The supervised classification methods were utilised for the classification and delineation of the land use categories (2019) in QGIS. The ground truth verification for 2019 was carried out to check the accuracy of the classification. The Landsat 4, Landsat 8 TM images of several years from 1981 to 2019 were downloaded and a Normalized Difference Vegetation Index (NDVI) analysis was carried out in ArcGIS to determine the vegetative cover factor of RUSLE. The average annual precipitation for every decade was calculated to find out the R factor of RUSLE, to detect whether the agricultural practice in a sloppy terrain has resulted in increased erosion.

Accuracy assessment of land use and land cover classification. In this study, the accuracy assessment was carried out based on the ground truth verification. The land use classification using QGIS and Google earth was verified by visiting more than 200 ground truth sample points which included croplands, tea plantations, built up areas, forests and fallow land. The classification accuracy was obtained with the ground truth data and the corresponding classified data using the confusion matrix (Sarkar 2018). The kappa coefficient (Rwanga & Ndambuki 2017) was determined using:

Soil loss estimation. The annual soil loss estimation is undertaken with soil erosion models, to effectively accomplish soil conservation practices. Among the various models, the Revised Universal Soil Loss Equation (RUSLE) was used in a GIS environment for this study. This is an empirical and dominant equation used worldwide to predict the soil erosion compatible with GIS at a feasible cost. It is widely applied for agricultural and forest watersheds by introducing improved means of computing the soil erosion factors according to Wischmeier and Smith (1978). The equation for the RUSLE method is:

$$A = R \times K \times LS \times C \times P \tag{2}$$

where:
A – the computed spatial average of the soil loss over a period selected for R, usually on a yearly basis (t/ha/year),
R – the rainfall-runoff erosivity factor (MJ·mm/ha·h·year),
K – the soil erodibility factor (t·ha·h/ha·MJ·mm),
LS – the slope length-steepness factor (dimensionless),
C – the cover management factor,
P – the erosion control (dimensionless) conservation support practices factor.

These five factors vary over space and time and depend on other input variables. In ArcGIS, for the soil loss estimation, this equation of five input factors should be given in a raster data format. The soil erosion is determined within each pixel using the RUSLE method for all the decades.

Generation of RUSLE factors. The RUSLE method has been utilised to determine the average annual soil loss occurring in the Sillahalla watershed. The inputs for the generation of the RUSLE factors are the rainfall data, soil map, land use map, Landsat images, digital elevation model and slope map. The inputs for the RUSLE equation are the five factors that are determined in the raster format for each pixel size of 30 × 30 m to incorporate the spatial analysis in GIS. The final result of the RUSLE equation is the annual soil loss occurring in each pixel.

Rainfall - erosivity factor (R). This factor depends on the rainfall, which is the causative force factor for erosion. This has been estimated with the rainfall data obtained from ICAR – Indian Institute of Soil

$$k = \frac{\left(\text{TotalSample} \times \text{TotalCorrectedSample}\right) - \sum \left(\text{ColumnTotal} \times \text{RowTotal}\right)}{\left(\text{TotalSample}\right)^2 - \sum \left(\text{ColumnTotal} \times \text{RowTotal}\right)} \tag{1}$$

and Water Conservation, Udhagamandalam for the Sillahalla watershed.

The annual rainfall was calculated for the years from 1981 to 2019 with the daily rainfall data and the decadal average annual rainfall was, hence, estimated.

R was estimated using the empirical equation developed by G. Singh (Vinay et al. 2015) which is the rain collected by a rain gauge station and the amount of soil eroded for the annual precipitation. R remains the same for the entire watershed, but varies for every decade.

$$R = 79 + 0.363 \times AAP \qquad (3)$$

where:
AAP – the average annual precipitation.

Soil erodibility factor (K). The soil erodibility is the inherent aspect of the soil properties reflecting the vulnerability of a soil to erode, as influenced by the biophysical and chemical characteristics of the soil (Renard et al. 1997). This factor depends on the different types of soil texture. It was found with the soil map of the study area and is determined using the equation from Williams J R (Wawer et al. 2005)

$$K_{USLE} = f_{csand} \times f_{cl\text{-}si} \times f_{orgc} \times f_{hisand} \qquad (4)$$

$$f_{csand} = \left[0.2 + 0.3 \cdot \exp\left\{ -0.256 \times m_s \times \left(1 - \frac{m_{silt}}{100} \right) \right\} \right] \qquad (5)$$

$$f_{cl\text{-}si} = \left[\frac{m_{silt}}{m_c + m_{silt}} \right]^{0.3} \qquad (6)$$

$$f_{orgC} = \left[1 - \frac{0.25 \times orgC}{orgC + \exp(3.72 - 2.95 \times orgC)} \right] \qquad (7)$$

$$f_{hisand} = \left[1 - \frac{0.7 \cdot \left(1 - \frac{m_s}{100} \right)}{\left(\left(1 - \frac{m_s}{100} \right) + \exp\left(-5.51 + 22.9 \cdot \left(1 - \frac{m_s}{100} \right) \right) \right)} \right] \qquad (8)$$

where:
m_s – the sand fraction content (0.05–2.00 mm diameter) (%),
m_{silt} – the silt fraction content (0.002–0.05 mm diameter) (%),
m_c – the clay fraction content (< 0.002 mm diameter) (%),
orgC – the organic carbon (SOC) content (%),
f_{csand} – a factor, that lowers the K indicator in soils with a high coarse-sand content and higher for soils with little sand,
$f_{cl\text{-}si}$ – gives low soil erodibility factors for soils with high clay-to-silt ratios,

f_{orgc} – reduces the K values in soils with a high organic carbon content,
f_{hisand} – lowers the K values for soils with an extremely high sand content. K can be computed with the above formulas using a soil properties map.

Slope length and steepness factor (LS). It is a dimensionless topography factor determined by the length and steepness of a slope. The erosion increases if the slope is steep and long, as the water speed increases which results in the larger transport of the soil surface. Using the Moore and Nieber (1989) equation algorithm in QGIS, the LS factor can be determined with the DEM and a slope map as inputs.

Cover management factor (C). The C factor represents the effects of the plants, crop sequence, their production, soil cover on soil erosion. The Normalized Difference Vegetation Index (NDVI), an indicator of a vegetation's vigour and health is used with the following formula to generate the C factor value for the study area (Zhou et al. 2008; Kouli et al. 2009). NDVI was found by using Landsat images in QGIS. For every decade, the average C factor was determined.

$$C = \exp\left[-\alpha \times \frac{NDVI}{(\beta - NDVI)} \right] \qquad (9)$$

where:
α = 2,
β = 1 (Van der Knijff et al. 2000).

$$NDVI = \frac{NIR - Red}{NIR + Red} \qquad (10)$$

where:
NIR – near infra-red

Conservation practice factor (P). This factor is for supporting practices, this takes the specific erosion control measures into account. The erosion control practices reduce the P factor. On highly erodible lands, specific methods like contour planting or terracing reduce the erosion. If the land is a forest, then a *P*-value ranging from 0 to 1 will have higher values. If the *P*-value is low, then the conservation practices are more effective. The P factor is found by using the slope percentage and the already existing soil conservation practices.

RESULTS AND DISCUSSION

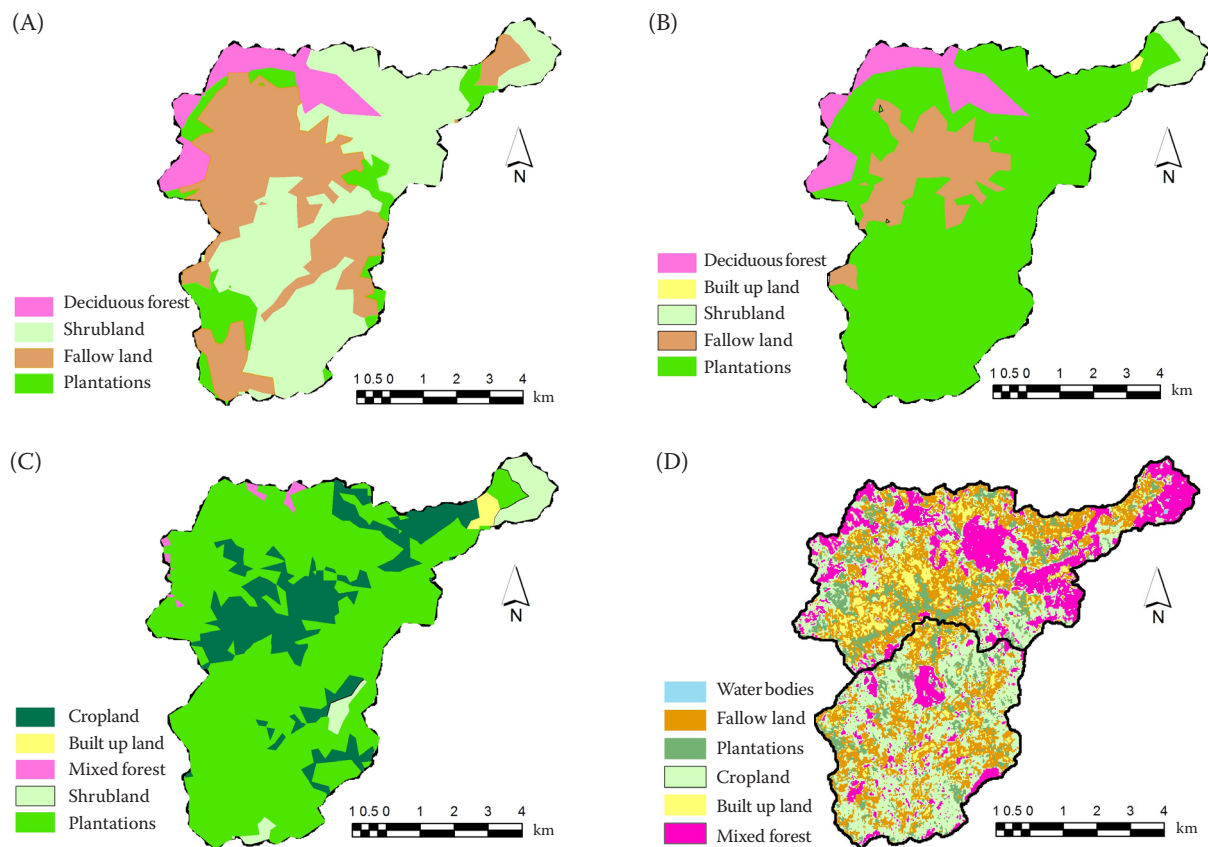**Estimated soil loss.** RUSLE is an empirically-based model having the ability to predict the long-term

Figure 2. Land use and land cover (LULC) classification for 1985 (A), 1995 (B), 2005 (C) and 2019 (D)

annual soil erosion on slopes with data like the rainfall, land use map, soil map, crop system, slope map, DEM, Landsat images and management practices. These data sources are used for the generation of the RUSLE factors as raster GIS layers in the ArcGIS software. The overall classification accuracy of the land use for the current decade (2019) was 87% and the Kappa coefficient obtained using the confusion matrix was 0.84. This accuracy helps in obtaining reliable soil loss results.

Soil loss for the decade 1981–1990. The average soil erosion rate estimated using the RUSLE method was 31.33 t/ha/year. During this decade, the land was under forests (5.95 km²) and shrublands (30.54 km²)

in the majority of the total study area (67.28 km²) and was also comprised of fallow land (24.16 km²) and mostly plantations like tea (6.74 km²) (Figure 2A). The average annual rainfall during the decade was about 1044 mm/year. The maximum soil loss that occurred is estimated at 464.19 t/ha/year. The total soil loss of the study watershed is 0.2 million t/year. The spatial pattern of the classified soil erosion risk zones generated (Figure 4 and Table 1) based on the criteria of the soil erosion risk classification suggested by FAO (2006) indicates that about 60% of the study area experiences a slight soil loss (30 t/ha/year), a moderate soil loss (30–80 t/ha/year) which accounts for 29%, a severe (80–150 t/ha/year) and extremely

Table 1. Soil erosion severity zones

Severity class	Soil loss (t/ha/year)	Area (%)			
		1981–1990	1991–2000	2001–2010	2011–2018
Slight	< 30	59.99	58.94	52.53	50.55
Moderate	30–80	28.70	24.01	23.89	21.85
Severe	80–150	9.75	12.79	16.95	19.24
Extremely severe	> 150	1.57	4.26	6.64	8.42

severe soil loss (> 150 t/ha/year) which account for 9.75% and 1.6 %, respectively, where the land is mostly shrublands, a few plantations and fallow land. The average soil loss rate for this decade is low compared to other decades as the human evolvement process is at a minimum in this decade.

Soil loss for the decade 1991–2000. The average soil erosion rate estimated using the RUSLE method was 37.78 t/ha/year. During this decade, the land was mostly under plantations like tea (49.7 km²) and fallow land (9.54 km²) in the majority of the total study area (67.28 km²), the other areas are settlements (0.133 km²) and forests (7.89 km²) (Figure 2B). The average annual rainfall during the decade was about 1042 mm/year. The maximum soil loss that occurred is estimated at 493.9 t/ha/year. The total soil loss of the study watershed is 0.254 million t/year. The spatial pattern of the classified soil erosion risk zones generated (Figure 4 and Table 1) based on the criteria of the soil erosion risk classification suggested by FAO (2006) indicates that about 59% of the study area experiences a slight soil loss (30 t/ha/year), a moderate soil loss (30–80 t/ha/year) which accounts for 24%, a severe (80–150 t/ha/year) and extremely severe soil loss (> 150 t/ha/year) account for 13% and 4.3%, respectively, where the land is mostly plantations and scrublands. In this decade, the severe and extremely severe soil loss has increased by 3%

compared to the previous decade due to the increase in the plantations, like the tea cultivation, made for developmental purposes to enable the livelihood of the local inhabitants.

Soil Loss for the decade 2001–2010. The average soil erosion rate estimated using the RUSLE method was 46.70 t/ha/year. During this decade, the land was under plantations like tea (49.5 km²) in the majority of the total study area (67.28 km²), the other land use being for crop cultivation (croplands – 13.8 km²), settlements (0.6 km²) and forests (3.49 km²) (Figure 2C). The average annual rainfall of this decade was about 1 248 mm/year. The maximum soil loss that occurred is estimated at 608.93 t/ha/year. The total soil loss of the study watershed is 0.3 million t/year. The spatial pattern of the classified soil erosion risk zones generated based on the criteria of the soil erosion risk classification suggested by FAO (2006) (Figure 5 and Table 1) indicates that about 52.5% of the study area experiences a slight soil loss (30 t/ha/year), a moderate soil loss (30–80 t/ha/year) which accounts for 23.8%, a severe (80–150 t/ha/year) and extremely severe soil loss (> 150 t/ha/year) which account for 17% and 7%, respectively, where the land is mostly used for plantations and shrublands. In this decade, slight soil erosion has reduced, the severe soil loss range has increased by 6% because of an increase in plantations and the cultivation of
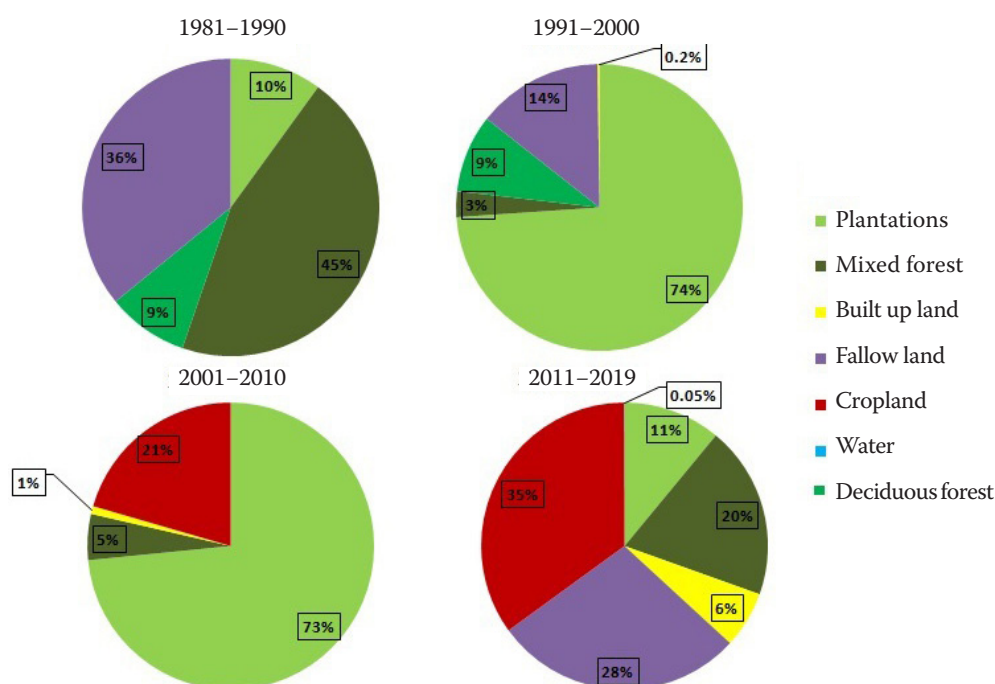

Figure 3. Land use and land cover (LULC) charts for 1985, 1995, 2005 and 2019 (area in %)

crops like carrots, cabbages, cauliflowers, potatoes, radishes, peas, beans on the land which were used as shrublands and fallow lands in the previous decades. The settlement land has also increased due to the need for the habitation of the farmers and resorts for tourism development. Best management practices are needed in addition to bench terracing to minimise the soil erosion in the cultivated lands. In relation to other soil erosion studies, it has been shown, by Saravanan et al. (2013), that the soil loss varies from 0.54 t/ha/year to 75.1 t/ha/year (average annual soil loss is 24.74 t/ha/year) in the Katteri watershed in the Nilgiri Hills which is a distance of 5 km from the Sillahalla watershed, the highest amount of soil loss has been identified in the fallow and agricultural lands as the forests have been cleared for agriculture, tea estates and horticultural croplands.

Soil loss for the decade 2011–2019. The average soil erosion rate estimated using the RUSLE method was 51.89 t/ha/year. During this decade, the land was occupied by cropland (23.39 km²) in the majority of the total study area (67.28 km²), other land

uses are fallow land (18 km²), plantations like tea (7 km²), forests (13 km²) and settlements (4.3 km²) (Figure 2D). The average annual rainfall during this decade was about 1 347 mm/year. The maximum soil loss that occurred is 625 t/ha/year. The total soil loss of the study watershed is 0.35 million t/year. The spatial pattern of the classified soil erosion risk zones generated based on the criteria of the soil erosion risk classification suggested by FAO (2006) (Figure 5 and Table 1) indicates that about 50.5% of the study area experiences a slight soil loss (30 t/ha/year), a moderate soil loss (30–80 t/ha/year) which accounts for 22% of the land that is mostly cropland, a severe (80–150 t/ha/year) and extremely severe soil loss (> 150 t/ha/year) account for 19% and 8%, respectively, where the land is mostly used for crop cultivation and forests, the severe and extremely severe soil loss has increased by around 2.5% due to the increase in the crop cultivation by the local inhabitants and an increase in the land area used for accommodation and resorts. The conservation practices need to be modified while cultivating on a
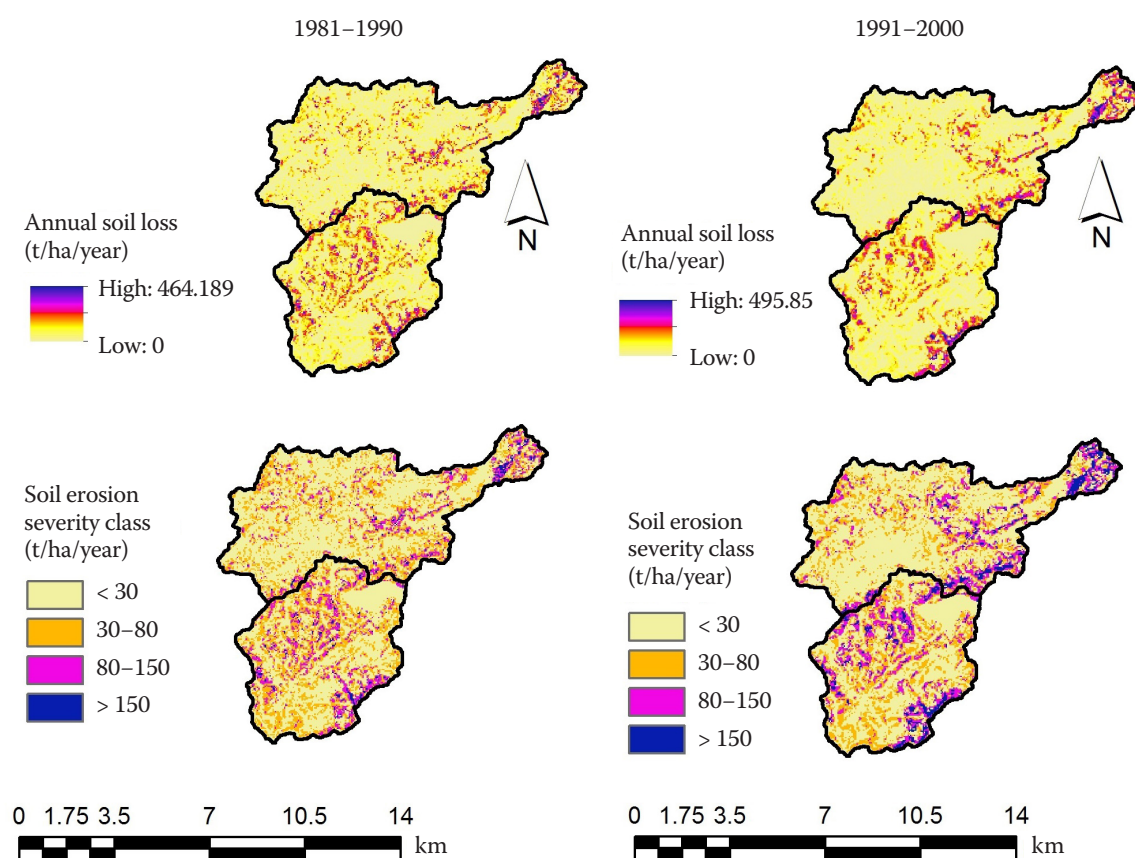

Figure 4. Predicted annual soil loss and classified soil erosion risk zones for the decades 1981–1990 and 1991–2000
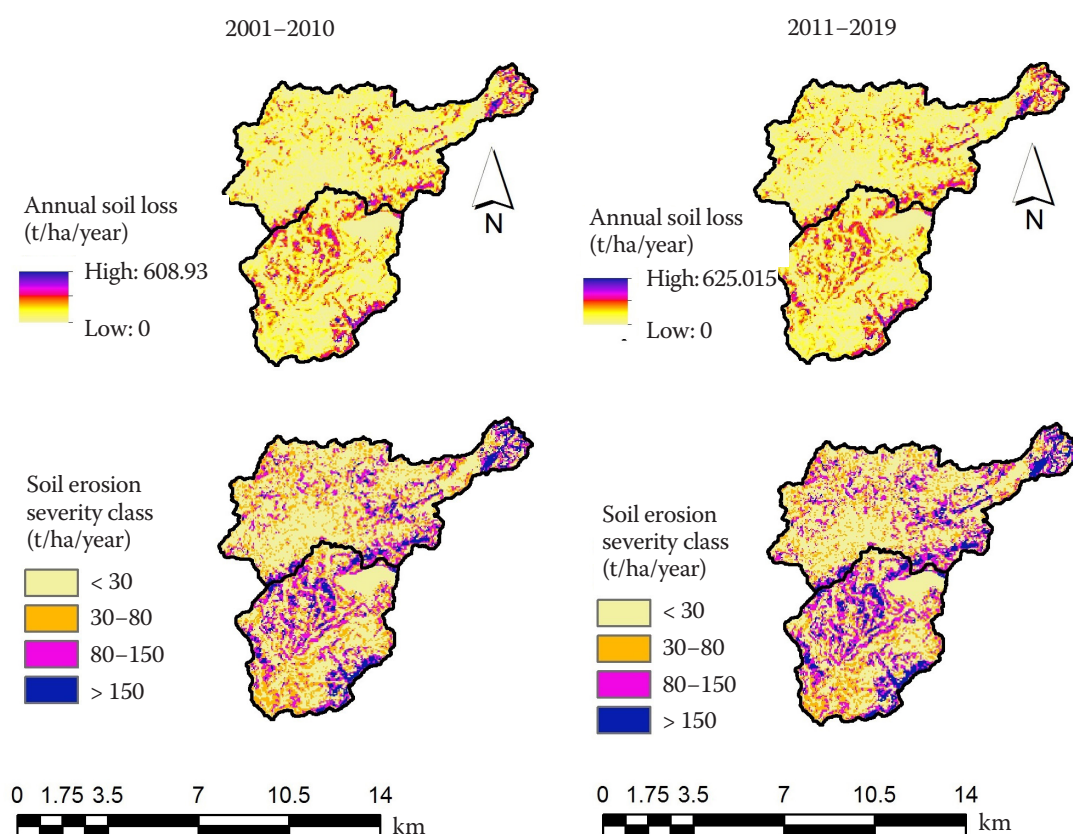
Figure 5. Predicted annual soil loss and classified soil erosion risk zones for the decades 2001–2010 and 2011–2019

sloppy terrain. People have to avoid building houses on unstable slopes to prevent erosion and to decrease the risk to their lives by landslides (Jayanthi et al. 2016). In relation to other soil erosion studies, it has been shown, by Saravanan et al. (2018), that in the Coonoor watershed in the Nilgiri Hills, the annual average soil loss during 2018 on the wasteland, croplands, tea plantations and urban settlements is 28.78, 26.75, 26.70 and 4.48 t/ha/year, the maximum erosion is about 1500 t/ha/year. The highest soil loss has occurred in the settlement region and in the deforested localities, where the forest cover has been replaced by tea plantations.

CONCLUSION

With the land use and land cover changes that have occurred from 1981 to 2019, human intervention in the developmental process without considerations in the Sillahalla watershed has helped to pile-up problems in the ecosystem, with the agriculture and livelihood of the inhabitants. The land being used for agriculture and settlements has seen an increas-

ing trend from 1991 onwards at the reduction of the forests and fallow lands. The process of land drift that has occurred in these decades has brought about an ecological crisis and is threatening the agricultural economy of the Sillahalla watershed by an accelerated soil erosion. The future environmental stability of this area will make tea become an economically sustainable crop (as in the first two decades), other vegetables like carrots, cabbages, cauliflowers, potatoes, radishes, peas, beans, and broccoli as well as tourism will be supplemental, hence, the land used for tea estates and farm activities should be provided with proper drainage, advanced conservation measures on unstable slopes to reduce the soil loss and landslides in order to attain a sustainable agriculture and fulfil a beneficial livelihood. This proves the study area is more vulnerable to soil erosion and undeniably needs model studies to achieve a sustainable agriculture.

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