

Geospatial Analysis of Soil Erosion in the Nilgiris Region of Tamil Nadu, India Using Rusle and Gis

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Abstract—Soil erosion is a critical land degradation issue globally, caused by agricultural intensification, deforestation, and anthropogenic activities. This study applies the Revised Universal Soil Loss Equation (RUSLE) and Geo-information technology to evaluate soil erosion vulnerability in the Nilgiris district, Tamil Nadu. Spatial analysis of the annual soil erosion rate was conducted using GIS-based raster methods, integrating five key factors: R (rainfall erosivity), K (soil erodibility), LS (slope length and steepness), C (cover management), and P (conservation practices). Results classify soil erosion risks into five categories: Low (>5), Moderate (5–10), High (10–20), Very High (20–40), and Severe (40–80). The study area shows that 70.2% of the district has low erosion risk, 15.6% moderate, 8.1% high, 4.1% very high, and 2% severe erosion risk. The maximum soil loss observed is 55.3 tons/ha/year, with a mean annual soil loss of 0.22 tons/ha/year. Steep slopes, deforestation, and intensive agriculture significantly influence erosion patterns.

Index Terms—soil erosion, soil loss, erosion risk, RUSLE, remote sensing and GIS.

I. INTRODUCTION

One of the biggest issues with land degradation caused by water is soil erosion, which is a serious environmental risk on a global scale in the modern era. For many states, soil erosion and the resulting depletion of land resources are significant spatiotemporal processes [1][2][3]. Common agricultural methods in humid and semi-arid nations endanger the development of sustainable agricultural output and water quality in these regions and have detrimental effects on the environment due to soil erosion. Soil erosion in India has a significant impact on agricultural fields, degrades soils, and clogs up reservoirs that are being constructed around the country. To address the issue and stop more soil layer degradation, the government is implementing a variety

of strategies and initiatives. In India, 16.4 t ha (5334 m-tonnes) of soil are lost annually due to soil erosion [4].

According to [5], sheet erosion is India's biggest issue. Gully lands, changing agriculture areas, wasteland, and waterlogged areas are all significantly impacted by soil erosion. In that region, soil erosion began at a pace far higher than sedimentation, and it has since reduced reservoir and fertility, creating a national ecological issue [6][7]. The rate of infiltration and soil erosion are correlated; a higher rate of infiltration results in a lower rate of soil erosion. In India, water is the primary cause of soil erosion. This area competes with the rest of the globe during the monsoon season because to the intense rainfall. At this season, there is a lot of surface runoff, which washes topsoil and nutrients away. Because of this, less fertile soil is needed to cultivate crops, which lowers agricultural productivity and contributes to food insecurity and economic inequality among rural populations. Deforestation and uncontrolled building activities are to blame for the Himalayan belt's increased erosion danger. Soil erosion by water is predicted using the USLE model, while RUSLE follows the same idea but incorporates significant improvements in computation for different factors. An important and non-renewable resource on Earth is soil erosion, but in many areas, people do not consider the issues of land degradation and soil erosion, which renders large areas of the planet economically unproductive. As a result, those areas think about giving management and soil productivity more priority. In order to evaluate soil erosion hazard, geoinformation techniques are frequently used to assess soil loss for the entire region. More recently, high-resolution data has been made available to create a large-scale inventory of Digital Elevation Models (DEM), land use/land cover (LULC), and soil resource maps [8][9]. The aim of this

research was to use the RUSLE model and geoinformation technology to estimate the geographical distribution of yearly soil loss and to examine the impact of rainfall, land use, slope exposition, and terrace farming on soil erosion.

II. OBJECTIVE OF THE STUDY

- To analyze the effect of Rainfall, land use, slope exposition and terrace farming on soil erosion using RUSLE model and Geo information technology.
- To determine the spatial distribution of annual soil loss

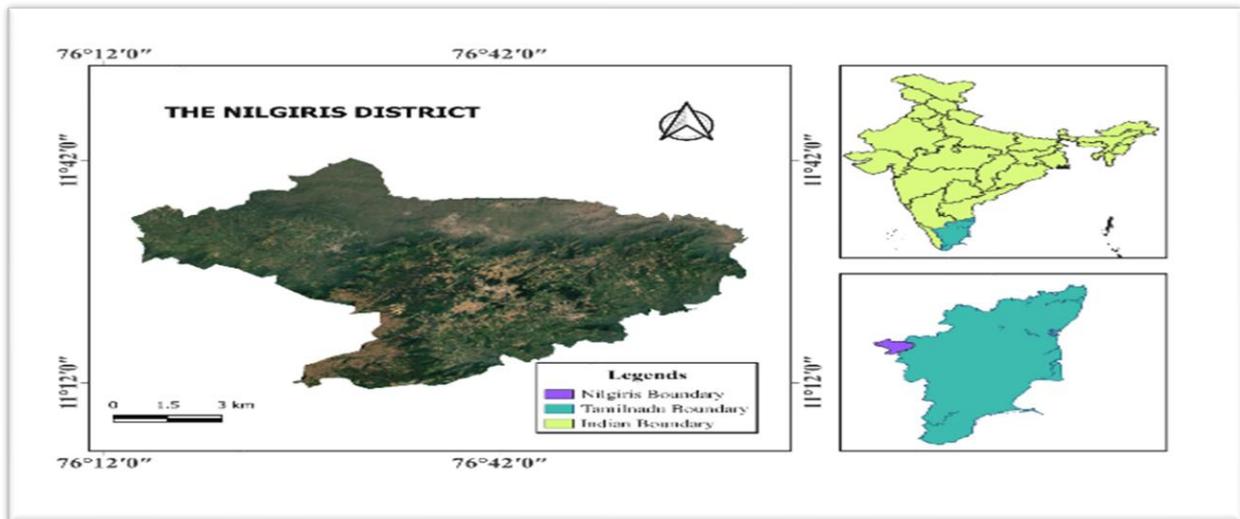
STUDY AREA

The Nilgiris district in India- another name would be Blue Mountains- is a district situated in the Western Ghats with Ooty (Udhagamandalam) as its administrative headquarters. It covers an area of 2,552.5 km² and has neighbouring districts like Coimbatore to the south, Erode to the east, ChamaraJanagar (Karnataka) to the north, Wayanad,

and Malappuram (Kerala) to the northwest and west of it.

The main topography of the district has steep mountains dotted with valleys and hollows and its highest point is Dodda Betta Peak (2637 meters). A very temperate climate, with a total annual average of 1920.8 millimetres of rain received, is susceptible to the southwest and northeast monsoons. The summers aren't very harsh, at a temperature of 10 to 25 degrees. Winters have pleasant weather, with a chill ranging from 0 to 20 degrees.

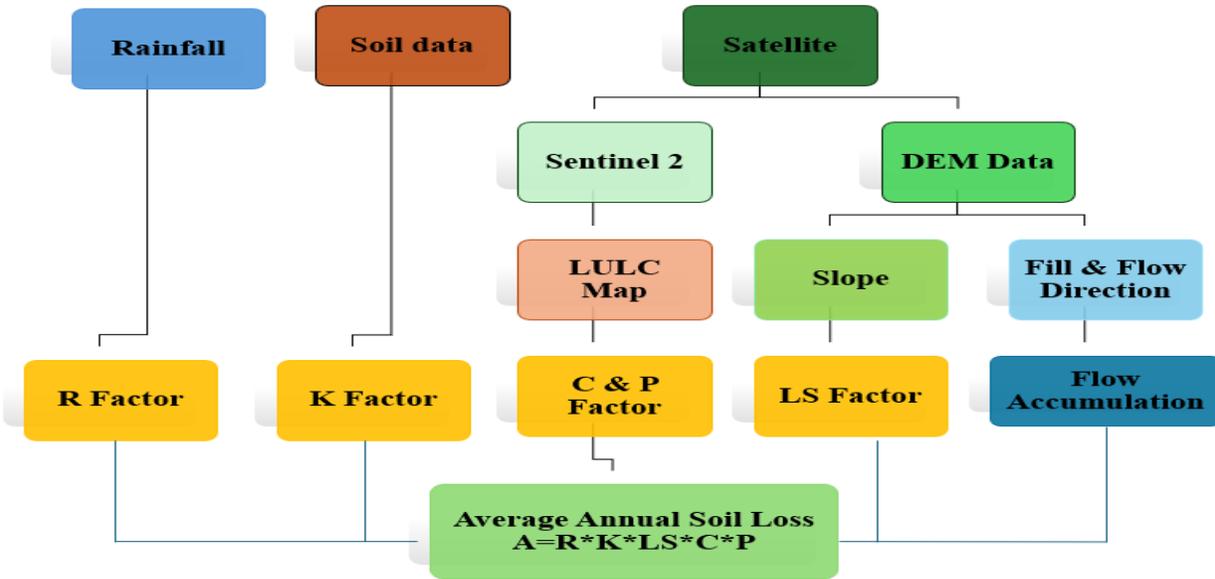
This significantly contributed to its result in turning much of the area into a tea and coffee-growing region. This is the area where agricultural practices are dominant. Tea, coffee, and horticultural crops like carrots, potatoes, and cabbage are abundant here, and the area consists of more forests, grasslands, and settlements. The district is characterized by its steep slopes, undulating terrain, and varying altitudinal zones ranging from 300 to 2,637 meters above sea level. These geographical features, coupled with climatic variations, have contributed to the development of distinct soil types such as red soils, lateritic soils, black cotton soils, and forest soils.



STUDY AREA MAP

III. MATERIALS AND METHODS

Detachment, transport, and deposition of soil due to wind, water, or human activity is known as soil erosion. Soil erosion causes environmental harm, loss of agricultural output, and land deterioration. There are numerous models and methods for estimating the hazards of soil erosion, and the RUSLE model and GIS approaches were used in this work to estimate and evaluate soil erosion.



IV. METHODOLOGY

DATA SOURCE

The information gathered from various data sources was utilized to assess the RUSLE factor and create the erosion hazard map. The following data sources were used: India and the soil data collected from the NBSS and land use planning centre, Tamil Nadu, rainfall data from the Centre for Hydrometeorology and Remote Sensing (CHRS), CARTO DEM (30 m Resolution) Bhuvan website, and Sentinel-2 data obtained from the Earth Explorer.

RUSLE PARAMETER ESTIMATION METHOD

The RUSLE parameters are generally used for both forest and agricultural region and assess for the average annual soil loss. It introduced and enhanced the soil erosion factor by [10]. The RUSLE model requires five major input factors R, K, LS, C & P these factors expressed in the calculation are

$$A = R * K * LS * C * P$$

Where

R is the factor for rainy runoff erosivity (MJ mm ha⁻¹ h⁻¹ y⁻¹); K is the factor for soil erosivity (ton/ha/h/ha1mm1); A is the average annual soil loss per chosen research area, expressed as tons per year; LS is the area slope and steepness; cover management is represented by C factor, which ranges from 0 to 1.5; conversion techniques are represented by the P factor, which ranges from 0 to 1.

RAINFALL EROSIVITY FACTOR (R)

Rainfall data and several researchers' R factors considered account in long-term average yearly rainfall were used to evaluate rainfall erosivity. Based on the causes of runoff, the force of "erosion" could quantify the level of erosivity in an area. According to the R factor, which is based on patterns of intermittent rainfall throughout the region, an area that is almost slope-grounded is considered to have low erosivity because water ponding prevents the soil particles from being eroded by the rainfall; as a result, it benefits from this rainfall.

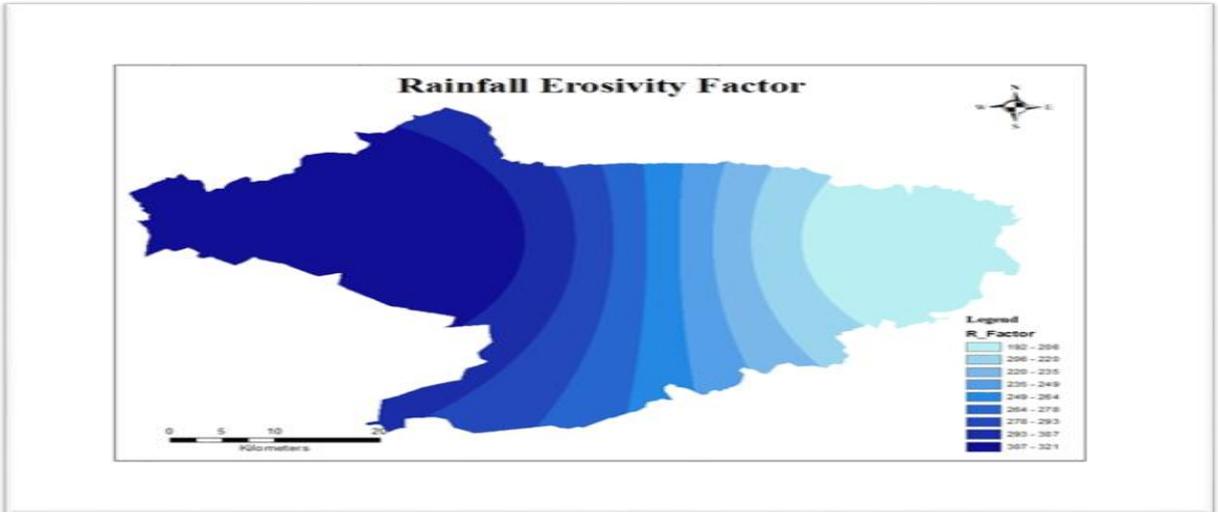
The rainfall erosivity factor (R) reflects the capacity of rainfall to cause erosion in an area based on its amount and intensity. It describes the influence of rainfall intensity on soil erosion; that is, it reflects the potential of rainfall to cause soil erosion. Generally, high-intensity, long-duration rainfall events produce the most erosive power and therefore, the greatest soil detachment and transport. The R factor can be derived from rainfall data that include the total amount of rainfall, its frequency, and intensity over time.

The derivation gives an idea about the effect of raindrop impact and addresses the amount and rate of runoff associated with rainfall erosivity (R) calculated by the equation. This equation and adopted by [10] were used to calculate the annual rainfall erosivity. The derived relationship is given below:

$$R = 79 + 0.363 * RN$$

Where

RN is the average annual rainfall in mm.

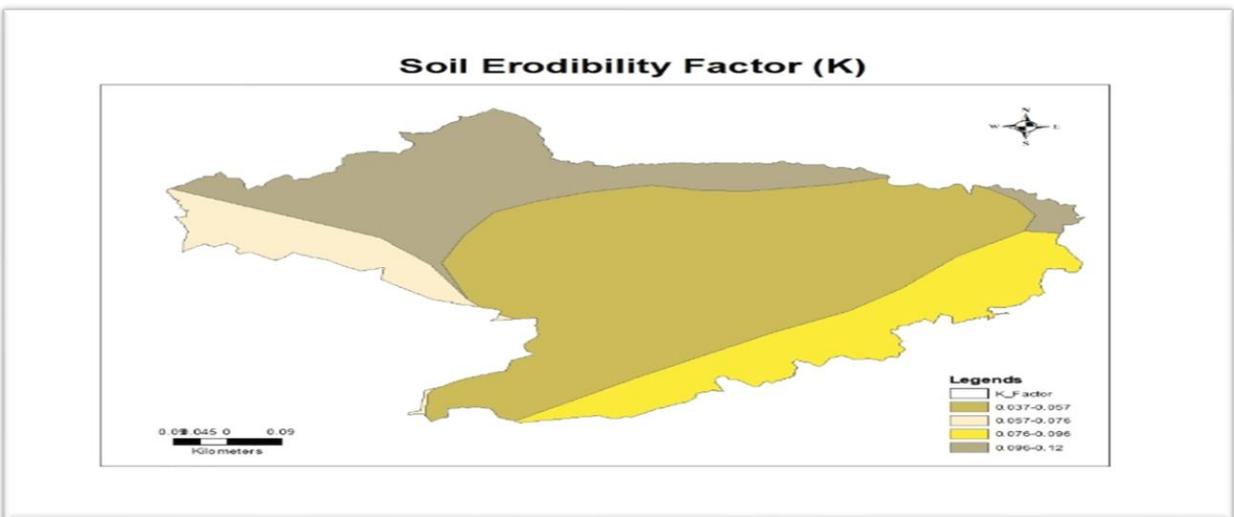


R FACTOR

SOIL ERODIBILITY FACTOR (K)

This variable shows how quickly certain soils disintegrate. Because of their physical makeup, certain soil types are inherently more vulnerable to soil erosion. Permeability, organic matter content, and soil texture all affect readability. To forecast the soil readability factor, a nomograph created by Wischmeier and Smith is frequently utilized. According to [11] soil erodibility is often influenced by soil and/or geological features, including texture, structure, parent material, organic matter, porosity, content, catena, and many more. Additionally, regardless of a correspondingly high percentage in the sand and clay fractions, soils with a low silt content

become less erodible [12]. Tamil Nadu's soil survey data was utilized to create the soil texture map used in this study for the K factor. Clay loam, clay, loamy sand, loamy, sandy clay, sandy clay loam, and sandy loam are the main soil textural types that are present in the regions. The K factor, which ranges from 1 to 0.01 and has an impact on the soil's infiltration capacity and structural stability, indicates that the region's soil has a very fine texture, such as silt or extremely fine sand [13]. Based on the permeability class, organic matter concentration, and particle size, the relevant K values for the different types of soil were determined using the soil erodibility nomograph (USDA 1978).



K FACTOR

SLOPE LENGTH & STEEPNESS FACTOR (LS)

The LS factor has a significant impact on soil erosion and is influenced by the area's slope length and steepness. They result in soil erosion on the topography, which includes the slope's length and steepness, which influence the pace of surface runoff [14][15]. According to [16][17][18] the RUSLE formula does not distinguish between rill and inter-rill in the S factor that calculates the impact of slope steepness on soil loss. A CARTO DEM (30 m Resolution) data set was used to create the research region Ls factor. The L-factor, which is a sub-component of LS, takes slope length into account inside RUSLE.

According to [19][20], slope length is the horizontal distance from the overland flow origin to the point where runoff gets concentrated into a defined channel or when the slope gradient drops to a point where deposition starts. The quantity of cumulative runoff increases with slope length. Additionally, larger runoff velocities that contribute to erosion occur on terrain with steeper slopes. [21][22] describe GIS-based techniques for determining the L and S factors, whereas [23][24] describe distinct approaches. Slope

gradient and LS factor maps were produced by processing the DEM. The largest elevation difference between each pixel and its eight adjoining pixels was used to determine the average slope of each pixel (in percentage terms). The empirical equation developed by Wischmeier and Smith is done by following equation:

$$LS = \frac{L}{S} mX(0.65+0.45 \times S+0.065 \times S^2)$$

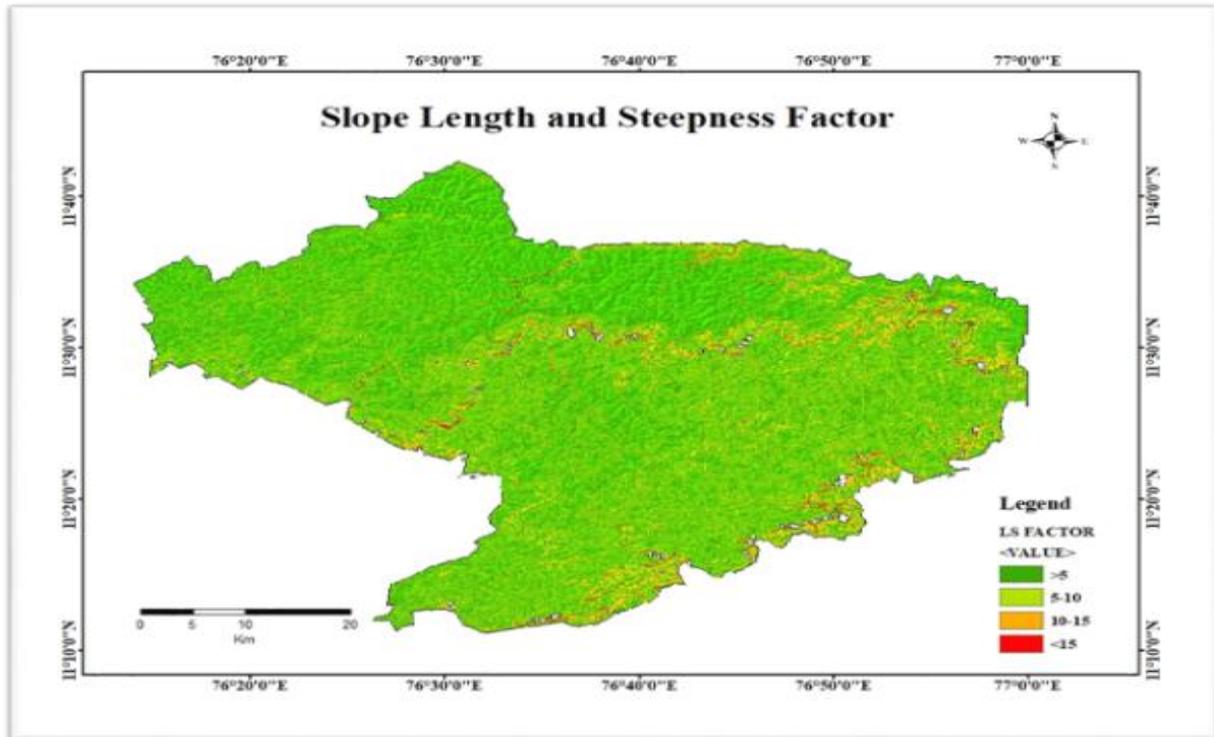
Where,

L – slope length (meters); S – angle of slope (percent); M – constant value dependent on the slope gradient 0.5 if the slope angle is greater than 5%, 0.4 on slopes of 3% to 5%, 0.3 on slopes of 1 to 3%, and 0.2 on slopes less than 1%. To implement LS factor in Arc GIS, the below formula of [26] was used.

$$LS = Pow\left(\frac{FA \cdot CS}{22.13}\right) 0.4X(0.65 + 0.45 \times S + 0.065 \times S^2)$$

where:

FA – Flow accumulation; CS – Cell Size.



LS FACTOR

COVER MANAGEMENT FACTOR (C)

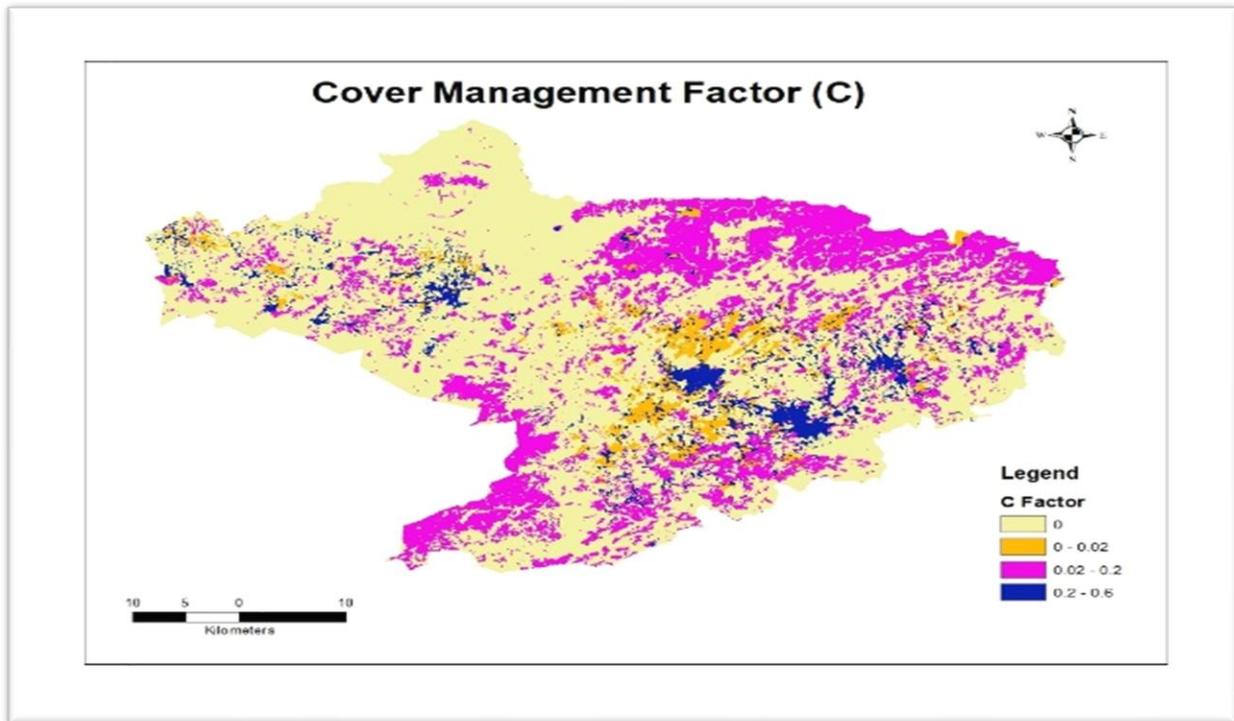
The C factor in the RUSSEL model describes how surface roughness and cover affect soil erosion. They are the most prevalent cover component. The impact of crops and management techniques on erosion rates was represented by this factor. The result of soil disturbing activities was the cover management factor (C), which was related to plant, crop sequence, productivity level, soil cover, and subsurface biomass in soil erosion. This factor is defined as the link between soil loss from cultivated land and fallow land under specific conditions [27].

According to [28], the C-factor shows how conservation programs would impact the average yearly soil loss and how that potential for soil loss will be dispersed over time during crop rotations, building projects, and other management strategies. Vegetation cover, slope steepness, and length factor all had a significant impact on soil loss [29]. Since there are a variety of land covers and spatial and temporal changes, a set of satellite data sets from different periods was used to prepare land use and land cover maps. The cover management factor was prepared based on land use and land cover conditions and the C value was assigned based on the Table.

Land use / land cover	P Value
Built-up	0
Water	0
Forest Scrub	0.2
Mixed Agricultural	0.5
Cropland	0.5
Plantation	0.5
Forest deciduous	0.7
Barren	0.1
Fallow land	0.9

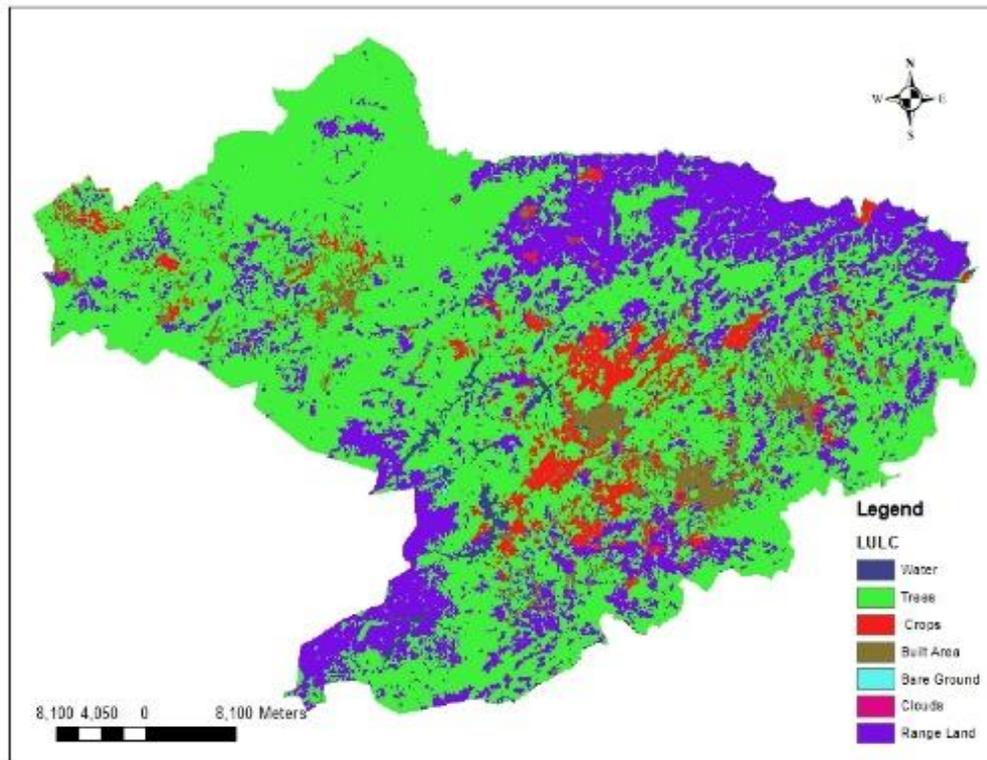
Supporting conservation practice factor range

A collection of satellite data sets from various eras were utilized to create a land use and land cover map because there are many distinct types of land covers as well as changes in space and time. The land use and land cover conditions were used to construct the cover management factor, and the table was used to assign the C value. Ponds, rivers, canals, dry rivers, and marshes are examples of water bodies that will see less erosion. As a result, they are given a very low value (e.g., 0.003); the likelihood of erosion in built-up areas can be regarded as zero. For that generation of the C factor map, the land use-land cover map has been reclassified according to the C-factor value.



C FACTOR

LANDUSE / LANDCOVER



LAND USE/LAND COVER

CONSERVATION PRACTICE FACTOR (P)

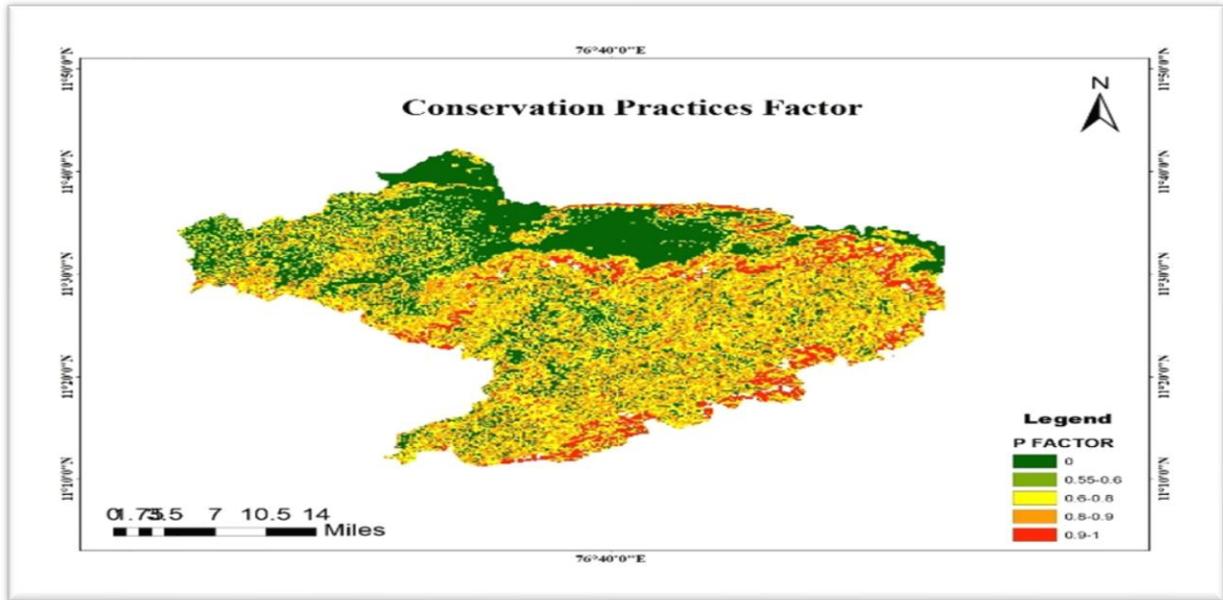
The conservation practice (P) factor is the ratio of soil loss from a certain support technology to the corresponding soil loss from up-slope and down-slope tillage [30]. The P factor describes specific management practices that affect the soil through drainage/flow patterns, contouring, and runoff velocity, hence reducing the probability of soil erosion from runoff [31][32]. The P factor ranges from 0 to 1, with the built-up land, plantation area with strip, and contour cropping zone having the lowest value and the forest, which is unmanaged, having the highest. Compared to the area with more successful management practices, the P value is lower.

The element of support practices P illustrates the results of surface management techniques used to lessen soil loss due to erosion. These techniques

include contour ploughing, strip cropping, and terracing, among others. The P factor value falls between 0 and 1, with 0 denoting the conservation practice's maximum effectiveness and 1 denoting the absence of any support practices or measures. The majority of conservation practices are used in artificial pastures or agricultural regions.

Slope (%)	Contour	Strip Cropping	Terraces
0-7	0.55	0.27	0.1
7-11.3	0.6	0.3	0.12
17.6 - 27	0.9	0.45	0.18
27>	1	0.5	0.2

VALUE FOR SUPPORT PRACTICE (P)



P FACTOR

V. RESULTS AND DISCUSSION

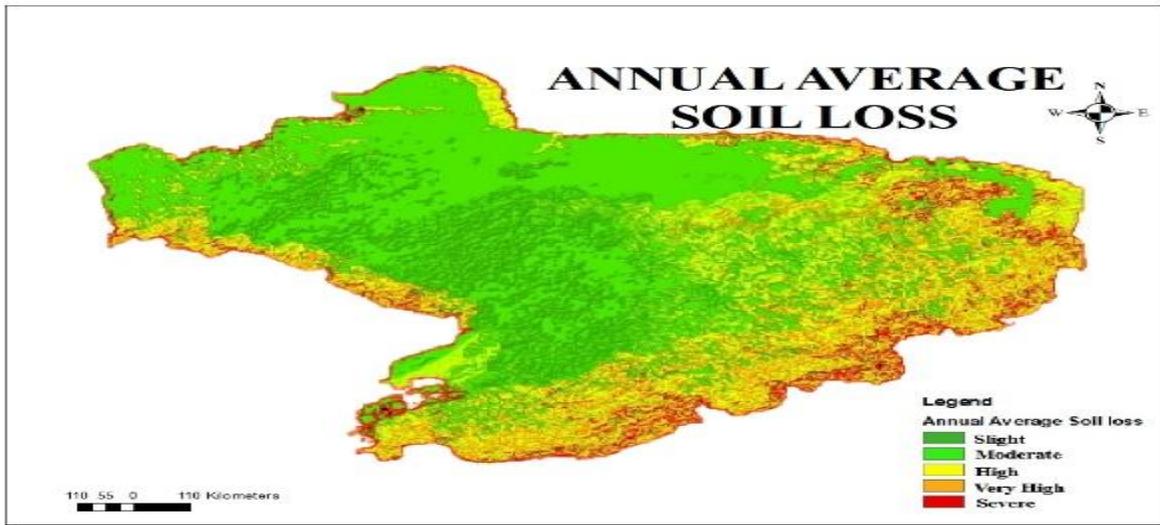
The RUSLE model uses geoinformation approaches to evaluate soil erosion concerns and optimize conservation strategies through disturbance, alternative, and spatial optimization. The conservative technique of creating a record is laborious, time-consuming, and difficult to manage. As a result, many theme components have been used in the RUSLE technique. The average annual rainfall (R) factor value was recorded in the range of Rainfall erosivity (R), with values ranging from 320 to 370 MJ.mm/ha/year observed in this study area, and soil erodibility (K) factor is recorded in the range of with values ranging from 0.037 to 0.12, which indicated moderate sensitivity of the soils, were important variables influencing soil erosion. In steep terrains, the slope length and steepness (LS) factor was considerably larger (>40), which exacerbated erosion in those regions. A key factor was land cover; plantations and forests had low cover management (C) values (~0.008), which reduced erosion, but bare lands with high C values (0.8) were more vulnerable. The efficiency of conservation practices (P) was proved by the decreased soil loss in areas using techniques like contour farming and terracing.

A geospatial investigation of soil erosion in the Nilgiris district was carried out using the RUSLE model in conjunction with GIS. The end product was a thorough soil erosion risk map that displayed the different levels of erosion in the area. Approximately 70.2% of the land (1,792.3 km²) was categorized as low risk, mostly in regions with moderate slopes that act as biological barriers against erosion and extensive forest cover. 15.6% (398.2 km²) of the region was categorized as moderately risky, mostly in regions with tea and horticultural crops where there is some natural protection. However, higher-risk regions that are less vegetated and more susceptible to soil loss are found on 8.6% of the land (220.0 km²) and 3.1% (80.0 km²), which represents areas that are extremely vulnerable to erosion due to their steep slopes and scant vegetation.

Lastly, the district's 2.4% (62.0 km²) most severely eroded area, with erosion rates surpassing 40 t/ha/year. These regions are mostly found in rocky, steep-topography, deforested places where excessive slopes and a lack of protecting vegetation worsen soil erosion. This classification emphasizes the necessity of focused conservation efforts, such as contour farming, terracing, and reforestation, to reduce the hazards of erosion and encourage sustainable land use.

Soil Erosion Severity Class (t/ha/year)	Average Annual Soil Loss Rate (t/ha/year)	Area (sq.km)	Area (%)
Slight	0-10	1792.3	70.22%
Moderate	10-20	398.2	15.60%
High	20-30	220.0	8.62%
Very High	30-40	80.0	3.13%
Severe	>40	62.0	2.43%

Soil erosion severity classes with average annual soil erosion rate



ANNUAL SOIL LOSS MAP

VI. CONCLUSION

The RUSLE and GIS techniques have been used to estimate and geographically distribute soil erosion in the Nilgiris district. Five distinct erosion risk groups are used to categorize the soil loss map. The analysis indicates that 398.2 hectares (15.6%) of the study area, which are primarily found in agricultural lands, are in the moderate erosion risk category, whereas 1,792.3 hectares (70.2%) have low erosion risk. About 362 hectares (14.2%) of the district have high and extremely high erosion risks, especially in areas that are deforested and have steep topography. The majority of 51 hectares (2%), which are mostly covered by severe erosion, are found in rocky, forested areas. For the purpose of properly managing soil and forecasting conservation actions, the average annual soil loss map is essential. Terracing and contour

farming are two methods of soil protection that local farmers are encouraged to use. To reduce erosion and improve soil productivity, planners and decision-makers must give both short- and long-term natural resource management including afforestation and sustainable land use policies top priority.

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