IDENTIFICATION OF HYDROLOGICALLY SENSITIVE AREAS IN VALANCHERY WATERSHED

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PROJECT REPORT

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DECLARATION

We hereby declare that this Project entitled "**IDENTIFICATION OF HYDROLOGICALLY SENSITIVE AREAS IN VALANCHERY WATERSHED**" is a Bona fide record of the project work done by us during the course of study and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of another university or society.

Date: 31/05/2025

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CERTIFICATE

This is to certify that the project entitled "**IDENTIFICATION OF HYDROLOGICALLY SENSITIVE AREAS IN VALANCHERY WATERSHED**" is a record of the project work done jointly by **Mr. ARJUN K (2020-02-009), Ms. ASHALAKSHMI M S (2021-02- 005) and Ms. SWATHY SURESH (2021-02-023)** under my guidance and supervision and that it has not been previously formed the basis for the award of any degree, diploma, fellowship or associateship or other similar title of any other university or society to them.

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SYMBOLS AND ABBREVIATIONS

%	:	Percentage
&	:	And
<	:	Less than
=	:	Equal to
>	:	Greater than
ARAS	:	additive ratio assessment
CC	:	collocated cokriging
		Centre
cm	:	Centimeter
COPRAS	:	complex proportional assessment
DEM	:	Digital Elevation Model
et al.,	:	And others
etc.	:	Etcetera
Fig.	:	Figure
gcm^{-3}	:	Grams per cubic centimeter
GIS	:	Geographical Information System
GPS	:	Global Positioning System
h	:	Hour
ha	:	Hectare
HSA	:	Hydrologically Sensitive Areas
IDRB	:	irrigation design and research
IDW	:	Inverse Distance weighted

IMSD	: Integrated Mission for Sustainable Development
KED	: kriging with external drift
Km^2	: Square kilometres
K_s	: saturated hydraulic conductivity
KSREC	: Kerala State Remote Sensing and Environment
L	: Litre
LIDAR	: Light Detection And Ranging
LRSE	: Lowest Residual Standard Error
LULC	: Land Use Land Cover
m	: Metre
m^3	: Cubic meter
MCDM	: multiple criteria decision making
MDD	: maximum dry density
MFD	: multiple flow direction
mg	: Milligram
mm	: Millimetre
MSL	: mean sea level
N	: North
NDVI	: Normalized Difference Vegetation Index
OK	: ordinary kriging
OM	: Organic Matter
OMC	: optimum moisture content
R^2	: residual standard error
SFD	: simple flow direction
SOC	: soil organic carbon

SOM	:	soil organic matter
SPI	:	Stream Power Index
SRTM	:	Shuttle Radar Topography Mission
SSURGO	:	Soil Survey Geographic Database
STI	:	Soil Topographic Index
t	:	Tonnes
TPI	:	Topographic Position Index
TRI	:	Topographic Ruggedness Index
TWI	:	Topographic Wetness Index
USGS	:	United States Geological Survey
VSA	:	variable source area
yr^{-1}	:	Per year

INTRODUCTION

CHAPTER - I

INTRODUCTION

Soil erosion is a natural geomorphic process involving the removal of the topsoil layer by agents such as water, wind, and gravity. While this phenomenon contributes to the long-term evolution of landscapes, its acceleration due to human activities like deforestation, overgrazing, unsustainable agricultural practices, and unregulated land development has transformed it into a serious environmental threat. The loss of topsoil diminishes land fertility, reduces water retention, and weakens soil structure resulting in ecological imbalance and long-term degradation of productive land.

India faces severe soil erosion, losing an average of 16.35 tons per hectare per year, far exceeding the safe limit of 4.5 to 11.2 tons. About 29% of this soil is lost to the sea, 10% fills reservoirs reducing their capacity by 1-2% annually and 61% is displaced across land, harming agriculture. Highly affected areas include black soil regions (64.5 tons/ha/year), northeast India (41 tons), and ravine lands (33 tons). Major rivers like the Ganga and Brahmaputra carry over 1 billion tons of sediment annually. Urgent steps such as erosion control, afforestation, and watershed management are essential to conserve soil and ensure sustainable farming (Singh *et al.,* 1992).

To find out the ideal locations for the implementation of soil conservation measures, such as check dams and contour bunds in high-risk areas, adopting agroforestry and mulching practices on degraded uplands, restoring vegetative cover in barren zones, and improving water management in paddy fields certain methodology need to be adopted. From a research perspective, it must be a localized, data-driven methodology that can be replicated in other vulnerable regions. Furthermore, it should establish a scientific baseline for future monitoring, helping policymakers and land managers assess the long-term effectiveness of conservation strategies. As climate change intensifies rainfall patterns and land pressure continues to grow, such predictive and site-specific approaches will become increasingly vital for ensuring sustainable and resilient land management.

The consequences of soil erosion are far-reaching, including reduced agricultural productivity, sedimentation of rivers and reservoirs, contamination of freshwater sources, and frequent occurrences of floods and droughts. These impacts are particularly severe in rural areas, where communities are highly dependent on land for their livelihoods. Given the scale of the problem, there is a need for localized, precise, and practical approaches to understand and mitigate soil erosion.

In this context, our study focuses on identifying Hydrologically Sensitive Areas (HSAs) within the Valanchery watershed in Kerala a critical step toward implementing targeted soil conservation strategies. Hydrologically sensitive areas are zones that disproportionately contribute to runoff and sediment transport due to factors such as soil type, slope, land use, and rainfall intensity. By precisely delineating these areas using advanced geospatial techniques as well as field validation, we aim to develop a scientifically robust framework for prioritizing erosion control measures.

Small watersheds, such as the Valanchery watershed, offer an ideal spatial unit for such studies. The watershed encompasses varied land-use types paddy fields, forested areas, barren lands, and cultivated uplands as well as diverse soil types like Vattekode, Irumbiliyum, Perumanna, Thuyyam, and Mungilmada. Its topography and climate characteristics, including high-intensity rainfall and sloping terrain, make it particularly susceptible to erosion, thus providing a representative setting for targeted research. By analyzing HAS's in this region, our study will contribute to sustainable land management practices that can mitigate erosion risks while supporting the livelihoods of local communities.

Hence the study entitled "Identification of Hydrologically Sensitive Areas in Valanchery Watershed" was undertaken with the following objectives

- Study the Spatial Distribution of soil properties in Valanchery Watershed.
- Identify the major runoff contributing areas or Hydrologically Sensitive Areas.
- Suggest conservation measures for the Hydrologically Sensitive Areas.

REVIEW OF LITERATURE

CHAPTER - II

REVIEW OF LITERATURE

Increased runoff from more impermeable subsoil, loss of nutrient-rich surface soil, and decreased plant water availability are all consequences of soil erosion, a global phenomenon that degrades cultivable land. Therefore, determining the critical area for adopting ideal management practices and measuring soil loss are essential to the effectiveness of soil conservation programs. Hydrologically sensitive areas of Valanchery watershed were delineated by analysing soil properties and integrating it with GIS to find soil topographic index and topographic wetness index. This chapter details the relevant literatures that were reviewed for carrying out the study.

2.1 SPATIAL DISTRIBUTION OF SOIL PROPERTIES

The spatial distribution of soil properties is crucial in understanding the characteristics of the watershed as well as planning of soil conservation measures, land management and decision making of agricultural activities.

2.1.1 Bulk Density

Using the Sedflume apparatus, Jepsen *and* Roberts (1997) evaluated how bulk density affects sediment erosion rates. The study examined how erosion rates changed with shear stress and sediment depth by analysing reconstructed sediments from the Detroit River, Fox River, and Santa Barbara slough. The findings indicated a high reliance on sediment compaction throughout time, with erosion rates declining as bulk density rose. Measurements of bulk density increased over a compaction period of 1 to 60 days, ranging from 1.275 to 1.505 g/cm^3 for Fox River sediments and 1.67 to 1.9 g/cm^3 for Santa Barbara sediments. The study found that the erosion rate was a unique function of bulk density, expressed as $E = A\tau^n\rho^m$, where A, n, and m varied across different types of sediments.

Athira, and Kumaraperumal (2019) investigated the relationship between soil organic matter and bulk density, emphasizing the role of organic matter in improving soil structure, health, and productivity. Their study, which analyzed approximately 200 soil samples from diverse landforms in Coimbatore, found that higher levels of soil organic matter were associated with lower bulk density, indicating improved soil quality. The authors demonstrated that bulk density, a key indicator of soil quality, is significantly influenced by organic matter content. By employing various regression models, linear, quadratic, and polynomial, they explored the statistical relationship between soil organic carbon and bulk density, obtaining R^2 values of 0.48, 0.6737, and 0.673, respectively. Among these, the quadratic model provided the best fit, showing the highest R^2 value and the Lowest Residual Standard Error (RSE), reinforcing the strong inverse correlation between organic matter and bulk density in Coimbatore soils. This work highlights the importance of maintaining organic matter to improve soil physical properties and optimize land use practices.

The LUCAS 2018 survey examined soil bulk density across the European Union at depths of 0-10 cm (6,140 sites), 10-20 cm (5,684 sites), and 20-30 cm (139 sites), highlighting land use as the main driver of bulk density variation (Ballabio *et al.,* 2020). Bulk density at 10-20 cm was found to be 5-10% higher than at 0-10 cm for all land uses except woodlands, where the increase was 20%. Croplands exhibited 1.5 times higher bulk density (mean: 1.26 g/cm^3) compared to woodlands (mean: 0.83 g/cm^3) for the 0-20 cm depth, reinforcing the impact of land use on soil compaction. The study applied a Cubist rule-based regression model, producing high-resolution bulk density maps (100 m) for different depths, with predictive accuracy of $R^2 = 0.66$ for the 0-20 cm layer, outperforming previous assessments. These bulk density maps serve as crucial tools for estimating packing density, a key indicator of soil compaction, ultimately aiding in soil health monitoring and refining carbon and nutrient stock estimates across EU topsoil (Ballabio *et al.,* 2020).

Özdemir *et al.,* (2022) examined the changes of some soil physical and chemical properties under different land use conditions in Turhal, Turkey. Soil samples were collected from 0-20 cm depth from twenty plots under eight different land uses which are sunflower, wheat, vegetable, orchard, sugar beet, meadow, pasture and alfalfa plants. Some soil properties where these plants are grown and their effects on the bulk density were investigated. The findings show that basic soil properties and practices related to plant management are effective on the bulk density. While the lowest mean bulk density value was determined in meadow (1g/cm^3) areas, the highest bulk density value was determined in soils cultivated with sugar beet (1.71g/cm^3). Correlations between the investigated parameters were tested with the use of Pearson's correlation method. Bulk density and some soil parameters used in the evaluation of structural stability and sensitivity to erosion were found to have significant relationships.

A review by Giap and Ahmad (2024) emphasized the significance of soil bulk density as a crucial aspect of soil characteristics that directly affects agroecological functions as resilience, diversity, efficiency, and recycling. They found that increased root penetration from lower soil bulk density improves access to nutrients and water, which in turn boosts plant growth and agroecosystem performance. They also underlined that agroecological efficiency is supported by moderately low bulk density, which minimizes environmental pollution and dependence on outside inputs when combined with sufficient soil moisture. Through more effective recycling and heat circulation processes within the soil system, the authors also connected higher bulk density to better agroecosystem resilience and output. On the other hand, excessive soil bulk density can impede these processes, which can cause problems with moisture retention and water infiltration, particularly during drought. Giap and Ahmad also pointed out that the assessment of temperature and moisture distribution in soil profiles is influenced by the bulk density of the soil. Their review sought to improve the predictive ability of current models by synthesizing results from more than 50 components, which were divided into physical, chemical, biological, environmental, and management-related influences. In the end, the study offers a conceptual framework that links these variables to variations in soil bulk density and suggests methods for creating quantitative prediction models that will aid in sustainable soil management.

2.1.2 Specific Gravity

Ile *et al.,* (2015) examined the role of specific gravity, in predicting soil erosion susceptibility. The researchers conducted field surveys and laboratory analyses on soil samples collected from erosion-prone sites, focusing on sieve analysis, Atterberg limits, compaction tests, and specific gravity measurements. Their findings indicate that soils with lower specific gravity values tend to be more erodible, particularly in areas underlain by the friable Ajali sandstone. The study establishes a correlation between specific gravity and soil texture, showing that lower values are associated with sandy, non-cohesive soils that exhibit weak structural integrity and high susceptibility to detachment by water runoff. Additionally, the researchers observed that soils with low maximum dry density and high optimum moisture content are more prone to erosion due to reduced compaction and increased permeability. The study highlights the importance of integrating geotechnical assessments into erosion prediction models to improve land management strategies and mitigate soil degradation in vulnerable regions.

Subash *et al.,* (2016) investigated soil erosion prediction using geotechnical properties, including specific gravity, in Thekkumalai mountain foot, Kanyakumari District, Tamil Nadu. The researchers conducted extensive laboratory analyses on soil samples collected from erosion-prone areas, focusing on sieve analysis, Atterberg limits, compaction tests, and specific gravity measurements. Their findings indicate that specific gravity plays a crucial role in determining soil erodibility, as lower values are typically associated with sandy soils that are more susceptible to erosion. The study establishes a correlation between specific gravity and soil texture, showing that soils with lower specific gravity values exhibit weaker cohesion and higher vulnerability to detachment and transport by water and wind forces. The researchers demonstrated that soils with high sand content and low specific gravity tend to have higher erosion rates. The study emphasizes the importance of soil stabilization techniques, such as vegetation cover, riprap, and organic amendments, to mitigate erosion risks in vulnerable landscapes.

Ojeaga and Afolabi (2022) examined soil erosion prediction using specific gravity. Soil samples were collected from three locations at a depth of 1m and analysed for sieve composition and moisture content. The results indicate that specific gravity values ranged from 2.34 to 2.59, with lower values corresponding to poorly laterized soils that exhibit weak cohesion and high susceptibility to erosion. The study found that soils with lower specific gravity tend to be non-cohesive, primarily composed of loose sands with minimal silt and clay content, making them more vulnerable to gully formation. The Maximum Dry Density (MDD) values ranged from 1.64 to 1.75 mg/m^3, and Optimum Moisture Content (OMC) varied between 11.20% and 16.5%, further confirming the loose, erodible nature of the soil. The study concludes that the low specific gravity and poor soil cohesion contribute significantly to gully erosion susceptibility in the Capitol area, emphasizing the need for soil stabilization measures to mitigate erosion risks.

2.1.3 Organic Matter

Polyakov and Lal (2003) examine the relationship between Soil Organic Matter (SOM) dynamics and soil erosion, emphasizing the significant role of soil organic carbon (SOC) in the global carbon cycle. The paper explores how erosion influences SOM through two primary mechanisms: redistribution within a watershed and loss to the atmosphere. The authors highlight that erosion alters soil microbiological activity and nutrient regimes, thereby affecting greenhouse gas emissions. In agricultural landscapes, cultivation and erosion are major contributors to SOC loss, complicating efforts to trace the fate of displaced carbon. Findings suggest that even moderate erosion rates can significantly reduce SOC levels over time, with as much as 19% of total SOC loss attributed to erosion after 90 years of cultivation. The study underscores the importance of soil texture, sediment enrichment, and deposition processes in shaping SOC dynamics.

Singh *et al.,* (2024) explores the fundamental role of soil organic matter (SOM) in maintaining soil fertility, structure, minimizing soil erosion and overall health, emphasizing its significance in sustainable agriculture and environmental conservation. The authors highlight how SOM enhances soil aggregation, water retention, and nutrient availability, which are critical for improving crop productivity, particularly in regions facing soil degradation, salinity, and water scarcity. The study discusses SOM's contributions to carbon sequestration, microbial activity, and soil pH stabilization, demonstrating its role in mitigating climate change effects and promoting ecological sustainability. Furthermore, the paper addresses challenges associated with declining SOM levels due to intensive farming, monocropping, and excessive reliance on chemical fertilizers, which threaten long-term soil health. The authors propose strategies such as organic farming, conservation agriculture, and the use of compost, biochar, and green manure to restore SOM levels and ensure sustainable agricultural productivity. Additionally, the review underscores the importance of policy interventions and farmer awareness programs to promote SOM management practices.

The study also examines SOM's role in regulating soil erosion dynamics, particularly in hilly terrains like the Western Ghats and Himalayan regions, where it enhances soil cohesion and stability, reducing susceptibility to erosion. The findings emphasize that maintaining and increasing SOM levels is crucial for addressing soil erosion, water scarcity, and salinity issues in India's agricultural landscapes.

Hancock *et al.,* (2019) explore the relationship between soil organic carbon (SOC) dynamics and soil erosion at the large catchment scale by studying two geomorphologically similar river catchments in southeastern Australia. The researchers assess SOC concentrations and their temporal stability over an eight-year period, examining how SOC is influenced by erosion and deposition patterns using the environmental tracer Caesium-137 (137Cs). Their findings indicate that SOC concentrations remained stable at the broader catchment level, but individual sites exhibited notable variations linked to erosion and deposition. Areas experiencing deposition showed an increase in SOC and 137Cs concentrations, while erosional sites demonstrated a decline in both SOC and 137Cs levels. The researchers attribute these patterns to a major rainfall event the largest in the region since 1969 which significantly altered soil movement and SOC redistribution. The study highlights the importance of high-resolution mapping and predictive modelling in understanding SOC spatial variability, particularly under changing climate conditions.

Obalum *et al.,* (2017) highlight the critical role of soil organic matter (SOM) in maintaining soil structure, controlling erosion, and improving soil fertility. SOM significantly influences physical, chemical, and biological soil properties, making it a valuable indicator of soil degradation. Since soil erosion accounts for a large portion of land degradation worldwide, the authors emphasize the importance of SOM in aggregate stability, nutrient retention, and reducing soil erodibility. They propose that instead of relying solely on absolute SOM levels, assessing its temporal changes and labile fractions could offer better insights into early soil degradation detection. While SOM remains a strong candidate for monitoring soil health, the study acknowledges its limitations as an all-purpose indicator, suggesting that microbial SOM fractions may provide more precise degradation assessments. Ultimately, sustainable land management strategies that enhance SOM are crucial for mitigating erosion and maintaining long-term soil productivity.

Li *et al.,* (2019) conducted a detailed study on the impact of soil erosion on soil organic carbon (SOC) dynamics and soil respiration along a cultivated slope in Northeast China, aiming to enhance mechanistic understanding of SOC redistribution and decomposition processes. Their findings reveal that depositional profiles store substantially more SOC- 5.9 times that of eroding profiles and 3.3 times more than non-eroding profiles- demonstrating the crucial role of erosion-induced SOC redistribution in long-term carbon sequestration. The study identifies a linear correlation between SOC and cesium-137 activity, confirming erosion-induced SOC depletion. In depositional topsoil, labile organic matter input significantly enhances soil respiration, whereas subsoil SOC undergoes effective stabilization within microaggregates, leading to reduced mineralization rates below 10 cm depth. The research underscores the dual role of erosion in carbon cycling acting as both a source and a sink depending on topographic position and soil depth and highlights the necessity of soil conservation practices in mitigating carbon loss while maintaining agricultural productivity.

2.1.4 Hydraulic Conductivity

Jarvis *et al*., (2013) conducted a study that due to inadequate data support, existing algorithms used to estimate soil hydraulic conductivity, K, in (eco)hydrological models ignore the effects of key site factors such as land use and climate and underplay the significant effects of soil structure on water flow at and near saturation. These limitations may introduce serious bias and error into predictions of terrestrial water balances and soil moisture status, and thus plant growth and rates of biogeochemical processes. To resolve these issues, they collated a new global database of hydraulic conductivity measured by tension infiltrometer under field conditions. The results of their analyses on this data set contrast markedly with those of existing algorithms used to estimate K. For example, saturated hydraulic conductivity, K_s, in the topsoil (< 0.3 m depth) was found to be only weakly related to texture. Instead, the data suggests that K_s depends more strongly on bulk density, organic carbon content and land use. In this respect, organic carbon was negatively correlated with K_s, presumably due to water repellency, while K_s at arable sites was, on average, ca. 2-3 times smaller than under natural vegetation, forests and perennial agriculture. The data also clearly demonstrates that clay soils have smaller *K* in the soil matrix and thus a larger contribution of soil macropores to *K* at and near saturation.

Usowicz *et al.,* (2021) assessed the spatial variability of saturated hydraulic conductivity (K) across a 140 km^2 region in south-eastern Poland and its relationship with various soil properties, including sand, silt, clay contents, organic carbon (OC), and bulk density (BD) in the 0-20 cm soil layer. Around 216 to 228 direct measurements of K, WC, BD, and FI, while 691 samples were analysed for other soil characteristics. The average K value was 2.597 m/day, ranging from 0.01 to 11.54 m/day, with notable differences between the northern and southern parts of the region. The northern sandy soils (>74% sand, <22% silt) had higher K values (>3.0 m/day), while southern soils with greater silt content displayed lower K values (<3.0 m/day). The study emphasizes that the spatial distribution of K is strongly influenced by soil texture, with sandier soils exhibiting higher water permeability. The soil topographic index maps highlight distinct zones of hydraulic conductivity, which could guide land management decisions aimed at improving water retention and soil fertility while minimizing chemical leaching. The findings underscore the necessity of tailored management practices in erosion-prone areas to optimize soil water resources and agricultural productivity while mitigating risks associated with excessive drainage and nutrient loss.

Yuksel *et al.,* (2024) examined the hydraulic conductivity (K) of soils in the Deviskel Watershed, Turkiye, focusing on how different land-use types forest, agriculture, and grassland- affect water movement through the soil. Around 108 soil samples were collected from a 0-20 cm depth and found that K varied significantly across land uses. The highest K was observed in forest soils (1.02 cm/min), followed by grassland (0.72 cm/min) and agricultural soils (0.67 cm/min), indicating better water infiltration in forested areas due to higher porosity and lower bulk density. Agricultural soils had higher bulk density (1.13 g/cm^3) than forest (0.96 g/ cm^3) and grassland (0.99 g/ cm^3) soils, reducing permeability. The study mapped hydraulic conductivity using GIS-based interpolation techniques to visualize spatial variations in K across the watershed. The hydraulic conductivity map highlights distinct zones of water infiltration, showing that forest areas have higher permeability, while agricultural zones exhibit lower infiltration due to soil compaction.

Using a field microplot experiment, Jadczyszyn and Niedźwiecki (2005) investigate the connection between soil erosion and saturated hydraulic conductivity (K) in ten common farming soil types in Poland. As indicated by log K = 10.7787 - $0.04448_{(Silt)}$ - $8.66336_{(BD)}$ - $1.13323_{(OM)}$ (R^2 = 87.1%, p = 0.004), the results show that higher saturated hydraulic conductivity is correlated with lower silt concentration, organic matter, and bulk density. Soil losses varied significantly, ranging from 0.8 to 16.5 t/ha/yr, with sandy soils exhibiting the lowest erosion rates (0.8 t/ha/yr) and loess soils experiencing the highest (16.5 t/ha/yr). Regression analysis established a direct negative relationship between saturated hydraulic conductivity and soil losses, expressed as soil losses = -3.19513(log K) - 4.9624 (R^2 = 47.7%, p = 0.027). The study found that combining saturated hydraulic conductivity with sand content increased predictive accuracy to R^2 = 82.4%, reinforcing their role in soil erosion assessment. The research concludes that measuring hydraulic conductivity can enhance soil loss estimations, aiding in erosion modeling and land management strategies.

2.2 HYDROLOGIC SENSITIVE AREAS (HSAs)

2.2.1 Topographic Wetness Index

A study conducted by Sharma (2010), explores a remote sensing and GIS-based method for identifying potential soil erosion risk areas in the Maithon reservoir catchment, covering 5553 km² in Jharkhand, India. The research integrates terrain and vegetation indices derived from satellite imagery and digital elevation models (DEM) to map erosion-prone zones. Using 90 m resolution SRTM DEM data, three terrain indices Length-Slope (LS) factor, Stream Power Index (SPI), and Topographic Wetness Index (TWI) were computed. Vegetation cover was assessed using the Normalized Difference Vegetation Index (NDVI) from satellite data for the years 1988 and 2004. The Topographic Wetness Index (TWI) was a key component in the assessment, capturing the influence of terrain on surface saturation and potential runoff. In this study, TWI values ranged from 5.2 to 11.0, with higher values indicating zones of moisture accumulation and increased risk of saturation-excess overland flow, which can initiate gully erosion. High TWI values were mainly observed in the northern, flatter, and converging areas of the watershed, whereas lower TWI values occurred in the steeper, diverging southern regions. These patterns are critical for identifying gully-prone zones, as saturated soil is more vulnerable to detachment and transport. The use of TWI helped delineate areas where soil conservation measures, such as gully plugs or vegetative buffers, would be most effective in reducing erosion risk.

Pei *et al.,* (2010) used soil topographic wetness index for mapping soil organic matter and studied that Terrain attributes derived from digital elevation models, particularly the topographic wetness index (TWI), are commonly used for mapping soil organic matter (SOM). While TWI is typically calculated using a single-flow-direction (SFD) algorithm, this method assumes water flows into only one neighbouring cell, which may be inaccurate in low-relief areas. To address this, a multiple-flow-direction (MFD) algorithm was developed to distribute flow to several downslope neighbours. This study, conducted in Nenjiang County, north-eastern China, compared SFD and MFD based TWIs in SOM prediction using various kriging methods. Results showed that MFD-based TWI correlated more strongly with SOM than SFD-based TWI. Among kriging methods, Collocated Cokriging (CC) incorporating MFD-based TWI performed best, while Ordinary Kriging (OK) outperformed simple kriging with local means (SKlm) and Kriging With external Drift (KED). SKlm and KED were less effective due to instability from rough TWI surfaces. Overall, CC with MFD-based TWI produced the most accurate SOM predictions, benefiting from stronger moisture representation and effective use of spatial and cross-correlations.

Giri *et al.,* (2017) conducted a study to establish Soil Topographic Index (STI) thresholds for delineating Hydrologically Sensitive Areas (HSAs) in landscapes, using field measured soil moisture data and polynomial regression models. Soil moisture was recorded at two sites Christie Hoffman Park and Fairview Farm with STI values ranging from 5.2 to 15.1 and 3.5 to 12.6, respectively. Corresponding soil moisture levels ranged from 2.8% to 46%. Trellis plot analysis identified optimal threshold STI values: 9 to 12.5 at Fairview Farm and 13 to 15 at Christie Hoffman Park, with STI values between 9 and 15 being effective for HSA delineation. These thresholds were applied to 15 watersheds in North and Central New Jersey, where STI values ranged from 1 to 33 and watershed sizes from 23 to 406 km^2.

The study by Wu *et al.,* (2016) investigates the spatial distribution of Hydrologically Sensitive Areas (HSAs) in Clinton and Tewksbury Townships, New Jersey, using the Soil Topographic Index (STI) approach. The STI, calculated using LiDAR DEM and SSURGO soil data, identified HSAs under three threshold scenarios: STI ≥9, STI ≥10, and STI ≥11. These scenarios revealed that 37.5%, 24.0%, and 17.0% of the study area, respectively, were classified as HSAs, covering 6,396.5 ha, 4,136.0 ha, and 2,868.0 ha. The analysis highlighted that perennial stream corridors were consistently identified as HSAs across all scenarios, emphasizing their critical role in watershed health. Land use analysis within HSAs showed that forest (28.2%), agricultural lands (26.1%), and urban areas (21.9%) dominated in the STI ≥9 scenario, while water bodies became more prominent (27.1%) in the STI ≥10 scenario, reflecting the increasing saturation potential with higher STI thresholds.

Lyon *et al.,* (2004) used soil topographic index (λ) to predict saturation zones and spatially distribute Variable Source Area (VSA) runoff within watersheds by integrating landscape and soil parameters. This index is modified to account for soil depth and saturated hydraulic conductivity (K), which influence water movement. The research integrates GIS-based spatial analysis, using DEM data and soil property distributions, to generate probability saturation maps. It was found that areas with higher λ values (>8.2) were more prone to saturation and corresponded closely with observed runoff source areas, while regions with lower λ values (<5.5) were better drained, demonstrating limited surface runoff. The method was applied in three watersheds, including Town Brook (New York), where a critical λ threshold of 8.2 was used to define saturated zones, leading to a predicted runoff source area of 5.6 km^2 during a rainfall event. Additionally, in the Tarrawarra watershed (Australia), the depth to water table measurements aligned closely with high λ values, confirming the reliability of this approach.

2.3 IDENTIFICATION OF MAJOR RUNOFF CONTRIBUTING AREAS

Alireza *et al*., (2018) conducted the awareness of erosion risk in watersheds provides the possibility of identifying critical areas and prioritising protective and management plans. Soil erosion is one of the major natural hazards in the rainy mountainous regions of the Neka Roud Watershed in Mazandaran Province, Iran. This research assesses soil erosion susceptibility through morphometric parameters and the land use/land cover (LU/LC) factor based on Multiple-Criteria Decision-Making (MCDM) techniques, remote sensing and GIS. A set of 17 linear, relief and shape morphometric parameters and 5 LU/LC classes are used in the analysis. The aforementioned factors are selected as indicators of soil erosion in the study area. Then, four MCDM models, namely, the new Additive Ratio Assessment (ARAS), Complex Proportional Assessment (COPRAS), multi-objective optimisation by ratio analysis and compromise programming, are applied to the prioritisation of the Neka Roud sub-watersheds. The Spearman's correlation coefficient test and Kendall's tau correlation coefficient test indices are used to select the best models. The validation of the models indicates that the ARAS and COPRAS models based on morphometric parameters and LU/LC classes, respectively, achieve the best performance. The results of this research can be used by planners and decision makers in soil conservation and in reducing soil erosion.

Das (2014) Conducted study to determine the priority watersheds for conservation of natural resources of the Haharo sub catchment in the Damodar catchment of upper Damodar valley area having an area of 565 km^2 involving four watersheds in Jharkhand State in eastern India by morphometric analysis using topographical maps on a scale of 1:50,000. To define the morphometric features of the watershed, the topographic information of the study area at 1:50,000 scaled are taken for analysis with the help of GIS tools. The topographical information derived from this map is utilized for calculating parameters and fixing of priority of watershed for suggesting conservation measures. The parameters computed include the morphometric parameters like bifurcation ratio, drainage density, stream frequency, texture ratio, and three basin shape parameters i.e., form factor, circularity ratio, and elongation ratio. Average of all these parameters for each watershed is calculated to determine the priority. Among the four watersheds 4/4 was the highest priority area where conservation measure has to be taken first then watershed 4/3. Watershed 4/1 was the medium priority area and watershed 4/2 was the low priority area.

Sørensen *et al*., (2006) Studied that The Topographic Wetness Index (TWI, ln(a/tanβ)) is a widely used metric to assess hydrological processes by integrating upslope contributing area and slope. However, different computation methods exist, primarily differing in how upslope area and slope are calculated. A study comparing multiple TWI calculation approaches found that performance varied depending on the measured variable (e.g., plant species richness, soil pH, groundwater level, soil moisture) and was site-specific. While no single method was universally optimal, certain parameter combinations proved more effective for specific variables.

Grabs *et al.,* (2009) investigated that Topography strongly influences the spatial distribution of saturated areas, which affects soil properties, hydrological processes, and stream water quality. While the Topographic Wetness Index (TWI) is widely used to assess wetness conditions, it assumes groundwater gradients align with surface topography a limitation in many landscapes. To address this, recent studies propose model-derived wetness indices based on distributed hydrological simulations. These dynamic indices outperform TWI in predicting saturated areas, particularly in regions with shallow groundwater tables. The findings highlight the advantage of integrating hydrological modelling for more accurate wetness mapping, especially in topographically complex watersheds like Valanchery, where precise identification of saturation zones is critical for erosion and flood risk assessment.

Hofmeister *et al*., (2019) studied that Soil moisture and groundwater dynamics play a fundamental role in shaping forest ecosystems by regulating biogeochemical processes, soil development, and hydrological connectivity. A field study conducted in a glaciated forest watershed in Michigan examined spatial and temporal moisture patterns across different landforms, revealing distinct hydrological regimes. Perennially saturated conditions prevailed in low-lying wetlands (53% median soil moisture with water tables near the surface), while upland outwash plains maintained consistently dry conditions (16% moisture without shallow groundwater). The research evaluated two predictive frameworks a landscape classification system and a topographic wetness index finding that an integrated approach best captured moisture distribution across the watershed's diverse terrain. These findings emphasize the importance of considering both broad ecosystem types and local topographic controls when assessing soil-water relationships, with significant implications for identifying critical hydrological zones and informing sustainable land management practices in complex watershed environments.

Chowdhury (2023) studied that hydrological modelling serves as a critical foundation for numerous scientific investigations, including species distribution studies, ecological assessments, agricultural suitability analyses, and climatological research. It also plays a vital role in hazard modelling, such as predicting floods, flash floods, and landslides. Over the years, various hydrological models have been developed and widely applied to analyse topographic influences on hydrological processes. Advances in Geographic Information Systems (GIS) have further enhanced these studies by enabling the extraction of landscape-related data from Digital Elevation Models (DEMs). Key hydrological factors such as the Topographic Wetness Index (TWI), Terrain Ruggedness Index (TRI), Stream Power Index (SPI), Sediment Transport Index (STI), Topographic Position Index (TPI), stream density, and distance to streams are commonly derived from DEMs and utilized in environmental modelling. These factors are instrumental in examining their relationships with other ecological and geomorphological variables, making them indispensable tools in contemporary hydrological and hazard-related research.

MATERIALS AND METHODS

CHAPTER - III

MATERIALS AND METHODS

This chapter covers the description of the study area, materials and software used for the study, and the detailed procedure for the calculation of morphometric characteristics of the basin, soil properties analysis and soil erosion estimation. Soil Topographic Index (STI) map was prepared and was used to analyse the hydrologically sensitive areas in Valanchery watershed. Different parameters involved in the equation were found by using appropriate methods. The details of the methodology followed to achieve the objectives is detailed below under the various sub headings.

3.1 DESCRIPTION OF STUDY AREA

The Valanchery watershed is located in the Malappuram district of Kerala. It covers a total area of approximately 79.46 sq.km, encompassing Valanchery town and adjacent regions. The watershed lies within the midland physiographic zone, characterized by undulating lateritic terrain and a tropical monsoon climate.

Five major soil types dominate the region: Thuyyum, Perumanna, Mungilmada, Vattekode, and Irumbiliyum soils, which support a mix of agricultural activities. Land use is mainly agricultural, with coconut plantations, paddy fields, and rapidly growing urban settlements, especially along National Highway 66. The Valanchery watershed plays a crucial role in groundwater recharge, sustaining agriculture and local biodiversity. However, increasing urbanization demands sustainable watershed management practices to preserve its hydrological and ecological balance.

3.1.1 Location

The Valanchery watershed is located between approximately 10°44’30” to 10°50’15” north latitude and 75°58’10” to 76°4’30” east longitude within the Malappuram district of Kerala. Fig. 3.1 shows the location map of the watershed and Fig. 3.2 shows the drainage map of the area. Topographically, the watershed exhibits gently undulating terrain with moderate slopes, with elevation ranging from around 20 m to 120 m above Mean Sea Level (MSL). Based on physiographic characteristics, the watershed falls within the midland region of Kerala, a zone characterized by lateritic soils and seasonal streams. The present study utilized the boundary shapefile of the

Valanchery watershed, which was delineated using topographic maps and secondary data obtained from the Irrigation Design and Research Board (IDRB) and Kerala State Remote Sensing and Environment Centre (KSREC).

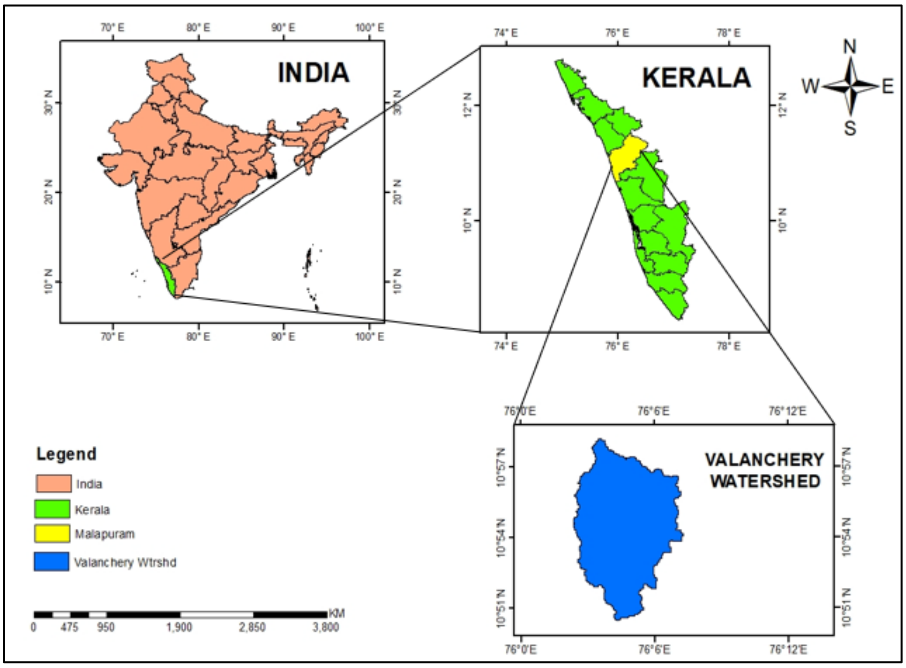

Fig.3.1 Location map of the study area

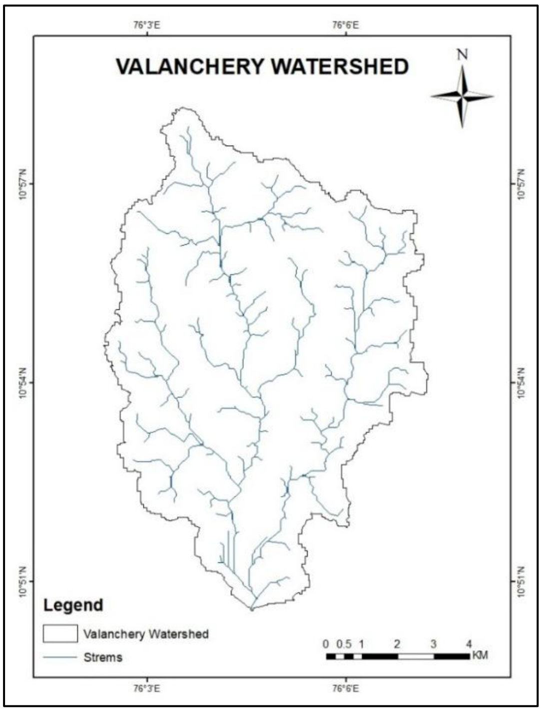

Fig.3.2 Valanchery watershed map

3.1.2 Climate

The Valanchery watershed experiences typical tropical monsoon climatic conditions, heavily influenced by the southwest monsoon season. The region receives an average annual rainfall of approximately 3100 mm, with about 65 per cent of the rainfall occurring during the southwest monsoon (June-September), 25 per cent during the northeast monsoon (October-December), and the remaining 10 per cent during the summer months. The climate is generally hot and humid, with maximum temperatures ranging from 29.5°C to 35.8°C and minimum temperatures between 19.0°C and 24.0°C.

3.1.3 Soil

The geology, soil, and land use/land cover (LULC) in the Valanchery watershed indicate fertile land supporting agricultural activities. The region is mainly underlain by lateritic formations, with occasional alluvial deposits along low-lying areas and seasonal stream courses. The major soil types present in the watershed are Thuyyum, Perumanna, Mungilmada, Vattekode, and Irumbiliyum soils, which are suitable for mixed cropping and plantation agriculture.

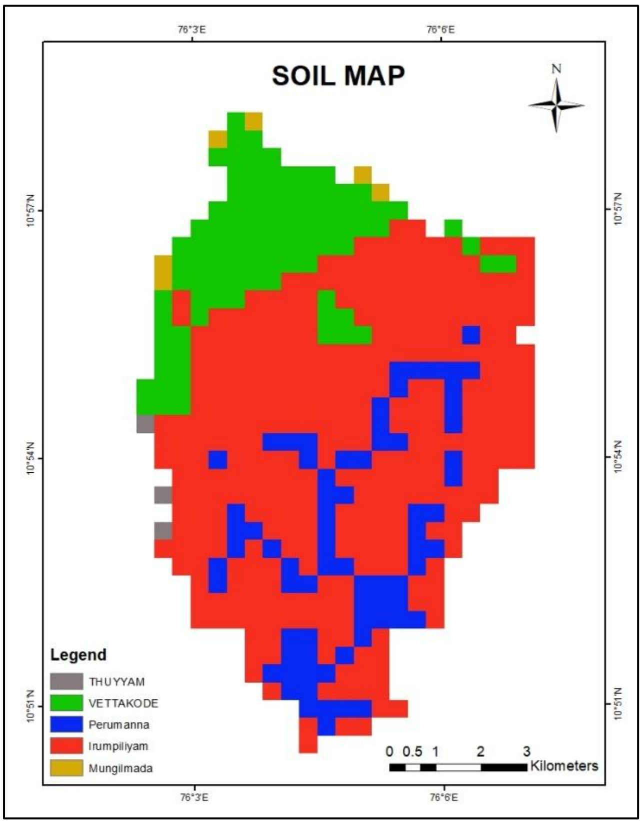

Fig.3.3 Soil map of Valanchery watershed

3.1.4 Land Use/Land Cover

The Valanchery watershed exhibits a varied land use and land cover pattern influenced by its midland terrain and tropical climate. Agriculture is the primary economic activity, although no major irrigation projects are present within the watershed. Agricultural activities are mainly supported by monsoon rainfall and groundwater sources such as dug wells. The major crops cultivated include paddy, coconut, banana, arecanut, tapioca, and vegetables.

Land use types observed in the watershed include cropland, plantations, built-up areas, water bodies, wastelands, and small patches of natural vegetation. Compared to surrounding regions, the Valanchery watershed shows a moderate level of urbanisation, particularly along major transportation routes like National Highway 66. Urban expansion is steadily increasing due to the growth of Valanchery town, but agricultural land still dominates the landscape.

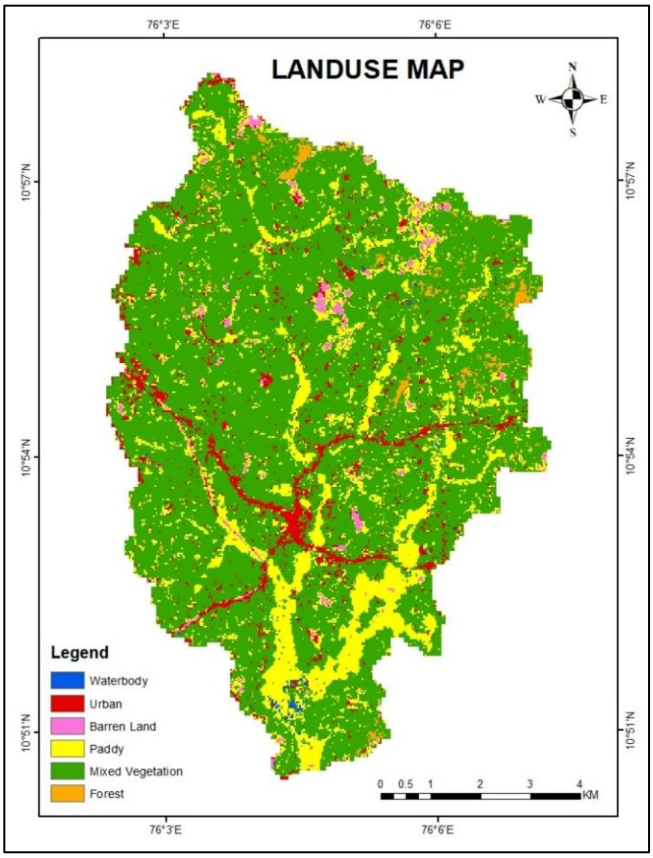

Fig.3.4 Land use map of Valanchery watershed

3.2 SOFTWARES AND TOOLS USED

The software and tools used in this particular study are explained in this section. It mainly includes a GIS platform, Google Earth pro, handheld Global Positioning System (GPS).

3.2.1 ArcGIS 10.7.1

ArcGIS 10.7.1 is a geographic information system (GIS) software developed by Esri, designed for creating, analysing, and managing spatial data. Released as part of the ArcGIS Desktop suite, this version includes tools for advanced mapping, spatial analysis, and data visualization. ArcGIS 10.7.1 offers improved performance and stability over previous versions, as well as enhanced capabilities for integrating with ArcGIS Online and Portal for ArcGIS. It supports a variety of data formats and allows users to share maps and geospatial content across different platforms. This version also introduces updated tools in ArcMap and ArcCatalog, with enhancements to geoprocessing workflows, data management, and cartographic output.

3.2.2 Google Earth pro

Google Earth Pro is a free geospatial desktop application that allows the user to see the world with the tip of a cursor. In contrary to basic google earth which is available in web browser, this pro version is accessible on a desktop. Earth Pro’s 3D mapping system allows the user to import and export GIS data and help the user to prepare more detailed maps. This study made use of google earth pro for the spatial analysis to prepare the land use map.

3.2.3 Handheld GPS

GPS provides a satellite-based navigation system which render the users with positioning, navigation and timing services. It is owned by US government, even though it is an open and dependable navigation system, which can be accessed by anyone with a receiver to collect the satellite data. Handheld GPS is a portable user-friendly device used for locating coordinates and other details of the places for future references. The present study made use of a handheld GPS for locating the coordinates of the ground control points selected to assure the accuracy of land use map.

3.3 SPATIAL DISTRIBUTION OF SOIL PROPERTIES

3.3.1 Collection of Soil Sample

To begin soil sampling, first the sampling locations were identified based on the study objectives. A uniform sampling depth, typically 20 cm was fixed to ensure consistency. Proper sampling tools were selected for soil collection. Before collecting samples, debris like leaves, stones, or organic litter etc. were removed from the surface. Soil samples were collected from 19 different locations within the watershed to capture variability (Table 3.1). All soil lumps were removed gently to maintain a fine, uniform texture. The collected soil was placed into clean, labelled soil sampling bags to avoid contamination. Each bag was labelled with relevant details such as location code, depth, and date.

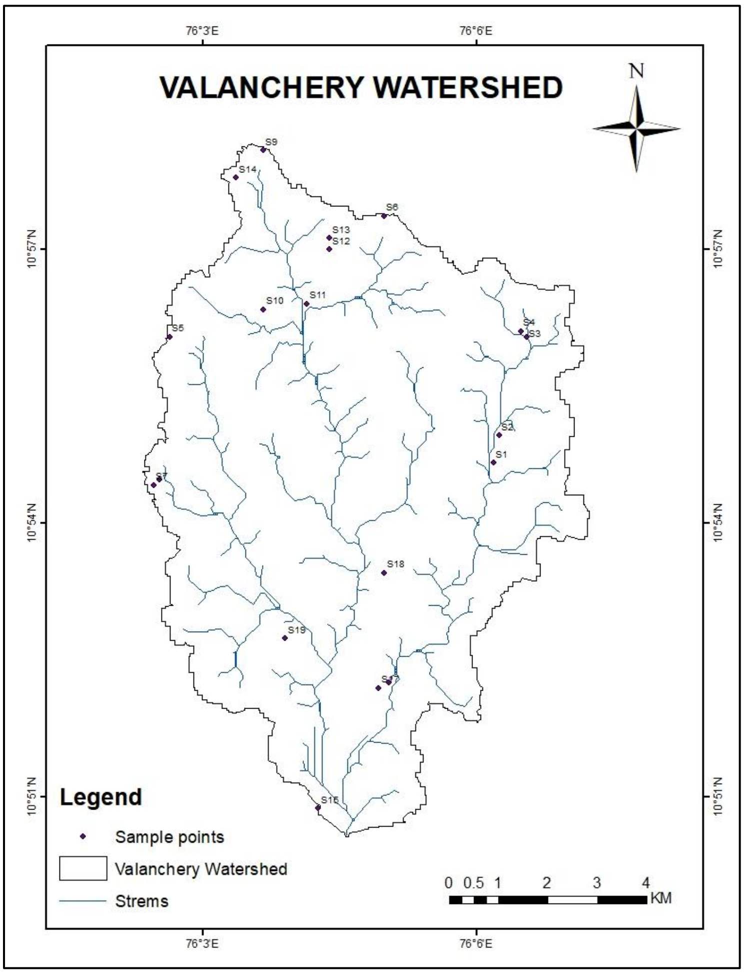

Fig 3.5 Map indicating soil sampling locations

Table 3.1 Details of locations for soil sample collection

Station name	Longitude	Lattitude	Land use	Soil type
S1	76.103	10.911	Tapioca Plantation	Perumanna
S2	76.104	10.916	Coconut Plantation	Perumanna
S3	76.109	10.934	Paddy	Irumpiliyam
S4	76.108	10.935	Plantation	Irumpiliyam
S5	76.044	10.934	Barren land	Mungilmada
S6	76.083	10.956	Forest	Mungilmada
S7	76.041	10.907	Plantation	Thuyyam
S8	76.042	10.908	Barren land	Thuyyam
S9	76.061	10.968	Plantation	Mungilmada
S10	76.061	10.939	Plantation	Vettakode
S11	76.069	10.94	Paddy	Vettakode
S12	76.073	10.95	Barren land	Vettakode
S13	76.073	10.952	Forest	Vettakode
S14	76.056	10.963	Paddy	Mungilmada
S15	76.071	10.848	Barren land	Irumpiliyam
S16	76.084	10.871	Paddy	Perumanna
S17	76.082	10.87	Plantation	Perumanna
S18	76.083	10.891	Forest	Irumpiliyam
S19	76.065	10.879	Mixed Vegetation	Perumanna

3.3.2 Analysis of collected soil samples

3.3.2.1 Bulk density (γ)

Bulk density is a measure of how compact soil is, representing the mass of dry soil per unit volume, including both soil particles and pore space. It is essentially the weight of soil in a given volume and is often used to assess soil health and compaction. Core cutter method was adopted to find out bulk density. First, measure the inside dimensions of the core cutter accurately to 0.25 mm and calculate its volume. Then weigh the core cutter to an accuracy of 1 g. Expose a small area of about 30 cm^2 to be tested and level it. Place the dolly on top of the core cutter and drive the assembly into the soil using a rammer until the top of the dolly protrudes about 15 mm above the surface. Next, excavate the surrounding soil and allow some soil to project from the lower end of the cutter. Using a straight edge, trim the bottom end of the cutter flat. Remove the dolly and similarly trim the top end of the cutter flat. Weigh the cutter now filled with soil. The bulk density was found out by using the following equation (Shammary *et al.,* 2018).

$$\gamma = \frac{W_s}{V_{cc}} \qquad \text{------(1)}$$

Where,

W_s = weight of wet soil, (g)

V_{cc} = volume of core cutter, (cm^3)

Plate.3.1 Sample collection for determining bulk density

3.3.2.2 Specific gravity (G)

The specific gravity of soil is a measure of the weight of a given volume of soil solids compared to the weight of an equal volume of water at a specified temperature. First, clean and dry the pycnometer, then find its mass along with the brass cup and screw cap (M_1). Take about 200 to 400 g of oven-dried soil, place it into the pycnometer, and record the mass of the pycnometer with the soil (M_2). Fill the pycnometer to half its height with distilled water, stir thoroughly, then add more distilled water until the level reaches the top of the glass bottle. After securely replacing the screw cap, continue filling the pycnometer with distilled water up to the top of the brass cup using a wash bottle. Dry the outside of the pycnometer and determine its mass (M_3). Next, empty the pycnometer, clean it thoroughly, and refill it with only distilled water up to the top of the conical cup, then find the mass (M_4). Finally, repeat steps 2 to 4 to obtain multiple readings and determine the mean value of the specific gravity by the following equation (Safuan *et al.,* 2017).

$$G = \frac{M_2 - M_1}{(M_2 - M_1) - (M_3 - M_4)} \quad \text{--------------(2)}$$

Where,

M_1 = empty mass of pycnometer unit, (g)

M_2 = mass of pycnometer + dry soil, (g)

M_3 = mass of pycnometer + soil + water, (g)

M_4 = mass of pycnometer + water, (g)

Plate.3.2 Pycnometer for Specific Gravity determination

3.3.2.3 Grain size analysis

Sieve analysis is a method that is used to determine the grain size distribution of soils that are greater than 0.075 mm in diameter. It is usually performed for sand and gravel but cannot be used as the sole method for determining the grain size distribution of finer soil. The sieves used in this method are made of woven wires with square openings. First, arrange the set of IS sieves in sequence, with the largest aperture sieve at the top and the smallest at the bottom (2mm, 1mm, 600µm, 425µm,300µm, 212µm, 150µm, 75µm), placing a collector below the smallest aperture sieve. Weigh the required quantity of dried soil and place it in the top sieve, then close the lid securely. Mount the sieve assembly on the mechanical sieve shaker, clamp it properly, and continue sieving for about 15 minutes. After sieving, carefully collect and weigh the soil fraction retained on each sieve for further analysis.

Plate.3.3 Sieve analysis

3.3.2.4 Organic matter (%)

The Walkley-Black method is a common laboratory technique used to determine soil organic matter content by measuring the organic carbon present. The procedure begins by weighing a soil sample (1g) that passes through a 0.2 mm sieve and placing it into a 500 ml conical flask. Add exactly 10 ml of 1N $K_2Cr_2O_7$ solution to the flask, followed by 20 ml of concentrated sulfuric acid. Gently mix the solution by rotating the flask for 1 minute to ensure complete contact of the reagents with the soil, being careful not to spill the soil. Allow the mixture to stand for 30 minutes. A standardization blank (without soil) should also be run in the same manner. After 30 minutes, add approximately 200 ml of distilled water, 30 drops of diphenylamine indicator, and 0.2 gm of sodium fluoride to the flask. Then, back titrate the solution using ferrous ammonium sulphate. The colour initially appears dull green due to the presence of chromic ions, shifting to a turbid blue as the titration progresses, and finally changes to a brilliant green at the endpoint. Percentage of organic matter can be computed by following equation Schulte and Hoskins (1995).

$$Organic\ matter(\%) = \frac{(B-S)\times N\times 3\times 100\times 100}{W_S\times 1000\times 77\times 58} \times 100 \quad \text{------------------(3)}$$

Where,

B = volume of FAS used up for blank titration (mL)

S = volume of FAS used for sample titration (mL)

N = normality of FAS from blank titration

W_S = weight of soil sample (g)

58 = percent carbon in organic matter

77 = recovery factor for this method

3 = equivalent weight of carbon

Plate.3.4 Testing of organic matter content in soil

Plate.3.4 Testing of organic matter content in soil

3.3.2.5 Hydraulic Conductivity (k)

The coefficient of permeability, also known as hydraulic conductivity, quantifies a material's ability to allow fluids, like water, to pass through it. It essentially measures how easily a fluid can move through a porous medium, like soil or a membrane, under a given pressure difference. The constant head test is suitable for coarse-grained soils like sand where the discharge rate is high. The accuracy of the test depends on maintaining a constant and consistent hydraulic head throughout the test.

To prepare the soil specimen for a permeability test, begin by taking 800 to 1000 g of a representative soil sample and mixing water with it. Then, pour the weighed quantity of soil into the mould assembly and insert the top 3 cm end plug into the top collar. The specimen is now ready for the permeability test. Connect the soil specimen to a constant head reservoir and open the outlet, allowing steady flow to establish. Collect the water flowing through the soil sample for a defined time interval and measure the volume. Repeat the measurement process three times to obtain consistent data. Hydraulic conductivity can be determined by following equation Mohsenipour and Shaid (2022).

$$k = \frac{Q \times l}{t \times h \times A} \text{ -------------------(4)}$$

Where,

Q - quantity of flow, (mL)

l - length of soil sample in the mould, (cm)

t - time interval, (s)

h - hydraulic head, (cm)

A - cross sectional area of soil sample, (cm^2)

Plate.3.5 Constant head test

3.3.3 Creation of spatial distribution map

To create different spatial distribution maps of soil properties, the first step is to interpolate the measured data using Inverse Distance Weighting (IDW) in ArcGIS. Begin by preparing a point shapefile that contains the measured soil property values at specific sampling locations. Load this shapefile into ArcGIS, ensuring that the attribute table includes the field representing the property values to be interpolated. Then, open the IDW tool from the Spatial Analyst toolbox under the Interpolation section. In the IDW dialog box, select the input point feature and specify the field containing the desired property values, such as hydraulic conductivity. After configuring the parameters, run the tool to create a raster surface that estimates the values across the entire study area based on the spatial relationship and magnitude of nearby points. Finally, apply an appropriate colour ramp to the output raster to visualize the spatial variation and trends in the soil property.

3.4 COLLECTION OF INPUT DATA

For this study, the base data for the calculation of each factor were gathered from different sources.

3.4.1 Digital Elevation Model

A digital elevation model is a three-dimensional computer graphics representation of elevation data to represent terrain or topography. Using DEM, one may quickly determine the topography characteristics and hydrologic characteristics of a region. Different forms of DEM are available for download from different websites, such as the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) Global DEM, Shuttle Radar Topography Mission (SRTM) DEM, and CARTOSAT DEM. The current investigation used SRTM DEM with a resolution of 30 m that was downloaded from the US Geological Survey's (USGS) Earth Explorer (https://earthexplorer.usgs.gov/).

USGS Earth Explorer provides imagery from numerous satellites, including ISRO Resource sat, Landsat, Sentinel, Radar, and others. With the use of interactive and query elements, users can look for information online with this user interface system. Users can establish search parameters in the system, including the location coordinates, a predetermined area, a shape file, and the necessary data range.

3.5 IDENTIFICATION OF HYDROLOGICALLY SENSITIVE AREAS (HSAs)

3.5.1 Creation of transmissivity map

Soil transmissivity is a measure of the ability of soil to transmit water horizontally through a saturated thickness of the soil layer. It can be calculated as,

$$T = Ks \times D \text{ -------------(5)}$$

Where,

K_s - average saturated hydraulic conductivity of topsoil layers (m/day)

D - topsoil depth to a restrictive layer (m)

To prepare a soil transmissivity layer using the raster calculator in GIS software, two input raster layers are needed, one representing hydraulic conductivity and the other representing soil depth or saturated thickness. Transmissivity is calculated by multiplying hydraulic conductivity by depth for each cell in the raster. After loading both raster layers into the GIS environment, open the raster calculator tool and enter a simple multiplication expression using the names of the two rasters (e.g., ‘hydraulic conductivity’ × ‘depth’). Once the formula is entered, specify the output file name and location, then run the calculation. The resulting output will be a new raster layer where each cell value represents the soil transmissivity at that location.

3.5.2 Creation of Topographic Wetness Index (TWI) map

The Topographic Wetness Index (TWI) is a quantitative measure used in hydrology and environmental modelling to represent the spatial distribution of soil moisture and potential water accumulation in a landscape. It combines information about local slope and upslope contributing area to estimate how water will accumulate in a given terrain location. It can be calculated as,

$$TWI = \ln\left(\frac{\alpha}{\tan(\beta)}\right) \text{--------------(6)}$$

Where,

α = upslope contributing area per unit contour length (m)

β = local topographic slope (mm^{-1})

To prepare a Soil Topographic Wetness Index (TWI) map, import a high-resolution Digital Elevation Model (DEM) of your study area to ArcGIS and fill any sinks using the Fill tool to ensure proper flow direction modelling. Next, use the Flow Direction tool to create a flow direction raster, followed by the Flow Accumulation tool to compute accumulated flow. Then, calculate the slope of the terrain using the Slope tool. The Topographic Wetness Index is derived using the (Eqn.). To compute this, convert the slope from degrees to radians if needed, calculate the tangent of the slope raster, and then divide the flow accumulation raster by the tangent raster. Use the Raster Calculator to perform this calculation and apply the natural logarithm to get the final TWI raster. Once the TWI map is generated, you can visualize it using a suitable colour gradient to highlight areas of potential soil moisture accumulation, which are often crucial for hydrological and ecological studies.

3.5.3 Creation of Soil Topographic Index (STI) map

The Soil Topographic Index, also known as the Topographic Wetness Index (TWI), is a measure used to quantify the effect of topography on the location and extent of soil moisture, calculated using the upslope contributing area and local slope and is calculated using equation (7).

$$STI = \ln\left(\frac{\alpha}{\tan(\beta)}\right) - \ln(T) \text{ ----------------(7)}$$

Where,

α = upslope contributing area per unit contour length (m)

β = local topographic slope (mm^{-1})

T = soil transmissivity ($m^2\ d^{-1}$)

To prepare Soil Topographic Index (STI) map using the raster calculator we input two raster layers, one representing Soil Topographic Wetness Index and the other representing transmissivity. STI is calculated by subtracting transmissivity layer from TWI layer for each cell in the raster. After loading both raster layers into the GIS environment, open the raster calculator tool and enter the expression using the names of the two rasters (e.g., 'Topographic Wetness Index' - 'Transmissivity').

3.5.4 Areal distribution of derived STI map

To determine the areal distribution of STI for the study area firstly classify the STI map into different classes by equal interval in Arc GIS. Plot a graph showing STI in X axis and the percentage area of the watershed (shown in attribute table) corresponding to each STI values in Y-axis.

A simple and convincing approach to identify Hydrologically Sensitive Areas (HSAs) by selecting a STI threshold value and use that value to delineate HSAs in the watershed. Qiu (2009) used this approach successfully in Neshanic River Watershed in New Jersey to delineate HSAs for conservation buffer planning and riparian restoration. Therefore, in this study similar approach was used to delineate HSAs in the study area (Wu *et al*., 2016).

3.5.5 Creation of Hydrologically Sensitive Areas (HSAs) map

Classify the STI values into two classes based on threshold value and the resulting HSA map highlighting areas that are more likely to contribute to surface erosion. The STI value lesser than the threshold STI will be less potential to erosion and the STI value higher than the threshold STI will be high potential to erosion. For better visualization, this map can be symbolized using contrasting colours. This HSA map can then be integrated with other biophysical datasets to prioritize conservation interventions and design targeted land-use-specific remedial measures, making it a vital tool in watershed management and sustainable planning.

3.6 TO SUGGEST CONSERVATION MEASURES FOR THE HYDROLOGICALLY SENSITIVE AREAS

3.6.1 Overlaying LULC map with HSA map

In order to understand the variability of land uses within HSAs, a 2023 LANDSAT SATTELITE IMAGERY was used to extract the land uses inside each HSA. This was the most recent land use data available in the public domain for the study area. Overlay a Land Use Land Cover (LULC) map and a Hydrologically Sensitive Areas (HSA) map in ArcGIS using the Intersect tool in Arc tool box. Ensure both the LULC and HSA layers are in the same coordinate system and are polygon feature classes. In the Intersect tool, add both layers as input features and specify an output location. The Intersect tool will generate a new layer that includes only the overlapping areas of the two input maps, combining their attribute data. This allows for the identification of specific land use types that fall within hydrologically sensitive zones, which is useful for further analysis and decision-making.

3.6.2 Suggesting conservation measures in Hydrologically Sensitive Area

Based on the overlay of LULC map with HSA map, identify the specific land use categories that falls under high sensitivity zones. Suggest the conservation measures for each land use types aimed to reduce surface runoff and soil erosion under Integrated Mission for Sustainable Development (IMSD) guidelines.

RESULTS AND DISCUSSION

CHAPTER - IV

RESULTS AND DISCUSSION

This chapter explains the results obtained from the analysis of spatial distribution of soil properties, identification of Hydrologically Sensitive Areas (HSAs) and suggesting remedial measures to prevent soil erosion in HSA. All the maps and graphs derived are also illustrated in the corresponding sub sections.

4.1 SPATIAL DISTRIBUTION OF SOIL PROPERTIES

The results obtained after doing the different soil analysis are presented in Table 4.1

Table 4.1 Bulk density, specific gravity and organic matter content of soil

Sample	Bulk density of soil (g/cm³)	Specific gravity	Organic matter (%)
S1	1.430	1.760	3.241
S2	1.491	2.506	3.83
S3	1.794	2.511	2.553
S4	1.532	2.367	2.687
S5	1.836	2.490	5.223
S6	1.562	2.620	5.458
S7	1.421	2.113	4.534
S8	1.688	2.759	0.890

Sample	Bulk density of soil (g/cm³)	Specific gravity	Organic matter (%)
S9	1.540	2.417	2.770
S10	1.443	2.273	6.449
S11	1.273	2.182	4.366
S12	1.292	2.144	0.655
S13	1.190	2.363	3.023
S14	1.851	2.367	5.525
S15	1.319	2.340	6.852

4.1.1 Bulk Density

From Table 4.1, the highest bulk density value observed is 1.85 g/cm^3 which is at Paddy field of Mungilmada soil type and lowest bulk density value is 1.17 g/cm^3 which is at forest of Vattekode soil type. High bulk density typically indicates compacted soil with fewer pore spaces, which reduces infiltration and increases surface runoff. This heightened runoff accelerates soil erosion, especially on slopes. Conversely, lower bulk density promotes better water infiltration, reducing the risk of erosion by minimizing water movement across the surface. The spatial distribution map of bulk density prepared using Inverse Distance Weighting (IDW) in ArcGIS is shown in Fig.4.1.

4.1.2 Specific Gravity

The highest specific gravity value observed is 2.76 which is at barren land of Thuyyum soil series and lowest bulk density value is 1.76 which is at plantation field of Perumanna soil type. It does not directly control erosion, at the same time it influences the weight and settling rate of soil particles. Soils with higher specific gravity tend to settle quickly and are less likely to remain suspended in water and reduce sediment transport. However, lighter particles (e.g., silts, clays) with lower specific gravity are more easily detached and carried away by water, contributing to erosion. The spatial distribution map of specific gravity prepared using Inverse Distance Weighting (IDW) in ArcGIS is shown in Fig.4.2.

4.1.3 Organic matter content

The maximum organic matter content obtained was 6.85 which is in the forest of Mungilmada soil type and lowest organic matter value is 0.65 which is at barren land of Vattekode soil type. Organic matter improves soil structure by increasing aggregation and porosity. This enhances water infiltration and water-holding capacity while reducing surface crusting and runoff. Soils rich in organic matter are more resistant to erosion because the roots and microbial activity help bind soil particles together, preventing detachment by wind or water. Additionally, organic matter cushions the impact of raindrops, which is a primary cause of soil particle detachment. The spatial distribution map of organic matter content is shown in Fig.4.3.

4.1.4 Textural properties

The results of the sieve analysis which gives the textural properties of the soil samples are given in Table 4.2

Table.4.2 Textural properties of soil samples

Sample	Sand (%)	Silt (%)	Clay (%)
S1	94.9	2.2	2.81
S2	93.1	3.45	3.3
S3	94.9	2.6	2.4

Sample	Sand (%)	Silt (%)	Clay (%)
S9	98.7	0.77	0.47
S10	98.75	0.47	0.72
S11	92.1	4.15	3.64

S4	92.15	3.5	3.9	S12	90.45	6.75	2.65
S5	98.9	0.35	0.7	S13	97.89	1.17	0.85
S6	98.4	0.7	0.86	S14	97.35	1.62	0.93
S7	98.9	0.5	0.5	S15	97.8	1.55	0.55
S8	94.25	2.9	2.65				

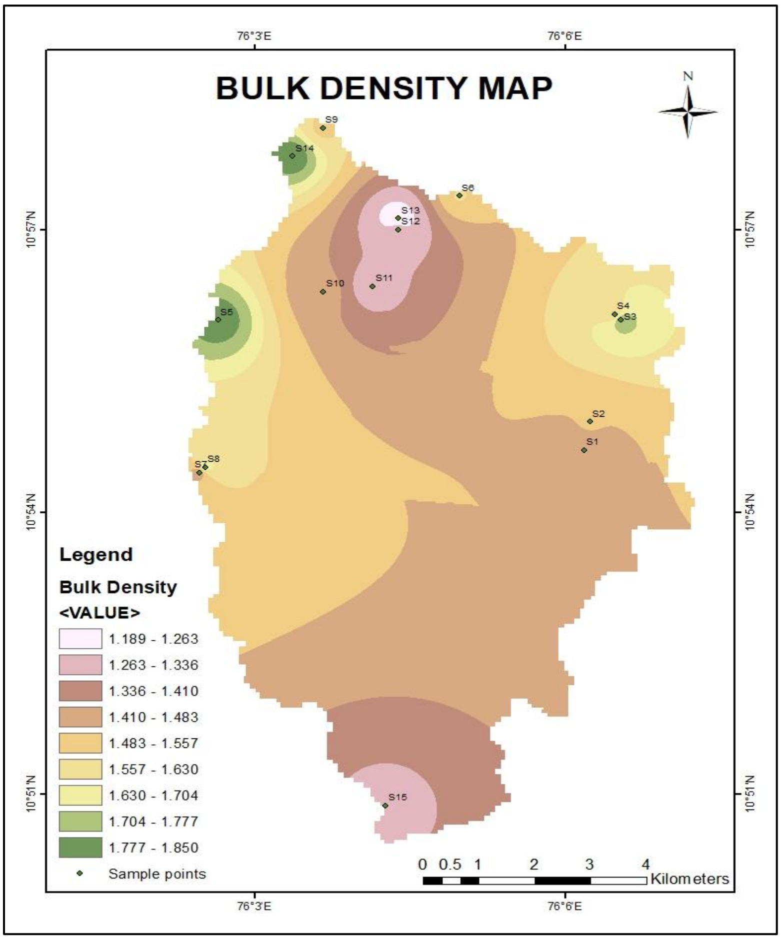

Fig.4.1 Soil bulk density map

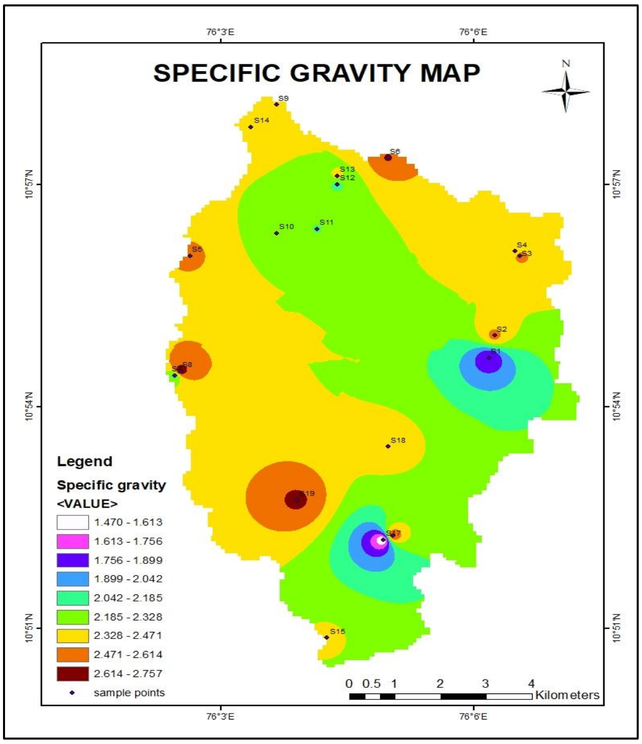

Fig.4.2 Soil specific gravity map

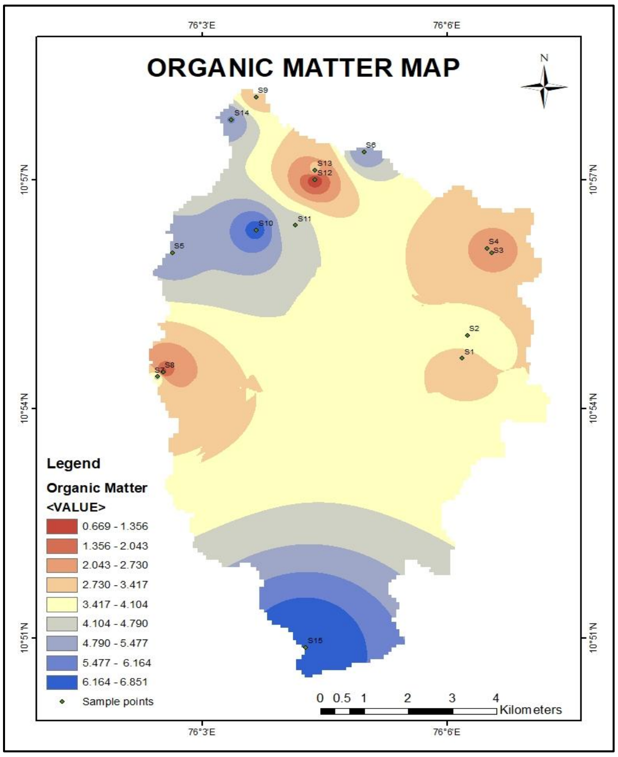

Fig.4.3 Soil organic matter content map

Using the percentage composition of sand, silt and clay, from textural triangle it was found out that the soil type is sandy soil since the sand content is much higher in the collected soil samples. Sandy soil affects soil erosion in both positive and negative ways. Due to its coarse texture and large pores, sandy soil has a high infiltration rate, which reduces surface runoff and thereby lowers the risk of water erosion compared to finer-textured soils like clay. However, sandy soils have low cohesion and weak binding, making them easily detachable under heavy rainfall with less vegetation cover.

4.1.5 Hydraulic conductivity

The hydraulic conductivity values of soil samples determined in the lab are given in Table 4.3. The maximum hydraulic conductivity value observed was 59.35 cm/hr which is at forest region of Irumbiliyum soil type and lowest bulk density value is 9.33 cm/hr which is at barren land of Vattekode soil type. Hydraulic conductivity is the soil's ability to transmit water through its pores. Soils with high hydraulic conductivity allow more water to infiltrate, reducing surface runoff and, in turn, limiting erosion. In contrast, low hydraulic conductivity causes water to pool or flow over the surface, increasing the potential for sheet and rill erosion. Therefore, promoting better conductivity through soil management helps control erosion. The spatial variation of hydraulic conductivity is shown in Fig.4.4.

Table.4.3 Hydraulic conductivity of soil samples

Sample	Hydraulic conductivity (cm/hr)
S1	21.208
S2	23.755
S3	13.605
S4	31.345
S5	46.043
S6	28.596
S7	34.274
S8	24.387
S9	29.534
S10	47.135

Sample	Hydraulic conductivity (cm/hr)
S11	37.531
S12	9.329
S13	44.945
S14	54.017
S15	29.722
S16	49.731
S17	50.870
S18	59.351
S19	52.345

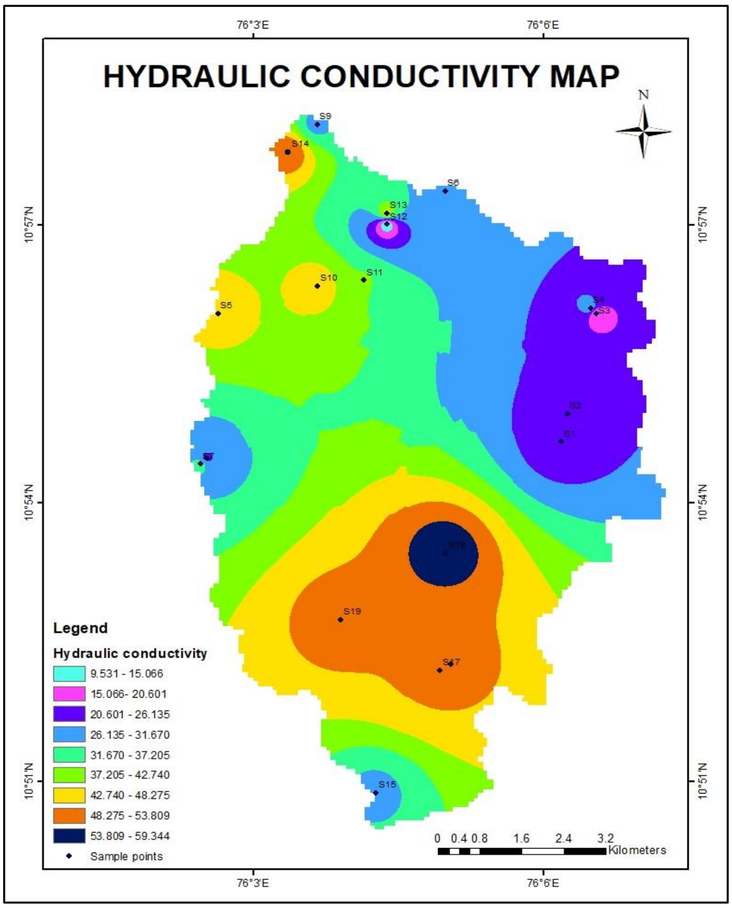

Fig.4.4 Soil hydraulic conductivity map

4.2 IDENTIFICATION OF HYDROLOGICALLY SENSITIVE AREAS (HSAs)

4.2.1 Saturated Hydraulic Conductivity map

The transmissivity map prepared as a product of two maps, one representing hydraulic conductivity and the other representing soil depth or saturated thickness. Transmissivity is calculated by multiplying hydraulic conductivity by depth for each cell in the raster. The lowest transmissivity values, ranging from 190.630 to 550.066, are shown in light blue and are mainly found in the sample points like S1, S2, S4, and S15. The highest transmissivity values, ranging from 932.94 to 1,186.89 are represented in red, mainly concentrated in the central region near points S18 and S19. Higher transmissivity leads to spreading of water through soil layers and it is good for groundwater recharge. When transmissivity becomes low, water spreads slowly. Higher risk of water logging may lead to surface runoff.

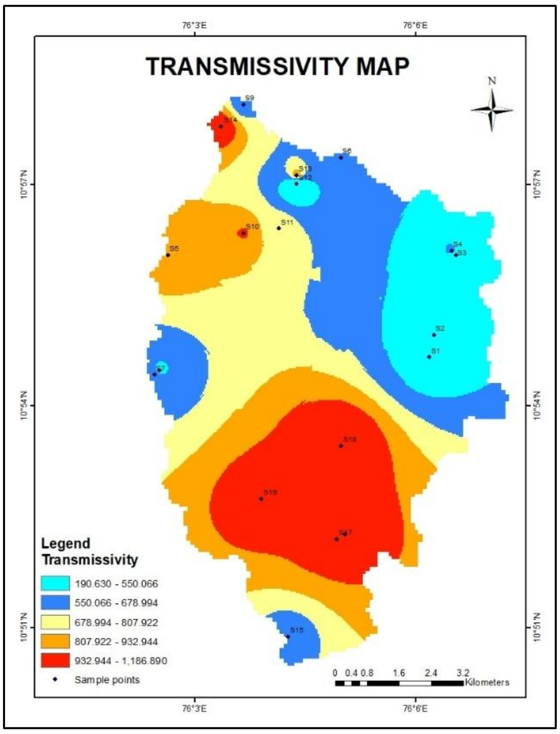

Fig.4.5 Transmissivity map

4.2.2 Topographic Wetness Index (TWI) map

Fig.4.6 shows the map of Topographic Wetness Index (TWI), which represents the spatial variation of wetness potential across the landscape. The value ranges from a low value of 3.997 to 21.679. Areas with low TWI values are displayed in light blue, representing higher slopes or well-drained regions with low moisture accumulation potential. In contrast, darker blue areas correspond to higher TWI values, typically found in valleys, depressions, or near stream networks, where water tends to collect. These zones are more prone to saturation and may support wetter soil conditions. Overall, this TWI map helps in identifying potential wet zones, guiding land use planning, soil moisture studies and hydrological modeling.

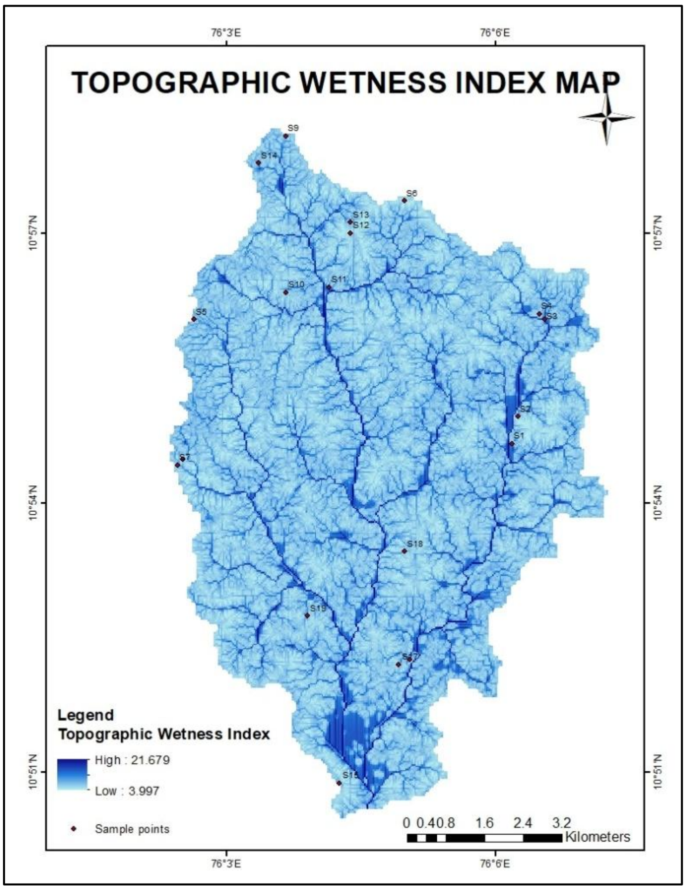

Fig.4.6 Topographic Wetness Index map

4.2.3 Soil Topographic Index (STI) map

Fig 4.7 shows the Soil Topographic Index (STI) map which illustrates variations in soil moisture based on terrain characteristics. The value ranges from a low value of -2.787 to a high value of 15.191. The map uses a colour gradient to represent different STI value ranges. Areas with low STI values are displayed in light green, representing low potential to generate runoff. In contrast, areas with high STI values depicts highest potential to produce runoff in the study area. These values help to identify zones prone to water accumulation or drainage, which is crucial for applications like agriculture, flood risk assessment, and ecosystem studies. By analysing this map, researchers can assess how topography influences soil moisture distribution, supporting better land-use planning and environmental management decisions.

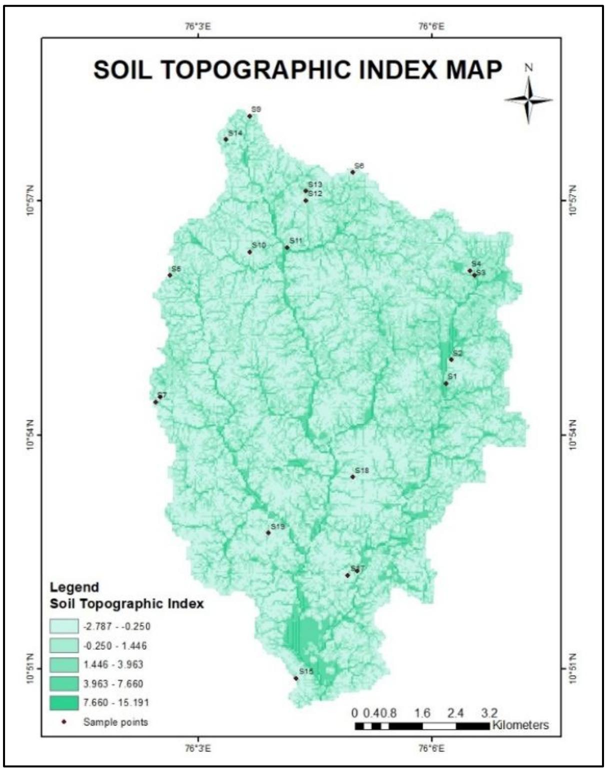

Fig.4.7 Soil Topographic Index map

4.2.4 Areal distribution of derived STI map

The aggregate area distribution of the soil topographic index based on the threshold levels is plotted in Fig.4.8.

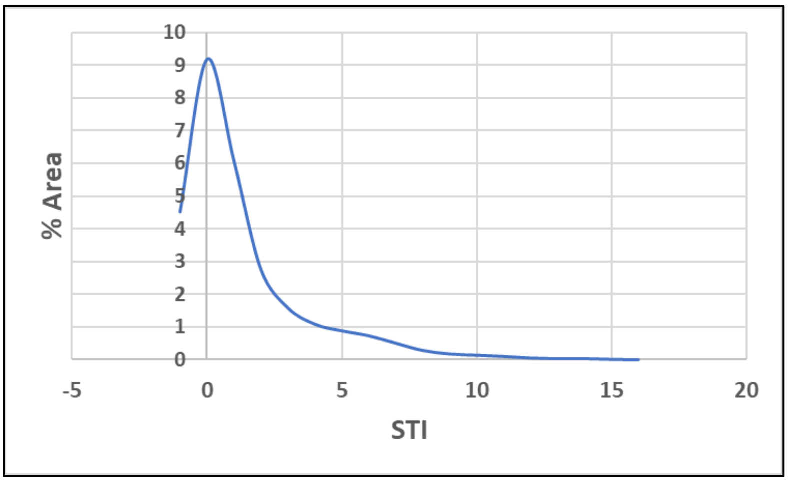

Fig.4.8 Areal distribution of the derived STI index

From many regional studies or guidelines, STI > 9 is a standard adopted to define “severe” or “extreme” condition, enabling comparability across studies. Hence, STI threshold value as 9 was used to delineate and analyse spatial variability of HSAs in the study. The quantitative meaning of STI 9 is the runoff producing ranking of the area in the watershed based on topography and soil transmissivity. Higher STI value means greater capacity to generate runoff in the landscape. The resulting HSA map highlights areas that are more likely to contribute to surface erosion.

4.2.5 Hydrologically Sensitive Areas (HSAs) map

Fig.4.8 shows Hydrologically Sensitive Area (HSA) map, which highlights regions within a watershed that are more prone to runoff and potential water quality impacts. The map shows STI value ranges: -2.787 to 9, represented in green, and 9 to 16, represented in red. The green areas dominate the landscape and indicate regions with lower STI values, suggesting less likelihood of saturation and lower runoff potential. In contrast, red areas are concentrated along drainage lines and valley bottoms, indicating higher STI values and thus higher susceptibility to saturation and runoff. These red zones are considered hydrologically sensitive and are critical for targeted soil and water conservation efforts.

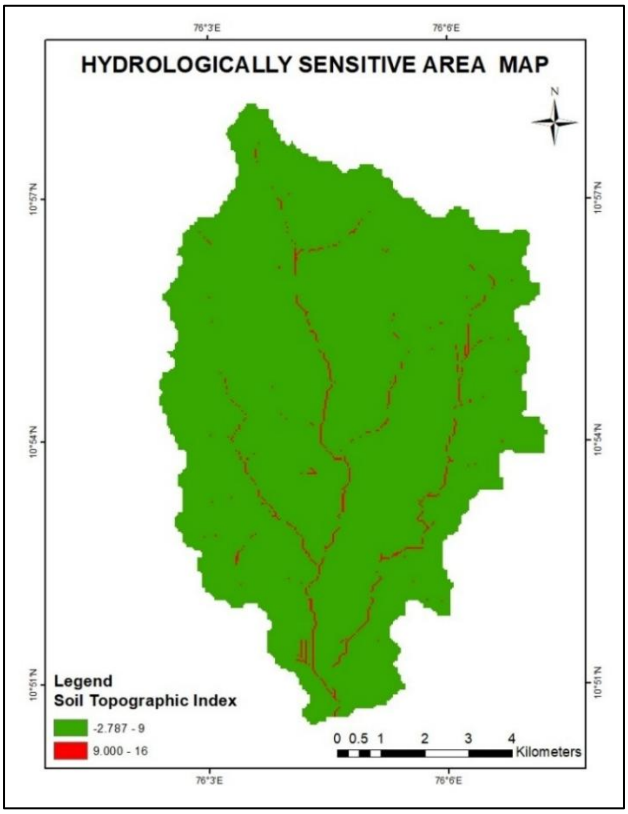

Fig.4.8 Hydrologically sensitive area map

4.3 SUGGESTION OF CONSERVATION MEASURES FOR THE HYDROLOGICALLY SENSITIVE AREAS

4.3.1 LULC - HSA overlayed map

A Land Use Land Cover (LULC) map was prepared using 2023 LANDSAT satellite imagery to classify different land use categories such as agricultural land, forest, water bodies, built-up areas, and barren land. This LULC map was then integrated with the Hydrologically Sensitive Areas (HSA) map using the overlay tool in ArcGIS, which helped to identify specific land use types within hydrologically vulnerable zones. The resulting overlayed map is shown in Fig.4.9. From this map the specific land use types that falls within hydrologically sensitive zones were identified, which is useful for further analysis and decision-making.

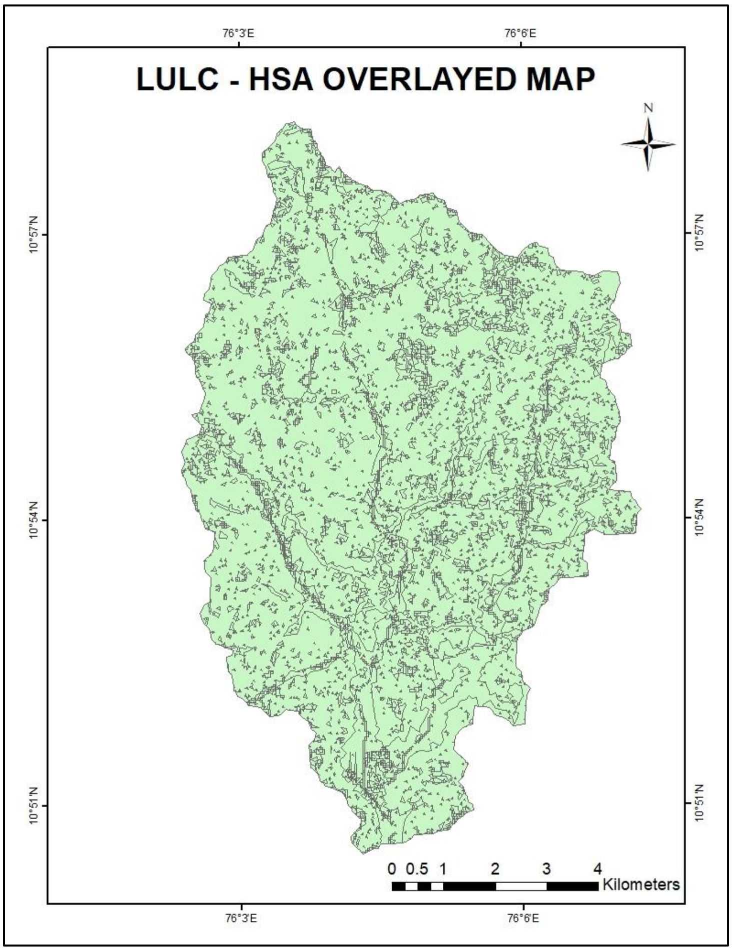

Fig.4.9 LULC - HSA overlayed map

4.3.2 Conservation measures in Hydrologically Sensitive Area (HAS)

Based on overlay analysis, the area (in km^2) was classified based on different land uses that falls under below and above threshold STI value as high and low. Table 4.4 shows the area of different land uses within the watershed.

Table 4.4 Area under different land uses corresponding to different HASs

HSA	Land use	Area (Km^2)
Low	Waterbody	0.293
Low	Urban	3.822
Low	Barren land	1.162
Low	Paddy	11.921
Low	Mixed vegetation	58.772
Low	Forest	1.042
High	Waterbody	0.018
High	Urban	0.024
High	Barren land	0.009
High	Paddy	0.569
High	Mixed vegetation	0.230

From table 4.4 we identified that the land uses urban, barren land, paddy and mixed vegetation which falls under highly sensitive zones of soil erosion. The following results about Valanchery watershed having a slope range of 0% to 32% and having land use classes mainly mixed vegetation and paddy were obtained. Also, only about 0.01% of the study area was found to be sensitive to erosion. Results obtained are helpful for giving recommendations for proper soil conservation measures in the study area. Considering the hydrologically sensitive areas, the following conservation measures are suggested for Valanchery watershed according to Integrated Mission for Sustainable Development (IMSD) guidelines. Table 4.4 shows the different conservation measures suggested for the watershed.

Table 4.1 Land use and their conservation measures

Land use	Conservation measures
Barren land	Percolation Pits Agroforestry
Paddy Fields	Farm ponds Earthen Bunds Check dams (Fields having streams)
Mixed Vegetation	Percolation Ponds Strip Terrace Contour bunds Stream bank stabiliser

SUMMARY AND CONCLUSION

CHAPTER - V

SUMMARY AND CONCLUSION

Soil erosion is one of the serious threats to the ecosystem to be addressed with regard to the problems related to natural resources. It creates significant environmental impacts, such as increased surface runoff, soil erosion, nutrient loss, and water pollution. Appropriate soil and water conservation measures can be suggested only if the extend or spatial distribution of the soil erosion is known. This approach improves the efficiency of watershed management by focusing efforts where they are most needed, helps in maintaining water quality, reduces the risk of downstream flooding, and supports long-term watershed sustainability.

The present study was undertaken to identify hydrologically sensitive areas (HSAs) in the Valanchery watershed of Kerala for effective soil and water conservation planning. The study was conducted using an integrated approach that combined field-based soil data collection, laboratory analysis, and geospatial techniques. The methodology aimed to assess the spatial variability of soil properties, terrain influences, and land use interactions to determine areas susceptible to surface runoff and soil erosion.

First step was to determine the key soil properties of the study area including bulk density, specific gravity, organic matter content, soil texture and hydraulic conductivity. Soil samples were collected from 19 locations across different land use categories, including paddy fields, plantations, forests, barren lands, and mixed vegetation areas. The samples were taken from a uniform depth using standard procedures. In the laboratory, the physical properties of the soil were determined. Bulk density was measured using the core cutter method, specific gravity using a pycnometer, organic matter content through the Walkley-Black method, and hydraulic conductivity using the constant head permeability test. Soil texture was analysed through sieve analysis.

The soil properties data were interpolated using the Inverse Distance Weighting (IDW) method in ARcGIS and the spatial distribution maps were created for each soil property. This allowed for a visual understanding of how these properties varied throughout the watershed. The bulk density values ranged from 1.17to 1.85 g/cm^3. The estimated value of specific gravity varied from 2.11 to 2.76. The highest organic matter content showed in forest and lowest value in barren lands ranged from 0.65 to 6.85 and all samples were found to be predominantly **s**andy in nature. The hydraulic conductivity value ranged from 9.33 cm/hr to 59.35 cm/hr.

A 30-meter resolution SRTM Digital Elevation Model (DEM) was used to derive terrain-related indices. The Topographic Wetness Index (TWI) was calculated using flow accumulation and slope layers to indicate soil moisture accumulation zones. The transmissivity map was generated by multiplying hydraulic conductivity with soil depth using the raster calculator in ArcGIS. Subsequently, the Soil Topographic Index (STI) was calculated by subtracting the transmissivity raster from the TWI raster. These steps enabled the identification of runoff-prone areas based on topography and soil infiltration capacity. The STI value ranges from a low of -2.787 to a high of 15.191 .

Areas with low STI representing low potential to generate runoff. In contrast areas with high STI values depicts highest potential to produce runoff in the study area. These values help to identify zones prone to water and can assess how topography influences soil moisture distribution, supporting better land-use planning and environmental management decisions. Using the derived STI map, the watershed was classified into areas of low and high sensitivity based on a threshold STI value of 9, following regional standards. This threshold helped isolate zones with high potential for runoff generation and erosion. These areas were considered Hydrologically Sensitive Areas (HSAs).

To understand the land use types affected by high STI values, a 2023 LANDSAT satellite-derived LULC map was prepared and overlaid with the HSA map using the intersect tool in ArcGIS. This integration allowed for the identification of critical land use categories such as paddy fields, barren lands, and mixed vegetation within sensitive areas. Based on this overlay, conservation measures were proposed for each land use type, following the Integrated Mission for Sustainable Development (IMSD) guidelines. Measures included the construction of check dams, earthen bunds, percolation pits, farm ponds, and stream bank stabilization.

The overall results of the study pointed that the Valanchery watershed, characterized by a slope range of 0% to 32%, encompasses diverse landforms and land use patterns, with mixed vegetation and paddy fields being the predominant land use classes. Through the analysis of terrain and soil characteristics using geospatial techniques, the Soil Topographic Index (STI) was applied to identify hydrologically sensitive zones within the watershed. Based on the established threshold (STI > 9), it was found that less than 0.01% of the total study area falls under the category of high erosion sensitivity. This result indicates that in the watershed, the small fraction of erosion-prone zones identified requires attention to prevent localized degradation and to maintain the overall health of the watershed. The results gave an idea about these areas in the watershed that need conservation practices Since larger part of the basin having slight erosion, most of the problems can be controlled by simple conservation measures.

The future prospects of this project highlight the potential for implementing targeted soil and water conservation measures within the identified Hydrologically Sensitive Areas (HSAs), which can significantly reduce surface runoff, soil erosion, and sedimentation, thereby contributing to the long-term preservation of watershed health. The HSA data generated through this study can also be effectively integrated into climate change models to predict and assess potential shifts in hydrological patterns under varying climatic scenarios. Furthermore, future research can benefit from the use of high-resolution satellite imagery and fine-scale soil analysis, which would enhance the spatial accuracy of HSA delineation and lead to even more precise and site-specific conservation planning. This would further strengthen the applicability of such geospatial methodologies in watershed management and environmental sustainability.

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IDENTIFICATION OF HYDROLOGICALLY SENSITIVE AREAS IN VALANCHERY WATERSHED

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PROJECT REPORT

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DEPARTMENT OF SOIL AND WATER CONSERVATION ENGINEERING

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ABSTRACT

Soil erosion poses a significant threat to agricultural productivity and environmental sustainability, particularly in vulnerable watersheds. This study aims to identify Hydrologically Sensitive Areas (HSAs) within the Valanchery watershed in Kerala, India, to propose targeted soil and water conservation interventions. A total of 19 soil samples were collected across various land use types and analyzed for key physical properties, including bulk density, specific gravity, organic matter content, soil texture, and hydraulic conductivity. Spatial distribution maps of the soil properties were generated using Inverse Distance Weighting (IDW) in ArcGIS. The study employed digital elevation models (DEMs) to calculate the Topographic Wetness Index (TWI) and Soil Topographic Index (STI), critical for delineating HSAs. Results revealed that areas with STI values above 9 were prone to high runoff and erosion, typically concentrated along drainage lines and valley bottoms. Overlay analysis of Land Use/Land Cover (LULC) and STI maps indicated that paddy fields, barren lands, and mixed vegetation in these zones are most vulnerable. Accordingly, conservation measures such as contour bunds, percolation pits, agroforestry, and check dams are recommended based on IMSD guidelines. This study provides a replicable geospatial framework for erosion risk assessment and soil conservation planning in similar agro-ecological settings.