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Soil Erosion Assessment For Northern Kerala Utilizing Rusle Method And Gis Techniques

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Abstract:
Soil erosion represents a critical factor contributing to environmental degradation and the depletion of natural resources. This research targets a potentially susceptible region in Northern Kerala and seeks to analyze and forecast the rate of soil erosion employing Geographic Information System (GIS) and remote sensing methodologies. The Revised Universal Soil Loss Equation (RUSLE) framework is utilized to examine essential parameters associated with soil erosion. This methodology is highly accurate and dependable, involving the detailed assessment of factors such as R, K, LS, C, and P derived from local precipitation, topography, soil classification, and satellite imagery. The findings of this study indicate that soil loss is projected to range from 2.5 to 25 tons per hectare per year within the study area. Grasping this information is vital for enhancing soil conservation strategies, augmenting soil fertility, maximizing crop yield, improving water quality, managing disasters, and addressing other related factors. The investigation integrates GIS with RUSLE to evaluate pixel-based soil erosion rates across five districts encompassing an area of 12,995 square kilometers. The vicinity of the Western Ghats in this region renders it susceptible to soil erosion, resulting in natural calamities such as landslides.
Keywords: *GIS, RUSLE, Northern Kerala, Soil erosion, Western Ghats.*

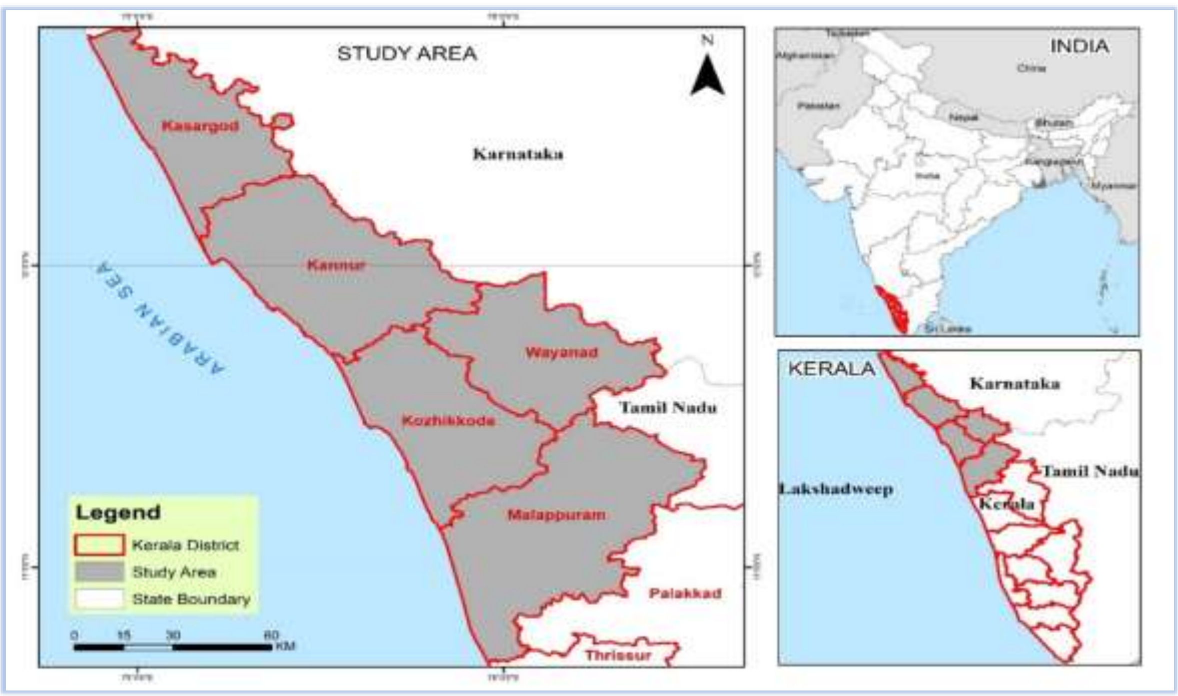
INTRODUCTION

Soil is the most crucial natural resource, directly focusing on sustainability worldwide. Erosion has been globally considered a serious environmental problem from the initial stages of the agricultural revolution. Soil erosion has also been referred to as a process of land degradation, affecting the production of food, ecosystems, and agricultural land utility(1). Estimations of yearly soil loss serve as valuable tools for comprehending the fundamental erosion in a watershed, while estimations of soil loss within a year and based on specific events are valuable for clarifying the temporal changes in erosion(2). An estimate of 22 to 100 tons per hectare of topsoil is lost per year, as per reports worldwide, thereby leading to a decline in productivity by 15 – 30 per cent annually. In India, about 91% of the entire geographic area is classified into five erosion categories, and the potential soil erosion rates range from less than 5 to 40 tons per hectare per year (3).The effects of soil erosion have further led to an estimated 30 – 40 billion USD being spent (4). Reversing effects of soil erosion and its related effects have been prioritized to attain sustainability and food security(5). Numerous biophysical factors modify the process of soil erosion. These include ground cover, climate, soil, terrain, runoff, slope-related aspects, and infiltration components, along with their interactions with each other(6). It is also observed that unconventional land use practices adversely affect soil and the environment(7). Soil erosion can be studied using various models, which use mathematical expressions to relate prevalent parameters involving the processes that happen on the surface of land. Erosion models can be physically or empirically based, and their efficacy depends upon the chosen parameters and approach. A catchment is usually represented in conceptual models as a string of internal storage. These models outline the general processes that underlie sediment and water movement between various storages(8).

The USLE forecasts the average yearly erosion rate on a field slope over the long term by considering the pattern of rainfall, type of soil, topography, crop system, and soil erosion factors affected by management practices(9).By identifying the areas in the baseline scenario that are susceptible to soil erosion, prospective rates of erosion, and potential causes of soil erosion, soil erosion models help with land management. They vary in complexity from more intricate physics-based models to comparatively straightforward empirical and conceptual models(8). The Revised Universal Soil Loss Equation (RUSLE) is a widely accepted empirical model for determining soil loss by erosion. The base of this is the USLE model, which was designed and established by scientists and conservationists who have had immense exposure in the field of soil erosion(10). In estimating soil loss in undisturbed areas with disturbance on land surface, reclaimed lands and overland flow, this model constitutes the most acceptable technique(11). This model is adaptable for use in unprecedented catchments and can be synchronized with GIS techniques for upscaling the process of erosion(12). Recent advances in land resource management have integrated spatial information technologies to monitor and analyze resource usage(13). Geographic Information System (GIS) has been proven effective in managing variations in parameters related to soil erosion, such as heterogeneous topography, geology, geomorphology, soil types, and usage. The database created through GIS utilizes interpolation techniques to map and model soil erosion. This technology also makes it easier to manage large datasets, allowing for better land management based on soil loss rate estimates(14). Advanced geospatial tools can provide critical information for implementing soil conservation plans(15).

Study Area

The geographical characteristics of Kerala comprise a warm and humid coastal plain that gradually rises to the lofty hills and mountains of the Western Ghats (16).The region selected for this soil erosion investigation in India includes five districts located in Northern Kerala, which are adjacent to the Western Ghats. These five districts are Malappuram, Kozhikode, Wayanad, Kannur, and Kasargod. This area covers approximately 12,988 square kilometers. Research pertaining to soil erosion in this segment of Kerala has not been conducted extensively. Therefore, it holds the potential to enhance the analysis and forecasting of significant parameters associated with soil erosion. The region of investigation is illustrated in (Fig 1). It is noted that this area demonstrates a moderately wet climate characterized by rugged terrain. The average temperature within the study area fluctuates between 20 and 38 °C. A significant portion of the area exhibits an undulating topography. Precipitation in this region predominantly occurs between May and August, with minimum and maximum values recorded at 759 and 1920 cm, respectively, according to data gathered from 2017-2021. The soil texture primarily consists of gravelly clay and clay with low permeability. The topography of the study area shifts from flat plains to steep hills, with elevations varying between 10 and 2570 meters. This region includes agricultural fields, forests and urban development. Vegetation is quite diverse, showcasing dense forests in the elevated areas and agricultural landscapes in the lowlands.

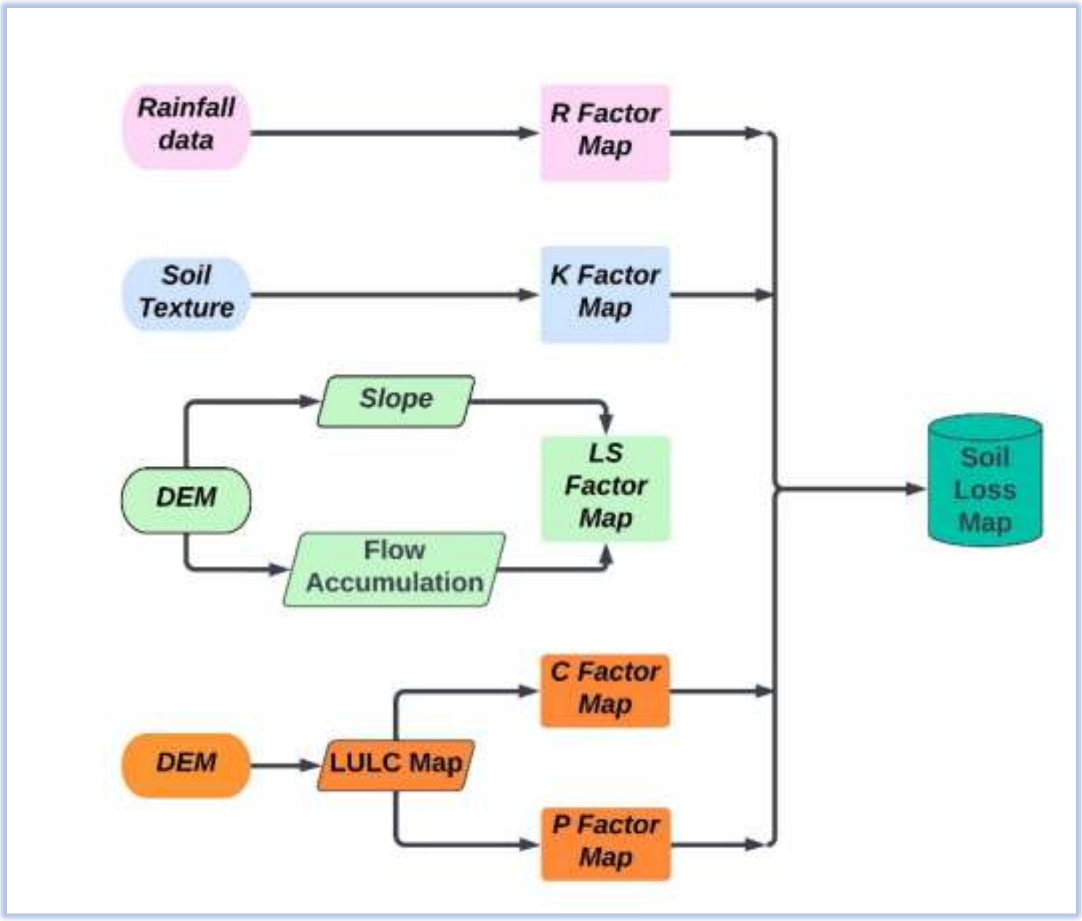


(Fig 1: Study Area)

Materials And Methods

Rusle model

Soil erosion studies in Northern Kerala were assessed using the RUSLE method. In 1978, Wischmeier and Smith developed the RUSLE method. This procedure has proven to be widely established and authentic in estimating soil loss characteristics to an acceptable range of accuracy. Its compatibility with GIS-enabled systems gives a wider range of applications of available data. The methodology used in this study is illustrated in Fig. 2.



(Fig 2: Methodology)

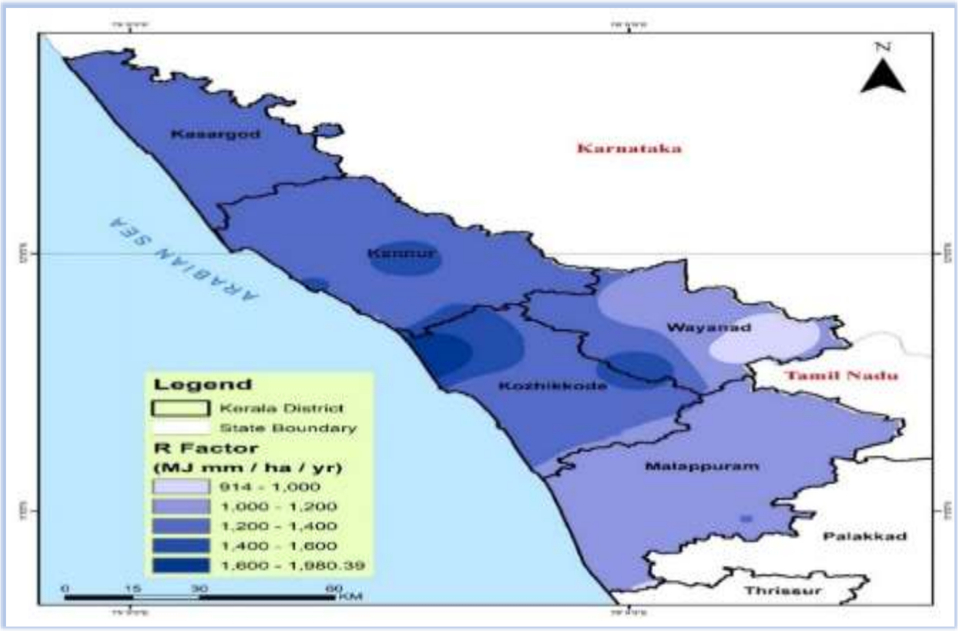
Estimation of soil loss

RUSLE employs a formula integrating five spatial and temporal parameters. The annual average soil loss equation is articulated as

$A = R \times K \times LS \times C \times P$

(1)In this equation, R stands for rainfall-runoff erosivity measured in MJ-mm/ha/h/year, K refers to soil erodibility expressed in t ha h/ha/MJ/mm, LS represents the combination of slope length and steepness as a dimensionless parameter, C shows the impact of cover management, and P indicates practices for controlling erosion, both of which are dimensionless factors. The integration of GIS with RUSLE was implemented to evaluate annual soil erosion in the designated study area. Data for this investigation was sourced from multiple origins. Precipitation information was obtained from the Indian Meteorological Department, encompassing a comprehensive five-year rainfall dataset. Soil texture data was gathered from the soil survey department, while geological data was obtained from the land use board to ascertain the soil erodibility factor (K). A 30-meter resolution Digital Elevation Model was utilized to compute the slope length and steepness factor (LS). Land cover data was collected from Sentinel II satellite imagery and classified through remote sensing techniques to identify the cover management factor (C). P factor values were determined for various land use categories based on the land cover data of the area.

(Fig 3: R Factor Map)



Rusle factors

The following significant parameters formed the basis of the prediction of soil loss based on the RUSLE method.

Rainfall Erosivity (R)

Rainfall in a designated region and of a specified character demonstrates an erosive capacity that is contingent upon the intensity, duration, and volume derived from either a singular event or a succession of storms. Uncultivated soil surfaces illustrate the occurrence of splash or raindrop erosion. The measurement of rainfall erosivity is determined by the volume, intensity, and spatial distribution of precipitation. The R factor incorporates the kinetic energy associated with the rainfall. An increase in kinetic energy signifies a greater likelihood for soil particles to be dislodged and transported. The R factor, which represents the erosivity of rainfall-runoff, shows significant variability across various geographic locales due to the differing climatic conditions. Scholars have developed numerous empirical equations based on historical rainfall records to quantify this factor (2). The R factor exhibits variability influenced by spatial and temporal scales across climatic zones and seasons. In tropical and subtropical regions, high-intensity storms increase the R factor, elevating soil erosion risk. In contrast, arid or semi-arid areas may have a lower R factor, yet intense storms can cause significant erosion. Long-term rainfall intensity data provide the most precise R-value estimates, although monthly precipitation records also yield reasonable results globally (17). The R-factor computation is based on the (18), equation, which has been further refined.

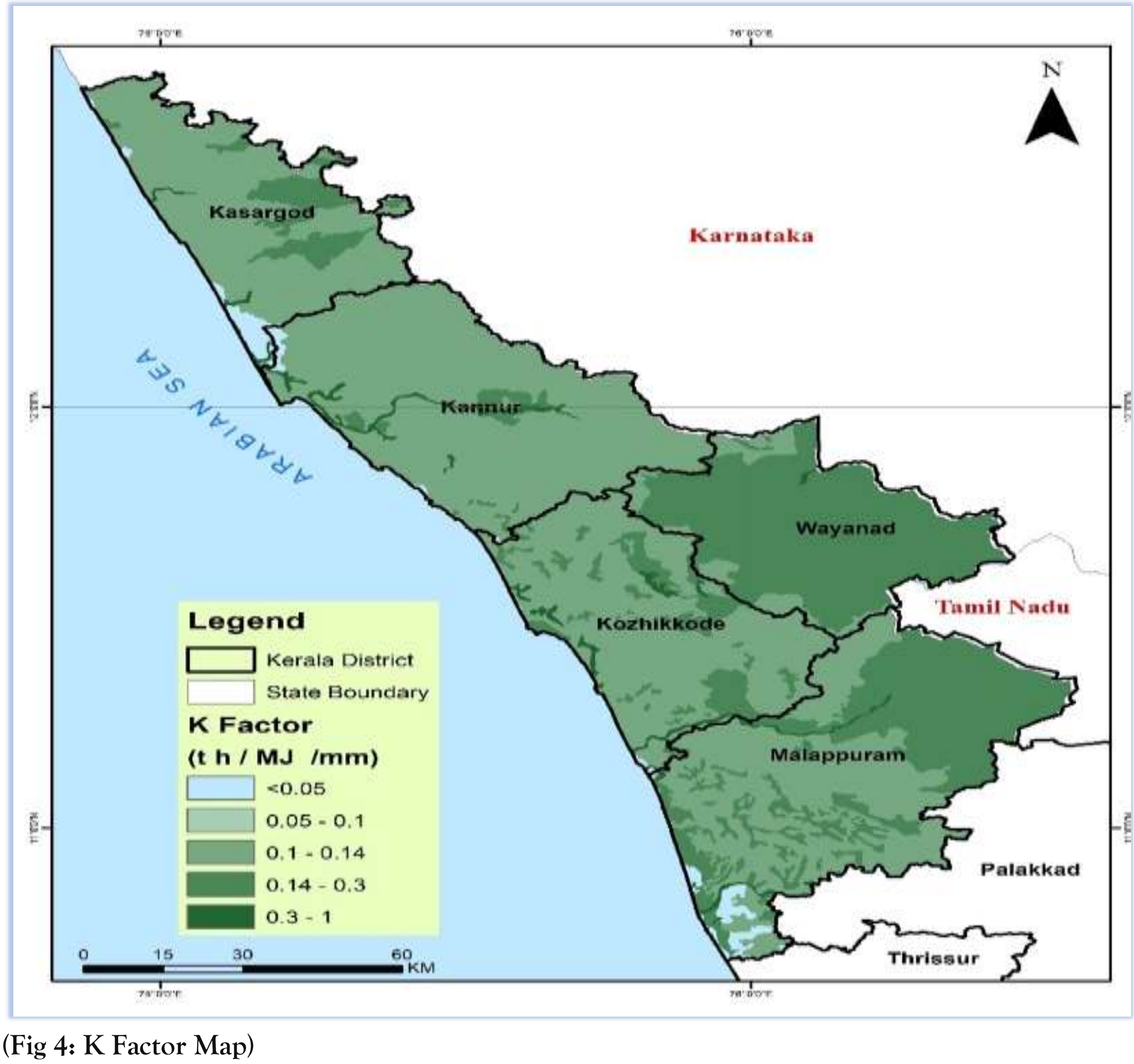
$$R=\sum_{i=1}^{12} 1.735 \text{ X } 10^{\left(1.5\log_{10}\left(\frac{Pi^2}{P}\right)-0.08188\right)} \qquad (2)$$

R represents the rainfall erosivity factor measured in MJ mm /ha /h /year. Pi and P denote monthly and annual rainfall in mm, respectively. Rainfall data spanning five years (2017-2021) were sourced from the Indian Meteorological Department to compute the R Factor as per Eq 2. The region showcases a notable annual average precipitation between 759 and 1920 mm. The R-factor variation was analyzed utilizing the spatial analyst function in ArcGIS. Rainfall data from gauge stations within and adjacent to the area were subjected to interpolation. The R-factor values for this region range from 914 to 1980 MJ mm /ha /h /year (Fig.3).

Soil Erodibility Factor (K)

The inherent resistance and vulnerability of various soil types to erosion are contingent upon several factors, including grain size characteristics, sediment transport efficiency, organic matter content, structural integrity, textural composition, drainage capabilities, and cohesiveness. The evaluation of geological formations' resistance to erosive forces is conducted through the K factor, which fluctuates based on texture, infiltration capacity, aggregate stability, as well as chemical and organic composition (19). The K factor quantifies the susceptibility of soil particles to detachment and transport resulting from rainfall and surface runoff, with elevated values signifying a heightened vulnerability to erosion (17). Soils characterized by a significant content of silt or fine sand, minimal organic matter, and suboptimal structure typically exhibit elevated K values, indicating an increased vulnerability to erosion. Conversely, soils enriched with clay or those exhibiting aggregate stability generally possess lower K values, thereby enhancing their resistance to erosive forces.

Several approaches are available for calculating the K-factor, mainly using a nomograph or the equation from Wischmeier and Smith (20). A comprehensive soil texture map was acquired from the land use board to aid in analyzing soil properties and calculating the K factor. Soils are divided into five textural categories: clay, gravelly clay, gravelly loam, loam, and sandy. K values for each category were obtained from soil erodibility data (USDA 1978) based on the specified soil characteristics. The estimated K values for these textural categories range between 0.13 and 0.30 t ha h ha^{-1} MJ^{-1} mm^{-1}, with gravelly loam at 0.13, clay at 0.22, loam at 0.30, gravelly clay at 0.14, and sandy soil at 0.05. The K factor for the area being analyzed ranges from 0.05 to 1 t ha h ha^{-1} MJ^{-1} mm^{-1}, as illustrated in Fig. 4.



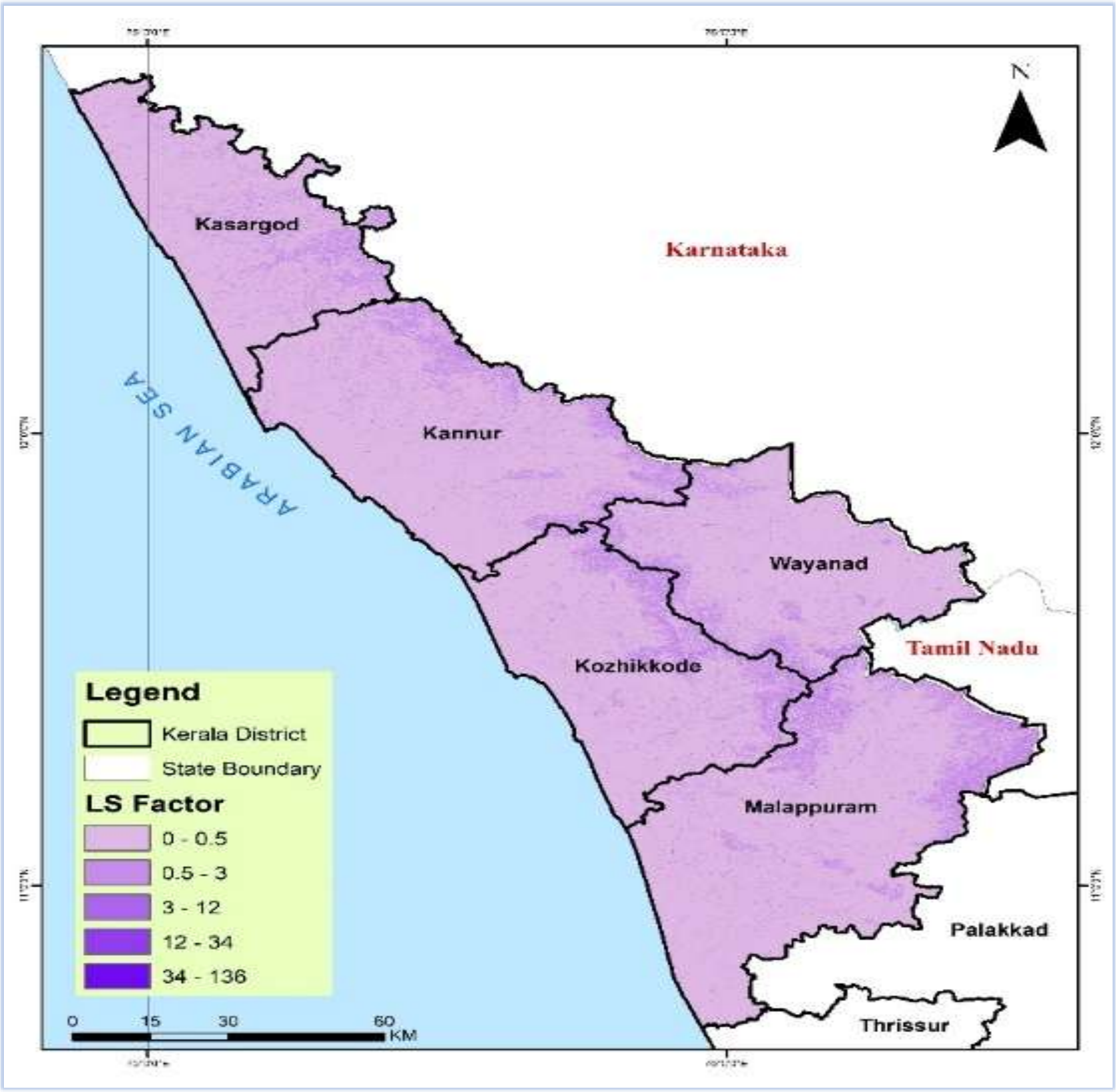
(Fig 4: K Factor Map)

Slope length and Steepness factor (LS)

In the RUSLE equation, the LS factor quantifies topographical influences on soil erosion. Increased slope length (L) correlates with heightened soil erosion due to runoff accumulation. Similarly, greater slope steepness (S) enhances runoff velocity, thus increasing erosivity. The LS factor is derived from both slope length and steepness, utilizing ArcGIS spatial analyst extension based on DEM, as articulated in equation 3 by (21). The LS factor computation does not distinguish between rill and interill erosion.

$$LS=\left[\text{flow accumulation} * \frac{\text{cell size}}{22.13}\right]^{0.4} * \left[\frac{\sin \text{slope}}{0.0896}\right]^{1.3} \quad (3)$$

Here, LS represents the combined slope length and steepness factor, with flow accumulation indicating the upslope contributing area and cell size denoting the grid dimension, set at 30 m for this study, while sin slope reflects the slope degree. The LS calculation takes into account the parameters of flow accumulation and slope steepness. DEM facilitated the computation of flow accumulation and slope steepness through the ArcGIS spatial analyst tools. Within the study area, the LS factor ranges from 0 to 136, as shown in the map in Fig. 5. These graphical representations highlight areas where the interplay of slope length and steepness presents significant risks to soil stability. Such spatial analyses play a crucial role in comprehensive land use planning, helping to prioritize erosion control efforts in areas at high risk.



(Fig 5: LS Factor Map)

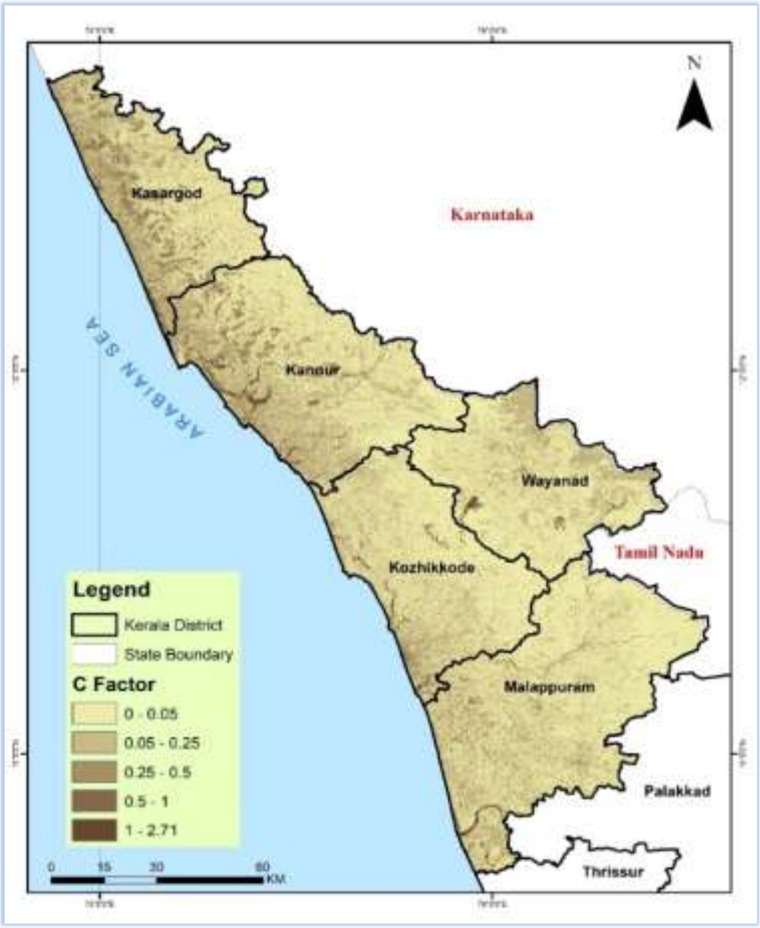
Cover Management Factor (C)

The C factor significantly influences soil erosion risk alongside topography. It encompasses vegetation cover, cropping impacts, crop rotations, and subsurface biomass effects. Increased vegetation cover correlates with reduced soil loss. This relationship is represented as a ratio comparing soil loss under specific conditions to that from clean tilled fallow(18).One methodology for determining the C factor utilizes the normalized difference vegetation index (NDVI) derived from satellite data. The NDVI is a dimensionless measure reflecting the variance between visible and near-infrared light reflected by vegetation. The C factor for the study area was determined using NDVI data obtained from Sentinel II satellite images, calculated through the following equation (9)(22).

$$C = \exp\left[-\propto \frac{\mathrm{NDVI}}{\beta - \mathrm{NDVI}}\right]$$

(Fig 6: C Factor Map)

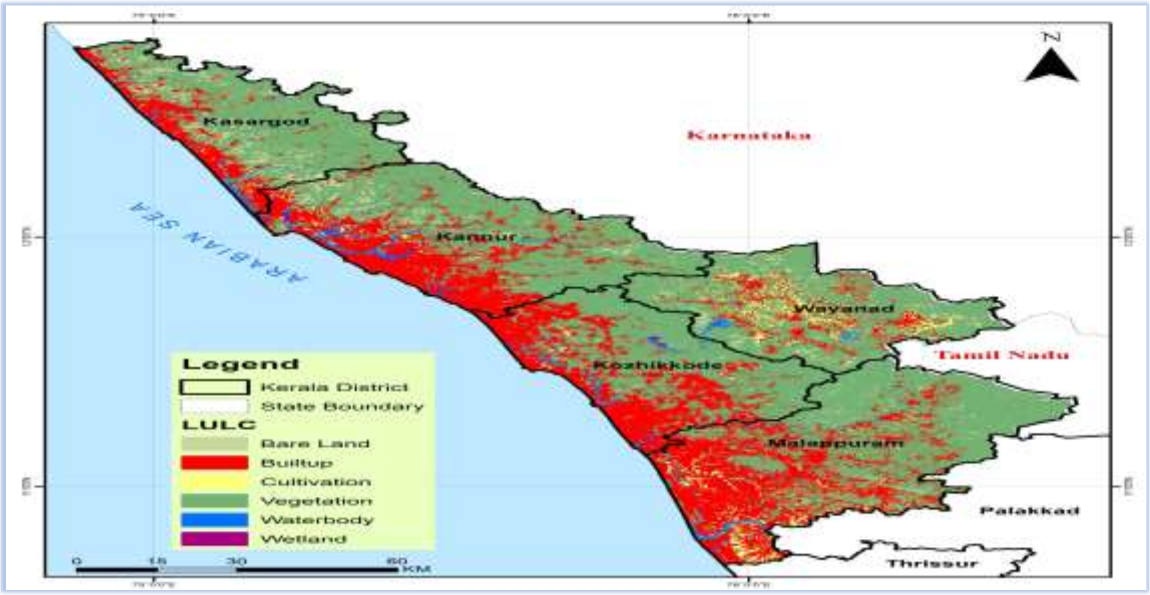
Here alpha and beta are parameters which are unitless. They aid in prediction of the shape of the curve relating to NDVI and C factor. It was observed by (23) that this scaling approach gave superior results as to assumption of a linear relationship using values 2 and 1 for alpha and beta parameters respectively.



The C factor for the study area ranges from 0 to 2.71 as shown in Fig 6. Lower C values indicate the presence of protective vegetation or effective management practices, which help to lower the risk of soil erosion.

Conservation Practice Factor (P)

The support practice factor P measures the soil erosion caused by specific management techniques. It encompasses methods that alter flow patterns, including contouring and terracing. This value derives from land use and cover shown in Fig 7, in relation to support practices like slope tillage. Primary erosion control methods investigated include contour farming, strip cropping, and subsurface drainage (24).The P value varies from 0 to 0.5, with the highest for areas lacking conservation and the lowest for land with effective crop patterns. The P factor map was created utilizing land use data and support elements (18), with values between 0 and 1, as shown in Table 1. Lower P values indicate superior conservation efforts, as depicted in Fig. 8.



(Fig 7: LULC Map)

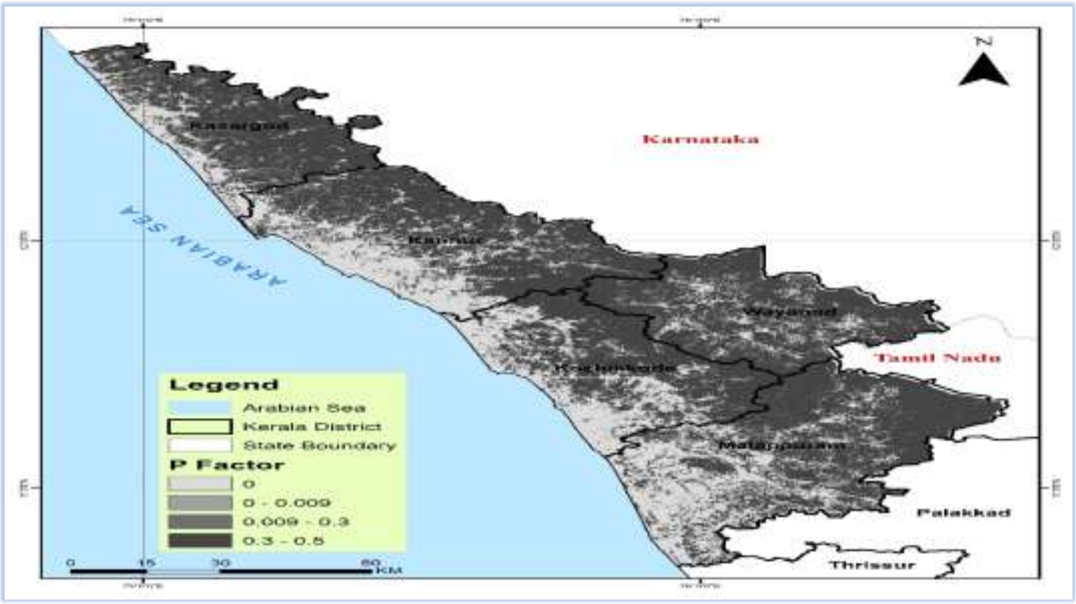
Table 1. Landuse / Landcover – P Value

Land use / Land cover	P Value
Bare land	0.01
Built-up land	0
Cultivation	0.5
Vegetation	0.3
Waterbody	0
Wetland	0.01

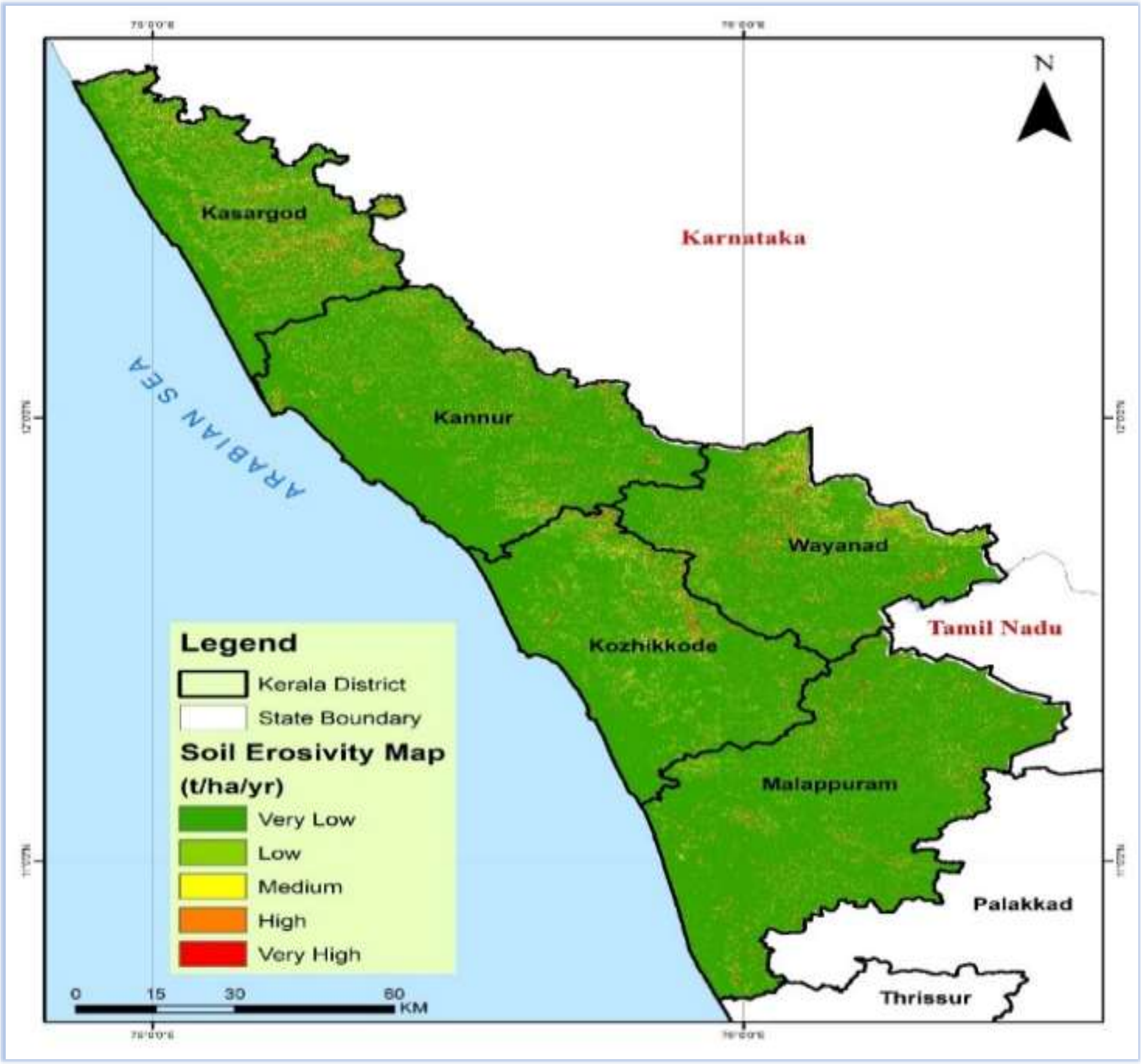
(Fig 8: P Factor Map)

RESULTS AND DISCUSSION

This study of soil erosion based on RULSE approach model incorporating GIS techniques evaluates the susceptibility to soil loss of five districts in Northern Kerala. The probability of soil erosion and soil loss



aids effective management of resources and optimum utilisation of agricultural land. The data gathered and examined is based on the calculation of the spatial average soil loss pertaining to five essential factors R, K, LS, C, and P, based on the RULSE equation. ArcGIS spatial analyst data was integrated for assessment and quantification of the rate of soil erosion. The soil erosivity map prepared using this model gave erosivity rate for the soil varies very low from 0 tonnes/hectare/year in low and plain areas to a very high value greater then 25 tonnes/hectare/year in highly steep regions of the study area as shown in Fig 9 and Table 2.



(Fig 9: Soil Erosivity Map)

Table 2. Erosion class and Rate

Erosion Type	Erosion Rate (t/ha/yr)
Very Low	0-2.5
Low	2.5-5
Medium	5-10
High	10-25
Very High	>25

Upon examining and assessing the various factors using the RUSLE model, it was determined that soil erosion ranges from a very low level of 2.5 t/ha/yr to a very high level exceeding 25 t/ha/yr. Upon comparing these findings with similar studies carried out in other regions of the Western Ghats, it validated the appropriateness of utilizing this approach for the area being studied. The results, when juxtaposed with regions exhibiting comparable environmental and rainfall conditions, were notably similar. Research undertaken in the aftermath of the Kerala floods in 2018 points to a notable rise in average soil erosion, recorded at 56.23 metric tons per hectare each year, which is greater than both the pre-flood average of 31.79 metric tons per hectare yearly and the post-flood average of 30.01 metric tons per hectare annually across Kerala. This marked increase in erosion necessitates immediate attention and intervention (16). According to the research carried out (25) regarding soil erosivity in Kerala, the findings revealed that 51.98 percent of the state falls within the slight soil loss category of 0-5 t/ha/yr. Furthermore, 2.36 percent of the land is categorized as severe with losses ranging from 20-40 t/ha/yr, while 0.09 percent falls into the very severe category of above 40 t/ha/yr. The assessment of soil erosion severity across different zones considers the relevant field conditions. It was discovered that 96.53% of northern Kerala is classified as having a very low potential risk for erosion. The total erosion rates in low and medium risk areas account for 2.64%, whereas the rates in high and very high-risk areas total 0.80%, as depicted in Figure 8. These rates align with the observed and calculated spatial distributions.

CONCLUSION

A comprehensive analytical examination of soil erosion and soil loss features in five districts of the Northern Kerala area adjacent to the Western Ghats uncovers the possibility and intensity of yearly soil loss determined by essential factors. This evaluation employs the RUSLE method, which integrates topographic, rainfall, soil, cover factors, and GIS spatial data to ensure accuracy and dependability. The combination of GIS with RUSLE has demonstrated its effectiveness in predicting soil loss, which results from a variety of influences. The region under study displays rolling terrain, primarily defined by elevated hills and a high plateau featuring steep inclines. The main types of land cover consist of tea plantations and forested areas. The numerical results obtained from the RUSLE equation, analyzed within a GIS framework, show that the potential for soil erosion varies from 0 to 25 tons per hectare each year. Approximately 96.53% of the total area is categorized as having a very low risk of significant erosion, whereas 3.43% of the overall area faces erosion rates that fall between low and very high severity. These results are consistent with earlier erosion studies carried out by scholars. They aid in forming essential data for soil and water conservation, providing a focused strategy to tackle the potential threats linked to erosion, landslides, and overall environmental sustainability.

Author Contributions

S. Babu: Conceptualization, Methodology, Original Draft Preparation, Software, Writing, Data Processing.
Rm. Narayanan: Data Curation, Data Analysis, Methodology, Original Draft Correction, Reviewing And Editing, Overall Supervision.
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Conflicts Of Interest: The authors state that there are no conflicts of interest.

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