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Assessment of carbon loss related to Soil loss in the tropical watershed of Maharashtra, India

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ABSTRACT

Soil carbon pools have a significant impact on the global carbon cycle and soil erosion caused by natural or human activities is one of the main drivers of changes in soil carbon sequestration. The present study aimed to estimate the carbon loss associated with soil loss in the watershed using remote sensing and GIS techniques. The study was carried out at the Central MPKV Campus Watershed, Rahuri, located in the rain shadow region of the Maharashtra state, India. The soil loss from the watershed was estimated using USLE model. The soil loss and carbon loss from the watershed were estimated before the implementation of conservation measures and after the implementation of conservation measures. It was found that the average annual soil loss from the watershed before and after conservation measures was 18.68 t/ha/yr and 9.41 t/ha/yr, respectively. Carbon loss was determined by soil loss rate, organic carbon content and the carbon enrichment ratio. The carbon loss from the watershed before and after conservation measures was 348.71 kgC/ha/yr and 205.52 kgC/ha/yr. The findings revealed that soil and carbon erosion was very severe on steep slopes without conservation measures and with limited vegetation cover. It was found that by reducing the carbon loss associated with soil loss, soil conservation measures not only aid in the conservation of natural resources but also serve as a climate change mitigation measure.

Introduction

Soil carbon pool, which is the dominant terrestrial carbon pool, is roughly 3.3 times bigger than atmospheric carbon pool and 4.5 times bigger than biotic carbon pool (Lal, 2004a). Soil erosion and subsequent sediment transport through runoff are important pathways for lateral soil carbon movement at the land surface and have a significant impact on the carbon flux of terrestrial ecosystems (Kuhn *et al.,* 2012; Li *et al.,* 2018; Wang *et al.,* 2019). Soil erosion induced from water and wind has a significant impact on both the lateral SOC dispersion within a landscape and vertical CO_2 fluxes into the atmosphere (Lal, 2003; Yue *et al.,* 2016). Key mechanisms governing the net carbon transfer between the soil and the atmosphere were enumerated by Van Oost *et al.,* 2005 as follows: 1) SOC replacement at eroding sites 2) deep burial of carbon-rich topsoils towards depositional sites 3) increased SOC degradation through physico chemical soil breakdown during detachment and

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transport process. In particular, last two mechanisms are vulnerable to changes in the precipitation pattern (Wang *et al.,* 2014).

Many studies have found that topsoil erosion caused by intense rainfalls and strong winds degrades soil quality and lowers SOC (Lal, 1990, 2013). However, following widely accepted land management practices (RMPs) can help to reduce soil erosion below tolerable limit and create an environment conducive to carbon sequestration. Soils that are degraded and depleted by soil erosion have a large carbon (C) sink capacity to replenish atmospheric CO_2 into SOC stocks when converted to regenerative land use and the use of effective soil conservation practices (Stallard, 1998; Jacinthe *et al.,* 2002) Due to anticipated changes in the Earth's climate, soil loss rate is likely to accelerate in the future (Berc *et al.,* 2003; Yang *et al.,* 2003). Accelerated soil erosion is one of four prime global pressures threatening human survival, the others being changing climate, increasingly rapid population explosion and biodiversity extinction (Ontl and Schulte, 2012). In recent years, a large number of research studies have been conducted in different regions of the world in order to better understand the dynamics and redistribution of carbon (C-erosion) associated with soil erosion (Bajracharya *et al.,* 2000; Mabit *et al.,* 2008; Wang *et al.,* 2014; Karmakar *et al.,* 2016; Wang *et al.,* 2019).

SOC loss can have a significant impact on soil quality by lowering soil stability, water holding capacity and productivity (Lal, 2015). Furthermore, soil organic carbon loss through soil erosion depleted carbon uptake by terrestrial ecosystems, lowering soil carbon sequestration capacities (Lal, 2004b). Carbon flux from soils as recently reported by Kindler *et al.,* (2011), is an important component of the ecosystem's net carbon balance. Despite its significance, it has gone unnoticed in tropical and subtropical regions, where episodic but intense rainfall storms can significantly damage soil productivity through soil erosion and carbon erosion (Li and Fang, 2016).

Erosion-induced carbon fate in India is poorly studied at the state and national levels, and even less at the watershed level. As a result, the purpose of this research is to estimate the lateral transport of carbon by erosion at the watershed level by multiplying amount of soil loss by SOC content and carbon enrichment ratio (CER). The present research was conducted at the Central Mahatma Phule Krishi Vidyapeeth (MPKV) Campus Watershed located in the rain shadow region of Maharashtra, India. The watershed receives moderate rainfall and is prone to water erosion. Nearly half of the watershed is treated with diverse soil and water conservation (SWC) measures. Therefore, carbon loss induced from the soil erosion was estimated before and after conservation measures. The impact of conservation measures on soil loss and subsequently on carbon loss was evaluated.

Material and Methods

Specifics about the study area

The study was carried out at "Central MPKV Campus Watershed" located in Rahuri Taluka in Ahmednagar District of Maharashtra State, India. The study area lies between latitudes $19^0$21.77' N and $19^0$18.73' N and longitudes $74^0$37.79' E and $74^0$36.49' E. The study area is 1260 ha in size, with an altitude of 441 to 542 m above mean sea level (Figure 1).

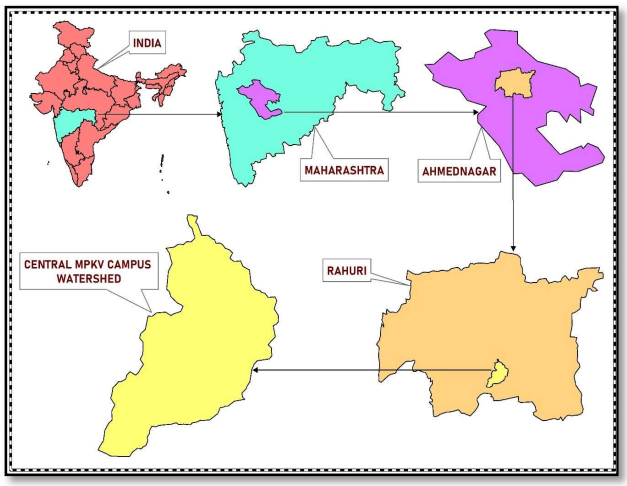

Figure 1: Location map of study area

Climate

The study area exhibits a unimodal precipitation pattern. The study receives rainfall from the monsoon, with the main rainy season extending from delayed June to early September. It receives 592 mm of average annual rainfall and the normal lowest and highest annual temperatures are 19°C

and 31°C, respectively. The study area is located in hot and dry climate zone.

Soil and water conservation measures in the study area

The Central MPKV Campus Watershed is treated with various soil and water conservation measures. In the year 2019 nearly half of the watershed was treated with both land area and drainage line treatments. The land area treatments in the watershed include Deep continuous contour trench (DCCT) and compartment bunding, while drainage line treatments include earthen nala bund, loose boulder structure and percolation tank. The details of SWC measures are given in the (Table 1) and (Figure 2, 3)

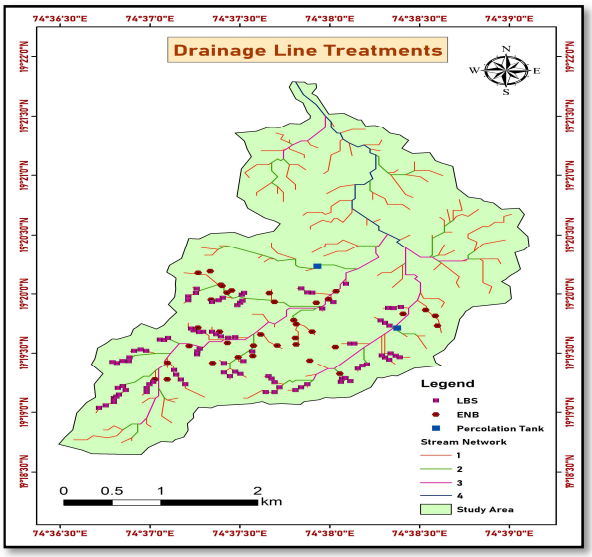

Figure 2: Drainage line treatments in the watershed

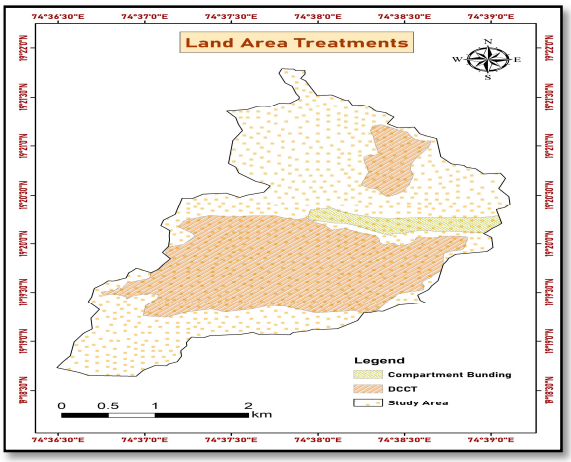

Figure 3: Land area treatments in the watershed

Table 1: Soil and water conservation measures in the watershed

Total Study Area	1260 ha
Total Treated Area	545 ha
Perimeter of treated area	12.77 km
Area Under DCCT	495 ha
Length of DCCT	99,600 running m
Area Under Compartment Bunding	50 ha
Earthen Nala Bunds	38 nos.
Percolation Tanks	2 nos.
Loose Boulder Structures	97 nos.

Land use pattern and crops grown in the study area

The watershed has six primary land-use types: barren land (37.95%), natural vegetation land (24.20%), agriculture land (21.48%), horticulture land (7.30%), settlement (5.78%) and waterbody (3.29%). The majority of cultivated land is concentrated in the lower reaches of the watershed, while natural vegetation land is found in the middle part. Farmers' landholding in the watershed is described as small and dispersed, with less than 0.5 ha per household. Cultivation is the primary source of income in the watershed and main crops cultivated are sugarcane (*Saccharum officinarum L.*), sorghum (*Sorghum bicolor L.*), Maize (*Zea mays L.*) and Onion (*Allium cepa L.*).

Estimation of soil loss risk in the watershed

The soil loss from the Central MPKV campus watershed was estimated using the universal soil loss equation (USLE) model coupled with GIS software. The Arc GIS 10.8 software was used for the estimation of soil loss. The soil loss in the watershed was estimated under two conditions: one without any SWC measures and another after implementation of SWC measures in the watershed. The construction of SWC measures started in the year 2017 and completed in the year 2019. Therefore, before conservation measures data was taken for the year 2016 and after conservation measures readings were taken in year 2021.

Description of data sources used

The data sets required for USLE model parameters were acquired from a variety of sources. The annual rainfall data for watershed was obtained from the Department of Agro-meteorology, Rahuri. Rainfall erosivity factor (R-value) of study area was calculated using annual rainfall data. Soil erodibility factor (K value) was calculated using

organic matter, structure, texture and permeability of the study area's soil. Slope length and gradient factor (LS value) were calculated using Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) with a resolution of 30m. The crop management factor (C) and conservation practise factor (P) were calculated using Sentinel-2A imagery and DEM data. The DEM and satellite images were acquired from Earth Explore web portal maintained by United States Geological Survey (USGS) (https://earthexplorer.usgs.gov/).

Estimation of USLE parameters

Rainfall erosivity factors (R)

The R factor of study area was calculated using an equation developed specifically for the hot and dry region of Rahuri tehsil and derived from spatial regression analysis. The average rainfall over the last 30 years (1991 to 2021) was used to calculate the R factor. The R factor value was kept constant for estimating soil loss before and after conservation measures.

The Eq. 1 was used to calculate R factor:

$$\mathbf{R} = \mathbf{0.0022}X^2 + \mathbf{0.7526X} + \mathbf{152.35} \quad \ldots(1)$$

Where, R= Annual Erosivity, MJ-mm/ha-hr-yr
X= Annual Rainfall, mm

Soil erodibility factor (K)

Total 50 soil samples were collected from the watershed using a 500×500 m grid, with samples collected from the centre of each grid for analysis. Soil samples were collected under different land use patterns from top 15 cm depth using soil auger in order to determine the physicochemical properties of soil. Soil samples were collected in November 2021 when most of the soil in the watershed had dried up. The soil samples were analysed according to standard laboratory procedures. The different soil properties such as organic matter content, soil texture, soil structural and permeability were estimated in the soil testing laboratory.

The K factor of different soil types was calculated using different soil properties such as texture, organic matter, permeability and structure (Foster *et al.,* 1981; Panagos *et. al.*, 2015). The K factor was calculated using Eq. 2 and mapped in this study (Tamene and Vlek, 2007; Addis and Klik, 2015; Wolka *et. al.*, 2015).

$$\mathbf{K(factor)} = \mathbf{2.77 \times 10^{-7}(12 - OM)\, M^{1.14} + 4.28 \times 10^{-3}(s - 2) + 3.29 \times 10^{-3}(p - 3)} \quad \ldots(2)$$

Where,

$$M = [(100 - C)(L + A_{rmf})] \quad \ldots(3)$$

C is % of clay (< 0.002 mm), L is % of silt (0.002–0.05 mm) and A_{rmf} is % of very fine sand (0.05–0.1 mm), OM is the organic matter content (%), p is a code denoting the class of permeability and s is a code for the structure size. It was found that soil physical and chemical properties did not change significantly over a 5-year period, therefore the K-factor is considered constant when estimating soil loss before and after conservation measures. Soil erodibility map of the watershed was prepared in Arc GIS software using interpolation techniques. The Inverse Distance Weighting (IDW) interpolation technique was used to transform soil sampling location points of erodibility factors (K) to surface raster data.

Slope length and gradient factor (LS)

Slope length and gradient factors i.e topographic factor was estimated in ArcGIS 10.8. The SRTM DEM with a spatial resolution of 30m was used to prepare slope map of study area. The DEM was pre-processed in ArcGIS environment to remove discontinuation in data set then different thematic layers such as flow direction, flow accumulation, slope steepness and slope gradient were prepared. The Eq. 4 developed by Wischmeier and Smith (1978) was used to generate LS factor map of study area. Similar approach also followed by other researchers (Shiferaw, 2011; Gerawork and Awdenegest, 2014).

$$\mathbf{LS} = (\mathbf{X/22.1})^m\,(\mathbf{0.065 + 0.045S + 0.0065S^2}), \quad \ldots(4)$$

$$\boldsymbol{X = (FLow\ Accumulation \times Cell\ size\ value)} \quad \ldots(5)$$

Where, LS = slope length–steepness factor/Topographic factor, S = slope gradient (%), X = length of slope (m) and m = exponent (slope-length exponent).

Since the slope pattern of the watershed did not significantly change before or after conservation measures, the LS factor was also held constant for both scenarios.

Crop management factor (C)

Land use land cover mapping of study area was performed to prepare crop management factor map of study area. The ratio of soil loss from areas with a particular vegetation cover to soil loss from areas that are fallow under the same rainfall conditions is represented by a C factor. (Wischmeier and Smith, 1978). The Sentinel-2A satellite imagery was used to generate the land-use and land-cover (LU/LC) map of the watershed. Image classification was performed using supervised digital image classification technique in ArcGIS 10.8 software. To create LU/LC maps before and after conservation measures, satellite images from December 15, 2016 and December 16, 2021 were used.The validation of the land cover classification was performed using Google Earth. A total of 105 reference points were generated in Google Earth and these points compared to the obtained land cover classification. Finally, seven LU/LC classes were identified as agriculture, horticulture, barren, natural vegetation, current fallow, settlement and waterbody (Table 1). The standard C-factor values of various LU/LC classes were assigned to the appropriate landcover class using the Reclassify tool in the ArcGIS 10.8 environment to obtain the watershed C-factor raster layer.

Conservation practice factor (P)

The conservation practice factor (P) is defined as the ratio of soil loss expected for a given soil conservation practice to that expected for uphill and hillside plowing (Wischmeier and Smith, 1978). The area under different conservation practices in the watershed was mapped by conducting field survey. The GPS device was used to map the area of different conservation measures. The P factor value of one was given for the entire watershed before conservation measures. However, after the implementation of recommended SWC measures on half of the watershed area, corresponding P factor values were assigned to the conservation measures in the Arc GIS 10.8 environment. Finally, the watershed's P factors raster layer was created by allocating adapted P factor values for conservation measures.

Estimation of soil loss from the watershed

The average annual soil loss from the Central MPKV campus watershed before and after conservation measures was calculated by interactively multiplying (Eq. 6) the USLE factor values (R, K, LS, C, and P) in the Arc GIS 10.8 environment using the Raster Calculator tool.

$$\boldsymbol{A = R \times K \times LS \times C \times P} \quad \text{.....(6)}$$

Where A = Average annual soil loss (t/ha/yr); R = Rainfall erosivity factor (MJ-mm/ha-hr-yr); K =Soil erodibility factor (t-ha-hr/ha-MJ-mm); LS = Slope length factor (dimensionless); C = Crop management factor (dimensionless); and P = Conservation practice factor (dimensionless).

Estimation of carbon loss from the watershed

The C-loss due to soil loss depends on soil erosion rate, SOC concentration and carbon enrichment ratio values. The C-loss from the watershed before and after conservation measures was estimated using (Eq. 6) developed by Mandal *et al.,* (2020)

$$\boldsymbol{C - loss}\left(\frac{t}{\frac{ha}{yr}}\right) = \frac{\boldsymbol{Soil\ loss}\left(\frac{t}{\frac{ha}{yr}}\right) \times \mathbf{SOC}\ (\%) \times \mathbf{CER}}{\mathbf{100}} \quad \text{...(6)}$$

Soil organic carbon content in the watershed

A total of 50 soil samples were collected from the watershed to determine SOC content of the watershed. The GPS locations of the sampling points were recorded to map the SOC content. The SOC content was determined for different land use classes by taking soil samples from different land cover classes using the grid sampling method. Soil samples were analysed in the laboratory to estimate after conservation measures SOC content. The SOC data prior to conservation measures was obtained from the Department of Soil and Water Conservation Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri. The SOC layer for the watershed was generated in Arc GIS environment by providing corresponding SOC values to the soil sample locations. The raster layer of SOC for before and after conservation measures was prepared using interpolation techniques.

Carbon enrichment ratio for the watershed

The CER is defined as the ratio of SOC content in the eroded sediment sample to that of the original soil (Sharpley, 1985). Mandal *et al.,* (2020) calculated CER values for various erosion classes for Maharashtra state (Table 2). In the Arc GIS environment, these values were assigned to the various erosion classes of the watershed, and CER layers for the watershed before and after conservation measures were created.

Table 2: Erosion class wise CER values

SN	Erosion class	Erosion range (t/ha/yr)	CER value
1	**Very low**	< 5	3.62
2	**Low**	5 to 10	3.28
3	**Moderate**	10 to 20	2.3
4	**Severe**	20 to 40	2.3
5	**Extremely severe**	>40	2.04

Carbon loss from the watershed

The average annual carbon loss from the watershed was estimated using raster calculator tool in the Arc GIS 10.8 environment. Soil loss rate, SOC concentration and CER ratio layers generated in the Arc GIS software were used for the estimation of C-loss from the watershed. The Eq. 6 was used in Raster Calculator to generate C-loss layer.

Results and Discussion

Rainfall erosivity (*R*) factor

Rainfall erosivity factor is directly influenced by amount of rainfall and intensity of rainfall. Average annual precipitation in the study area is 592.19 mm, resulting in rainfall erosivity of 478.19 MJ-mm/ha-hr-yr. The lower the R-value, the lower the erosivity of rainfall to erode the soil (Asmamaw and Mohammed, 2019) and lower the rainfall intensity in the study area (Devatha *et al.,* 2015). The estimated moderately low rainfall erosivity index for the study area signifies further risk of soil erosion hazards, especially under conditions of increasing rainfall. The rainfall erosivity is highly dependent on the frequency and intensity of precipitation. Additionally, variations in climatic conditions and weather patterns can also affect the rainfall erosivity by modifying precipitation patterns and intensities. Consequently, fluctuations in rainfall erosivity can greatly impact soil erosion rates in the watershed. In estimating soil loss before and after conservation measures, the erosivity factor was held constant. Bagwan, 2020 found similar rainfall erosivity values, ranging from 392 to 1014 MJ-mm/ha-hr-yr, in the rainfed region of the Urmodi river watershed, Maharashtra.

Soil erodibility (*K*) factor

The soil erodibility value indicated the susceptibility of soil to erosion. Soil erodibility is mainly affected by the kinetic power of rain drop and surface runoff (Khairunnisa *et al.,* 2020). The structural stability and water infiltration capacity of the soil influence the value of the K factor (Devatha *et al.,* 2015). The soil structure in the watershed is coarse granular, with moderate to rapid permeability. The greater the soil erodibility, the higher will be the soil erosion, and vice versa. Soil erodibility in this watershed ranged from 0.0310 to 0.0599 t-ha-hr/ha-MJ-mm (Fig. 4). Low soil erodibility was observed in regions with low levels of organic matter and high soil bulk density. The watershed has three major types of soil: sandy clay loam, sandy loam and clay loam. Among the different soil types found within the watershed, sandy loam soil has the highest erodibility and clay loam soil has the lowest. The areas with clay loam soil type were found in the lower reaches of the watershed, where agriculture land is the dominant land cover. Therefore, the majority of agricultural land cover in the watershed was found to have lower soil erodibility values. Similarly, areas with sandy clay loam and sandy loam soil types were found in the upper reaches of the watershed, where barren land is the predominant land cover. Consequently, values of soil erodibility were found to be greater in the majority of barren land covers than in other types land covers. It indicates that barren lands with high soil erodibility values in the watershed are more vulnerable to soil erosion hazards and require immediate soil conservation measures. The soil type wise average K factor values are given in (Table 3).

Topography factor (*LS*) factor

The LS factor varied from 1.02 in the plains to 5.92 in the highlands (Fig. 5). The watershed's slope ranges from 0 to 30.23%, with a mean slope of 4.17%. Around 90% of the watershed had a slope of 0-9%, with the remaining 10% having a slope greater than 9%. The majority of the watershed, 90%, has a moderate slope range, indicating moderate soil erosion potential, while the remaining 10% has a high erosion potential.

Table 3: Soil type wise soil erodibility (K) factor values (t-ha-hr/ha-MJ-mm)

Soil Type	Minimum	Maximum	Mean	Coefficient of Variation
Sandy Clay Loam	0.031	0.052	0.044	15.64
Sandy loam	0.052	0.060	0.056	4.48
Clay Loam	0.029	0.033	0.031	6.08

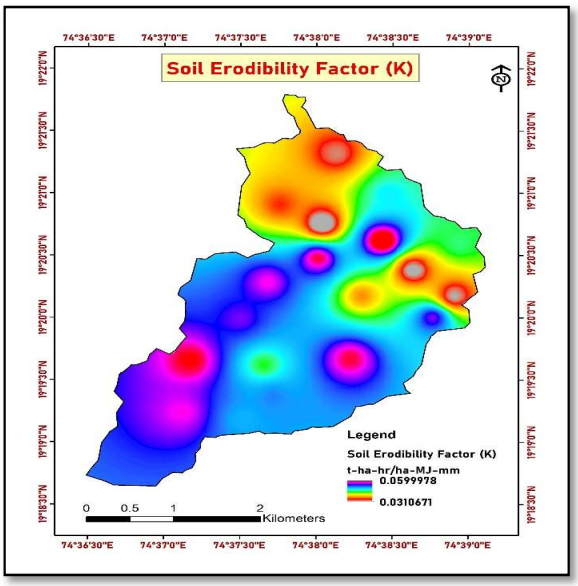

Figure 4: Soil erodibility (K) factor map of watershed.

This 10% area of the watershed with hilly terrain is located in the watershed's middle reaches and requires soil conservation measures that intercept long slopes into several short ones in order to keep runoff water at less than a critical velocity. Karhade and Vangujare (2018) found the LS factor in the range of 0 to 11 in the Kham River Basin, Aurangabad, Maharashtra.

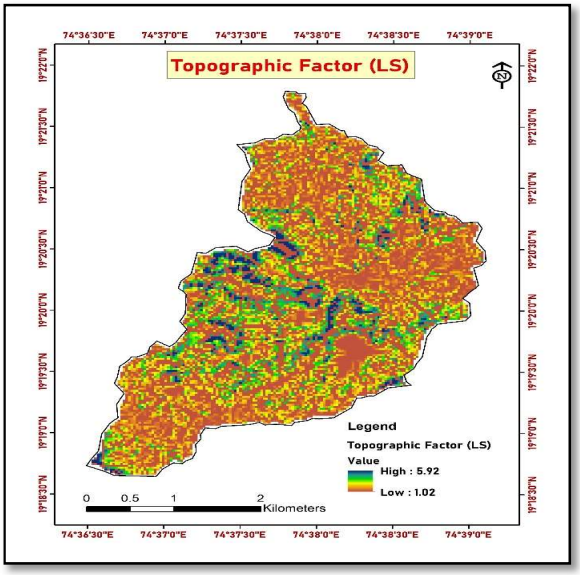

Figure 5: Topographic factor (LS) map of watershed

Crop management factor (C)

Two land cover maps were created, one before conservation measures and one after the implementation of conservation measures in the watershed (Fig. 6, 7). The conservation measures implemented in the watershed affected the land cover within the watershed. Through satellite image classification seven land classes in the watershed were identified as agriculture, horticulture, barren, natural vegetation, current fallow, settlement and waterbody. The overall accuracy of image classification and Kappa coefficient for watershed were 88% and 0.78, respectively, for before conservation measures image and 89% and 0.80, respectively for after conservation measures image. The land cover classification before and after conservation measures is given in the Table 4. It was observed that barren land was dominant land cover class in the watershed followed by natural vegetation. After implementation of conservation measures in the watershed area under barren land and current fallow land was decreased while area under all other land cover classes were increased. Before conservation measures nearly 37.5% of the watershed area was under vegetation cover but after implementation of conservation measures in the watershed vegetation cover area increased upto 50%.

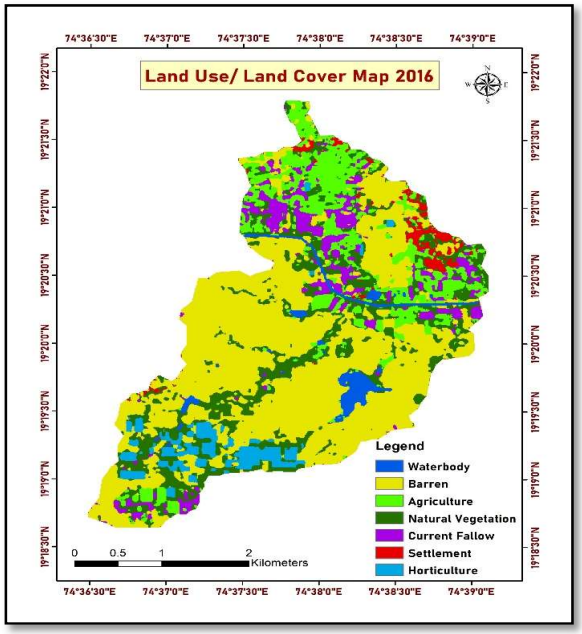

Figure 6: Before conservation measures land use/ land cover map of watershed

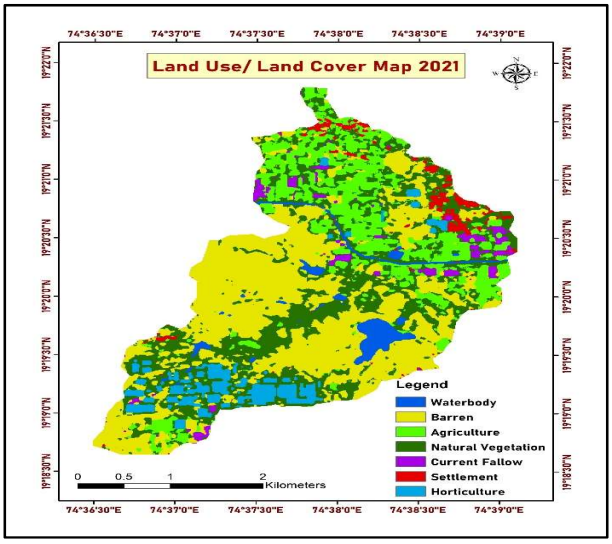

Figure 7: After conservation measures land use/land cover map of watershed

Table 4: Area coverage by different land use/ land cover classes before and after conservation measures

Land Cover Class	Year 2016 (Before Conservation Measures) Area (ha)	Year 2021 (After Conservation Measures) Area (ha)	Change in Area (ha)	Change in Area (%)
Waterbody	32.91	41.48	8.57	26.04
Barren Land	605.65	478.17	-127.48	-21.05
Agriculture	162.17	230.1	67.93	41.89
Natural Vegetation	231.95	304.97	73.02	31.48
Current Fallow	93.74	40.49	-53.25	-56.81
Settlement	58.39	72.82	14.43	24.71
Horticulture	75.19	91.97	16.78	22.32
(-) ve value indicates decrease in area.				

Table 5: Crop management (C) factor for different land cover classes

Land use/land cover	C value
Forest (Rasool *et al.*, 2014)	0.04
Barren land (Rasool *et al.*, 2014)	0.84
Settlement (Rasool *et al.*, 2014)	0
Horticultural crops (Pal and Samanta 2011)	0.1
Agriculture land (Pancholi *et al.*, 2015)	0.45
Waterbody (Pancholi *et al.*, 2015)	0
Current fallow (Pancholi *et al.*, 2015)	0.6

The C factor values of respective land cover class are given in Table 5. The mean value of the C factor in the watershed area was 0.27 and ranged from 0 to 0.84. The barren land comprises most of the land use in the watershed and has a maximum C-factor value, indicating that the area is at high risk of erosion. According to previous research, the value of crop management factors tends to decrease as vegetation cover increases, which is consistent with the findings of our study (Manik *et al.,* 2019).

As the area covered by various land covers changed after the implementation of conservation measures, the different C factor layers were used to estimate soil loss before and after conservation measures from the watershed. The before conservation measure LU/LC image was used to generate C factor layer prior to conservation measures, and the after conservation measure LU/LC layer was used to generate C factor layer later conservation measures.

Conservation practice factor (P)

P factor value of one is considered for the entire watershed prior to any conservation measures in the watershed. Following the implementation of conservation measures in the watershed, the respective P factor value of the conservation measure was provided to the respective area, with one value considered for the untreated area. The P-factor value ranges from 0 to 1, with 0 indicating complete protection from soil erosion and 1 indicating no protection against soil loss. The P factor value for the watershed were ranged from 0.03 to 1. The conservation measures constructed in the watershed and their P factor value is given in the (Table 6). Other studies have also reported a wide range of P factor values for watersheds. For instance, López-Ballesteros *et al.,* 2019 found P factor values ranging from 0.02 to 0.8 in their study, while ElKadiri *et al.,* 2023 reported values ranging from 0.04 to 0.9. The P factor layers after conservation measures is given in Fig. 8.

Table 6: Conservation practice (P) factor

Conservation Measure	Area (ha)	P factor
Deep Continuous Contour trench	495	0.15
Compartment Bunding	50	0.03

Soil erosion in the watershed

The yearly average soil loss rate from study area was estimated by multiplying five USLE parameters (rainfall erosivity, soil erodibility,

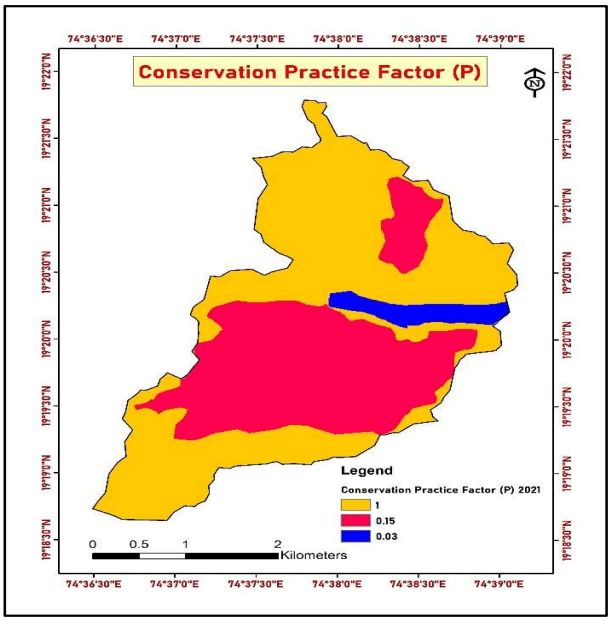

Figure 8: After conservation measures conservation practice (p) factor map of watershed

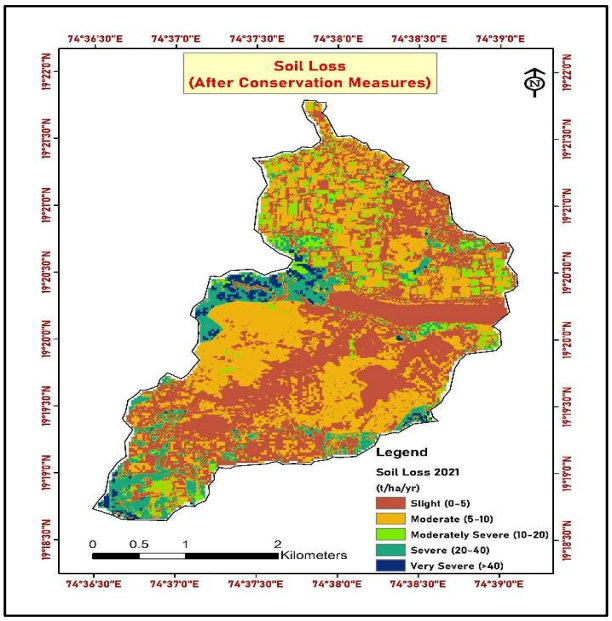

Figure 10: Soil loss from watershed after conservation measures.

topography, crop management and conservation practice factor) in Arc GIS software. The final USLE maps of before and after conservation measures display the yearly average soil loss potential (A) of the Central MPKV Campus watershed shown in Fig 9, 10.

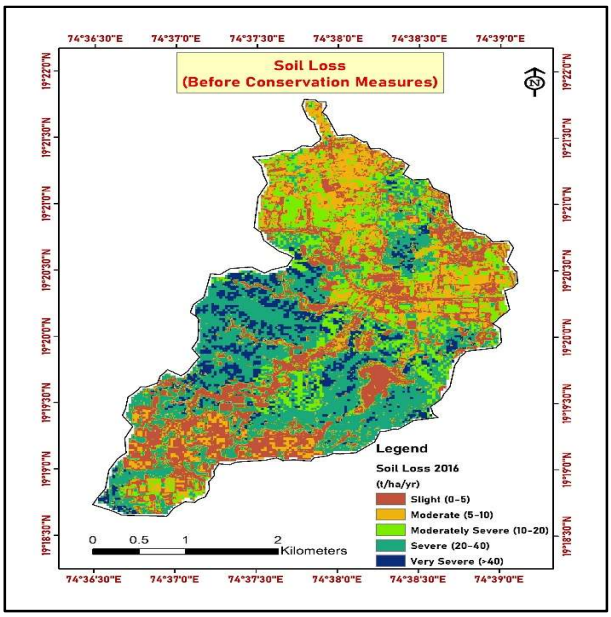

Figure 9: Soil loss from watershed before conservation measures

Soil loss before conservation measures

The yearly average soil loss rate before conservation measures was estimated at 18.68 t/ha/year. The soil loss rate in the watershed was ranged from 0 to 78.23 t/ha/year, with negligible soil loss in plains and severe soil loss in hilly areas. The soil loss rate before conservation measure was greater than tolerable limit of 11 t/ha/yr (Hudson, 1981). The yearly soil loss estimated from the watershed was found to be 23119.36 tonnes. The soil erosion rate was classified into five classes as shown in (Table 7).

Table 7: Area under different soil erosion classes before and after conservation measures

Soil Erosion Class	Soil loss (t/ha/yr)	Before Conservation Measures	After Conservation Measures
		Area (ha)	Area (ha)
Slight	< 5	365.27	574.75
Moderate	5 to 10	161.54	414.36
Moderately Severe	10 to 20	216.51	102.53
Severe	20 to 40	397.13	130.12
Very Severe	>40	119.54	38.224

The result indicated that 28.99% of the area has a slight erosion rate (0–5 t/ha/year) and such areas can be considered as areas with low erosion-risk. The slight erosion risk area was mainly found in

flat lands with vegetation cover. The remaining areas were classified as moderate (5–10 t/ha/year) erosion risk area (12.82%), which was mostly found in agricultural land; moderately severe (10–20 t/ha/year) erosion risk area (17.18%), which was found in barren land with spare vegetation cover; severe (20–40 t/ha/year) erosion risk area (31.52%), which was found in hilly area with spare vegetation and extremely severe (>40 t/ha/year) erosion risk area (9.49%), which was found in slopping areas without any vegetation cover. The severity of soil erosion was directly affected by the LU/LC, soil type, topography and rainfall intensity. Areas with dense vegetation cover, flat lands and cohesive soils were found to have less soil erosion. Whereas areas with no or sparse vegetation, steep and long slopes were found to have severe soil erosion. The results of soil loss before the adoption of conservation measures emphasise the importance of soil conservation within the watershed in order to maintain soil quality and fertility. Implementing site-specific conservation measures in the watershed can help to keep soil loss within a tolerable limit while also improving soil quality. Other studies have also reported higher soil loss rates without soil and water conservation measures, which is consistent with the findings of our study. A study conducted by Li *et al.* 2016 in semi-arid Yellow river basin of china found that soil loss rates without conservation measures ranged from 4.2 to 31.9 t/ha/yr in different watersheds.

Soil loss after conservation measures

The yearly soil loss rate after conservation measures was found at 9.41 t/ha/year. This post-conservation soil loss rate was 9.27 t/ha/year lower than the pre-conservation soil loss rate. The post-conservation measures soil loss rate was ranged from 0 to 53.24 t/ha/year in the watershed. The implementation of recommended SWC measures in the watershed reduced the soil loss rate below tolerable limit (11 t/ha/yr). The annual soil loss estimated from the watershed was found to be 11560.6 tonnes. Soil loss after conservation measures was reduced by half compared to soil loss before conservation measures. Similar to above, erosion rate risk was classified into five classes as shown in (Table 7). The result indicated that 45.62% of the watershed area has a slight erosion rate (0–5 t/ha/year), which was increased by 20%. The area under moderate (5–10 t/ha/year) erosion risk (32.89%) increased by 20%; area under moderately severe (10–20 t/ha/year) erosion risk (8.14%) decreased by 10%.; area under severe (20–40 t/ha/year) erosion risk (10.33%) decreased by 20% and area under extremely severe (>40 t/ha/year) erosion risk (3.03%) decreased by 6% post-conservation measures. The effectiveness of conservation measures in reducing soil loss rates has been confirmed by multiple studies. Lal (2015) and Wen and Zhen, (2020) both reported similar findings, demonstrating that implementation of conservation measures led to a significant reduction in soil loss rates.The average annual soil loss from the watershed before conservation measures was 40% and 50% higher compared to tolerable soil loss limit and the soil loss after conservation measures, respectively. The maximum soil loss before conservation measures occurred in hilly terrains and in the mainstreams, possibly due to high LS factor values and steep slope gradients greater than 25%. Areas with spare vegetation cover also have high rates of erosion as there is no any obstruction to the runoff. Implementation of conservation measures in the watershed increased water availability in the watershed. The water spread area in the watershed was increased by 25%. The increased water availability increased vegetation cover in the watershed, agricultural area increased by 40%, natural vegetation increased by 30% and horticulture plantation increased by 22%. This increased vegetation cover acted as a natural barrier to runoff, reducing the rate of water flow to a safe limit. Increased vegetation cover has a considerable impact on the rate of soil loss after conservation measures. Implementation of conservation measures in the watershed reduced the average annual soil loss rate below the tolerable limit and by 50% less than the soil loss rate before conservation measures. It was observed that after the implementation of conservation measures in the watershed, area under slight and moderate erosion risk class increased while area under moderately severe, severe and extremely severe erosion risk class decreased. Almost 75% of the watershed area is now classified as having a low to moderate risk of erosion. Only 13% of the watershed area is remained in the severe to extremely severe erosion risk class. The spatial distribution of soil loss

reveals that areas with high erosion risk have long slopes, sparse vegetation and fine soils with no conservation measures. This suggests that scientifically appropriate implementation of conservation measures in the watershed can drastically reduce soil loss from the watershed. This allows soil fertility and productivity to be maintained. It was suggested that additional conservation measures can be implemented in the watershed to further minimize the soil loss rate from the watershed.

SOC content before and after conservation measures

The SOC content before and after conservation measures under different land covers in the watershed is given in the Table 8. The average SOC content before and after conservation measures in the watershed was 0.74% and 0.77%, respectively. It was observed that SOC content was increased in each major land cover class but the rate of increase was varied depending on the land cover class. Natural vegetation land cover has the highest SOC increase rate while barren land has the lowest. There is ample evidence in the literature to suggest that the implementation of conservation measures can lead to significant increases in soil organic carbon (SOC) content. He *et al.,* (2022) demonstrated that the implementation of conservation practices resulted in a significant increase in SOC content in the topsoil and subsoil. Another study by Lai *et al.,* (2022) found that the application of conservation measures such as straw mulching and intercropping significantly increased SOC content in the topsoil. Thematic layers of SOC generated with Arc GIS software were used to estimate carbon loss from the watershed (Fig. 11, 12).

Table 8: Land Cover wise SOC content before and after conservation measures

Land cover	SOC content before conservation measures (%)	SOC content after conservation measures (%)	Total number of samples
Agriculture land	0.74	0.76	10
Barren land	0.67	0.69	15
Natural Vegetation land	0.78	0.82	15
Horticulture land	0.76	0.79	10
Average	**0.74**	**0.77**	

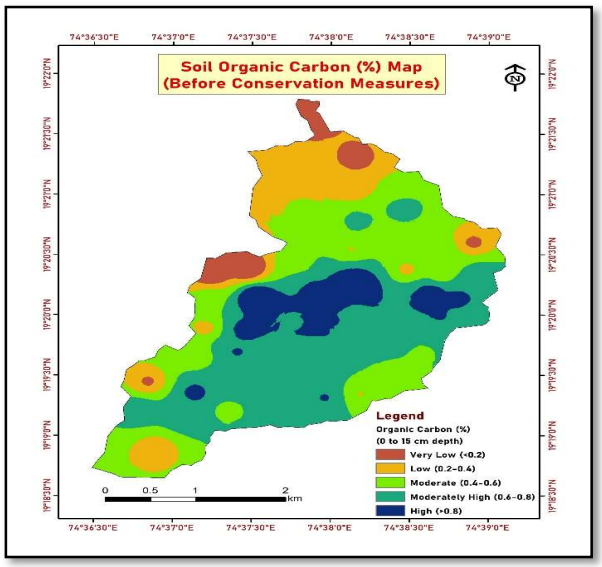

Figure 11: Soil organic carbon content before conservation measures

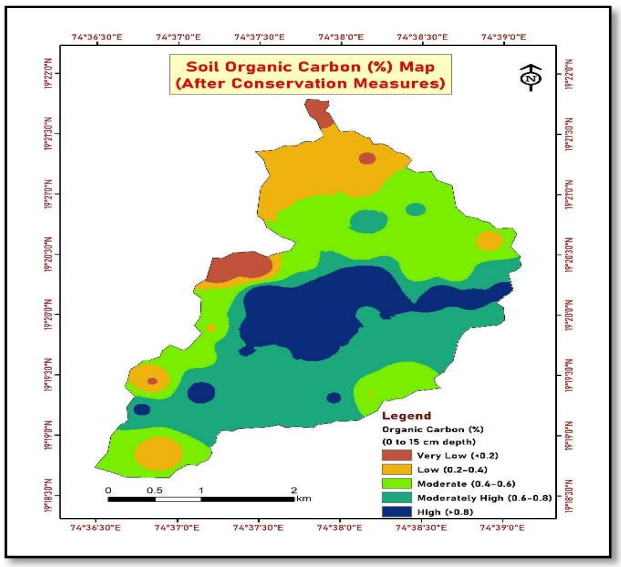

Figure 12: Soil organic carbon content after conservation measures

Carbon Enrichment Ratio

The CER layers generated using Arc GIS software were used in the estimation of carbon loss from the watershed. The CER value depends on the classes of soil erosion rate; higher soil erosion rates have lower CER values, while lower soil erosion rates have higher CER values. The CER values in the watershed were ranged from 2.04 for extremely severe erosion class to 3.62 for slight erosion class.

The 48% of watershed area was having the CER value of 2.3 before conservation measures and after conservation measures 45% area was having the CER value of 3.62. The change in the area under CER ration was observed due to significant difference in the rate of soil erosion before and after conservation measures. Similarly, a study by Wang *et al*. (2019) used a range of carbon enrichment ratio values, from 1.6 to 3.4, to estimate carbon loss in soil aggregates.

Carbon loss risk assessment

The yearly carbon loss from the watershed was estimated using soil loss rate, soil organic carbon content and carbon enrichment ratio layers in raster calculator tool in Arc GIS software. The C-loss layer depicts the average yearly carbon loss potential of the Central MPKV Campus Watershed before and after implementation of conservation measures (Fig 13, 14).

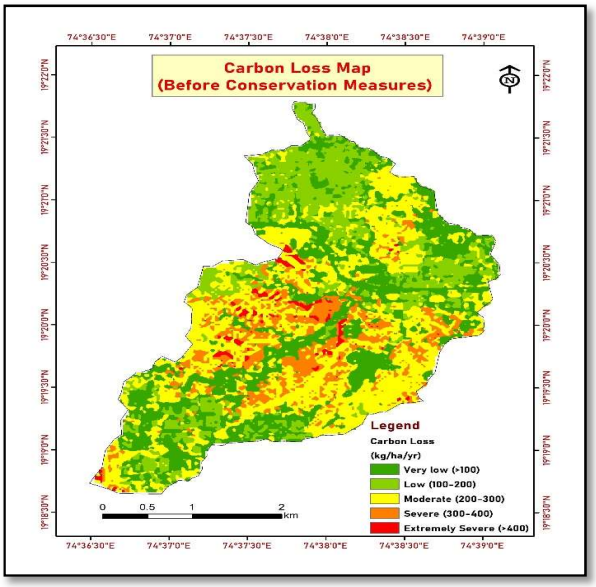

Figure 13: Carbon loss from the watershed before conservation measures

Carbon loss before conservation measures

The average annual carbon loss before conservation measures was 348.71 kgC/ha/yr, ranging from 0 to 618.42 kgC/ha/year. The total carbon loss from the watershed was 439.37 tonnes of C. The carbon loss was found higher on steep slopes and in baren land class without any vegetation cover. Similar to soil loss, carbon loss rate was categorized into five distinguished classes. The carbon loss rate categories varied from very low carbon loss rate (0-100 kgC/ha/year) to extremely severe carbon loss (>400 kgC/ha/year) rate (Table 9). It was found that area under very low carbon loss class (0-100 kgC/ha/year) was 25.63% this area is categorised as very low risk carbon erosion area. The remining area was classified as low (100–200 kgC/ha/year) carbon erosion area (19.84%); moderate (200–300 kgC/ha/year) carbon erosion area (34.52%); severe (300–400 kgC/ha/year) carbon erosion risk area (14.68%) and extremely severe (>400 kgC/ha/year)

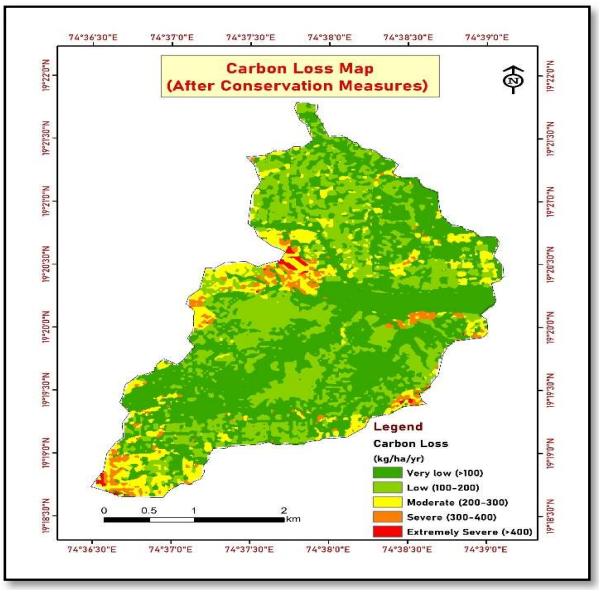

Figure 14: Carbon loss from the watershed after conservation measures

Table 9: Area under different carbon erosion classes before and after conservation measures

Carbon Loss Class	Carbon Loss Range (kgC/ha/yr)	Before Conservation Measures	After Conservation Measures
		Area (ha)	Area (ha)
Very low	<100	323	560
Low	100-200	250	415
Moderate	200-300	435	172
Severe	300-400	185	81
Extremely Severe	>400	67	32

bon erosion risk area (5.32%). Nearly 53% of the watershed area had a carbon loss rate above 200 kg C/ha/yr before the adoption of conservation

measures. It was observed that as the severity of soil erosion increased, so did the rate of carbon erosion. The rate of carbon loss in the watershed varied according to land cover, with the highest rate observed in barren land and the lowest rate observed in natural forests. Soil carbon loss was also significantly affected by the organic carbon content and carbon enrichment ratio in the top soil layer. Similarly, a study by Krauss *et al.,* (2017) found that the application of soil conservation measures significantly reduced carbon loss in a hilly area of southwestern China. The carbon loss rate in the untreated plots was approximately three times higher than in the treated plots.

Carbon loss after conservation measures

The average annual carbon loss after conservation measures was 205.52 kgC/ha/yr, ranging from 0 to 538.30 kgC/ha/year. The total carbon loss from the watershed was 258.95 tonnes of C. The carbon loss from the watershed after conservation measures was reduced by 40%. Similar to before conservation measures, carbon loss after conservation measures was also classified into five classes (Table 9). It was found that area under very low carbon loss class (0-100 kgC/ha/year) was 44.44%. The remining area was classified as low (100–200 kgC/ha/year) carbon erosion area (32.94%); moderate (200–300 kgC/ha/year) carbon erosion area (13.65%); severe (300–400 kgC/ha/year) carbon erosion risk area (6.43%) and extremely severe (>400 kgC/ha/year) carbon erosion risk area (2.54%). The carbon loss values from the watershed are comparable to those found by Lense *et al.,* (2021) in the tropical watershed, which ranged from 0.16 kgC/ha/yr to 209.50 kgC/ha/yr.

Similar to the soil loss rate, the yearly carbon loss rate in the watershed prior to the conservation measures was 40% higher than the after conservation measures carbon loss rate. It was found that nearly 75% of the watershed area is now classified as very low to low carbon erosion risk after the implementation of conservation measures. The area under severe to extremely severe carbon erosion risk also decreases from 20% to 8%. The severe carbon erosion risk area is associated where there is spare vegetation cover and no conservation measures. The significant reduction of 60% was observed in the moderate carbon erosion class. It is evident that SWC measures not only help to conserve natural resources but also reduces carbon emissions from soil. This can be validated through comparison of SOC content before and after conservation measures given in (Table 8). The SOC content increased under each major land cover class following implementation of conservation measures. This is due to increased vegetation cover and reduced soil degradation in the watershed, achieved through proper natural resource conservation planning. Implementation of conservation measures increases the carbon sequestration capacity of natural resources. Therefore, soil and water conservation measures can be regarded as climate change mitigation measures. The study is useful for sustainable watershed planning in order to counteract future climate change challenges.

Conclusion

The average soil loss before conservation measures ranged from 0 to 78.73 t/ha, with an average of 18.68 t/ha/year, which is above the tolerable limit. The soil loss after conservation measures ranged from 0 to 53.24 t/ha/yr, with an average of 9.41 t/ha/yr, which is below the tolerable limit. Implementation of recommended conservation practices reduced soil loss by half compared to soil loss before conservation measures. Soil loss rate, organic carbon content, and carbon enrichment ratio were used to calculate the carbon loss associated with soil loss. The carbon loss from the watershed before and after conservation measures was 378.71 kgC/ha/yr and 205.52 kgC/ha/yr, respectively. Carbon loss from the watershed was reduced by 40% after conservation measures. The study found that USLE model coupled with GIS technique makes soil loss estimation simple and credible. It was observed that implementing recommended conservation measures reduces soil loss rate as well as carbon loss rate from the watershed. The conservation measures serve the dual purposes of protecting natural resources and reducing climate change. The remaining portion of the watershed, where there are no existing conservation measures, can be used to implement additional conservation measures. That will further cut down on soil loss and carbon loss in the watershed.

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Conflict of interest
The authors declare that they have no conflict of interest.

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