Eco. Env. & Cons. 30 (1) : 2024; pp. (295-303)
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ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2024.v30i01.054

Quantitative Analysis of Soil Erosion in the Kurumanpuzha Sub Watershed of Chaliyar River Basin: A Remote Sensing and GIS Approach for Sustainable Resource Management

Aishwarya M.S.[1*], Rema K.P.[2], Adarsha Gopalakrishna Bhat[3], Vinayak Paradkar[4] and Pragya Balley[5]

[1,2]Department of Irrigation and Drainage Engineering, Kelappaji College of Agricultural Engineering and Technology, Tavanur, Malappuram, India
[3]Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi, India
[4,5]Centre for Protected Cultivation Technology, Indian Agricultural Research Institute, New Delhi, India

(Received 17 August, 2023; Accepted 6 October, 2023)

ABSTRACT

Soil erosion is a significant contributor to land degradation. This study aimed to determine soil loss in a specific sub-watershed using remote sensing and GIS. Morphometric parameters were assessed based on linear, areal, and relief characteristics. The sub-watershed had a dendritic drainage pattern with a mean bifurcation ratio of 2.05, indicating easier flood management due to longer durations of low peak flows. The analysis revealed fine drainage, indicating a prevalence of soft rocks prone to erosion. The watershed had high relief and steep slopes, characterized by hills, breaks, and low mountains. The hypsometric curve indicated an equilibrium stage of geomorphic evolution. Morphometric parameters were grouped into three clusters at the sub-watershed level, demonstrating spatial variability. Soil erosion is influenced by intrinsic factors like rainfall, soil erodibility, topography, crop cover, and conservation practices. The Revised Universal Soil Loss Equation (RUSLE) was employed using RS and GIS to estimate soil loss in the Kurumanpuzha sub-watershed. Forest/dense vegetation were the dominant land use, followed by rubber plantations and scrubland. The average annual soil loss was estimated at 8.00 t/ha/yr with a total soil erosion quantity of 82,872.4 t/yr. A bare land experienced the highest soil loss, followed by scrubland. The generated soil erosion map provides a basis for implementing measures to ensure sustainable resource management in the watershed.

***Key words**: Soil erosion, Remote sensing, GIS, RUSLE, Watershed*

Introduction

Natural resources have played a dynamic role in balancing the ecosystem (Jackson *et al.*, 1986). However, the expansion of human activities, such as urbanization, industrialization, and intensified agricultural practices, has led to serious environmental problems, particularly affecting the 'soil' and "water" components of the biosphere (Jain *et al.,* 2001). Soil, being the earth's subtle skin that supports plant growth, is a non-renewable dynamic natural resource consisting of organic and inorganic material

([1*]M.Tech. Scholar, 2 Prof. and Head, [3]Ph.D. Scholar, [4]Senior Research Fellow, [5] Research Associate)

(Jackson *et al.,* 1986).

Human activities have accelerated soil erosion, which is the detachment and movement of topsoil (Jackson *et al.,* 1986). Soil erosion involves the detachment, transportation, and accumulation of fertile surface soil (Jain *et al.,* 2001). Water and wind are the major agents contributing to soil degradation, with wind erosion primarily affecting regions with lower rainfall (Guerra *et al.,* 2020). Water erosion occurs through the impact of raindrops and runoff, while wind erosion affects loose soil particles on flat and unprotected lands **(**Balasubramanian, 2017). The severity of soil erosion has led to significant economic losses, including the removal of productive topsoil, damage to crops and crop yield, and pollution of water bodies (Flanagan *et al.,* 2013). In India, approximately 174 million hectares, or 53% of the land, are affected by various land degradation problems (Alam, 2014). The average annual soil erosion in India is estimated to be 16.35 tons per hectare, resulting in the removal of 5,334 million tons of soil annually (Alam, 2014).

To address soil erosion, various soil loss estimation models have been developed. The Universal Soil Loss Equation (USLE) and its revised version, the Revised Universal Soil Loss Equation (RUSLE), have been widely used to estimate soil erosion by raindrop impact and surface runoff (Wischmeier and Smith, 1978). These empirical models consider factors such as rainfall energy, soil susceptibility to erosion, topography, vegetation, and land management practices (Abdo and Salloum, 2017). Geographic Information System (GIS) and remote sensing technologies have been integrated with erosion models to estimate and visualize soil loss (Renschler and Harbor, 2002). GIS provides a powerful decision-making tool for capturing, storing, analyzing, and visualizing spatial information (Elias *et al.,* 2004). By utilizing these technologies, it is possible to quantify soil loss, identify erosion-prone areas, and inform soil conservation and management strategies (Panagos *et al.,* 2015; Zhang *et al.*, 2009; Yang *et al.,* 2012).

To mitigate soil erosion, various conservation methods can be implemented. These include contour bunding, contour tillage, construction of check dams, terrace farming, checking the extension of gullies, strip cropping, shelter belts, afforestation, ban on shifting cultivation, controlled grazing, mixed cropping, mixed farming, rotation of crops, and mulching (Bhattarai and Dutta, 2007). In the state of Kerala, which is prone to natural hazards such as landslides and flooding, the 2018 floods significantly increased soil erosion rates, emphasizing the need for sustainable soil conservation measures (Alam, 2014). The integration of the RUSLE model with GIS is being used in the Kurumanpuzha subwatershed of the Chaliyar river basin in Kerala to estimate soil loss and identify erosion-prone areas for better policy decisions (Ganasri and Ramesh, 2016).

Materials and Methods

Description of the Study Area

The Kurumanpuzha sub-watershed is located within Kerala's Chaliyar river basin. It is a tributary of the Chaliyar River and spans a length of 19.084 km. Encompassing an area of 103.6 km², it constitutes about 3.55% of the entire catchment area. The geographical coordinates range from approximately 11°17′30′′N to 11°23′0′′N and 76°7′0′′E to 76°12′30′′E. This region displays undulating topography, featuring forested hilltops, sloping valleys, and coastal plains. The climate is humid and tropical, with an average annual rainfall of 2419 mm. Rainfall is concentrated during the southwest and northeast monsoons. The mean annual temperature is 27.8 °C. The Kurumanpuzha sub-watershed showcases diverse soils and supports a variety of cultivated crops.

Software and Tools Used

ArcGIS and ERDAS IMAGINE played crucial roles in the study, providing the necessary tools for geospatial analysis, hydrological analysis, and image processing. These software tools were instrumental in handling and analysing the geographical data, enabling researchers to derive meaningful insights for the study.

Collection of Remote Sensing Data

Satellite imagery from diverse sources, such as ISRO Resourcesat, Landsat, Sentinel, and RADAR, was acquired via the USGS Earth Explorer platform to construct a land use land cover (LULC) map for the study area. The interactive interface of Earth Explorer facilitated customized searches based on location, predefined areas, shape files, and specific data ranges, including cloud cover filtering. ISRO's Bhuvan platform supplied CartoSat-DEM satellite imageries with 30-meter resolution. Selecting cloudfree images from Bhuvan, ArcGIS was employed for further processing, including pan-sharpening.

Initial elevation adjustments were made using ArcGIS's Fill tool to rectify flow interruptions caused by terrain depressions. Flow direction maps were generated through the Flow direction tool, while the Flow accumulation tool quantified surface flow per cell. Watershed boundaries were delineated via the ArcGIS Hydrology tool, and aspect was determined using a DEM-generated slope raster. A Landsat 8 image was pre-processed with ERDAS IMAGINE 2015 software for LULC mapping. Unsupervised classification grouped the image into 150 classes. Validation employed aerial and Google imagery, along with ground truth data, as per Alexandridis *et al.* (2015). The tools and techniques employed facilitated comprehensive analysis and data extraction for the study.

Estimation of Potential Soil Erosion

As USLE has limitation in estimating gross erosion, handling complex terrain, and accounting for erosion along streams without the direct impact of water flow, present study incorporates Revised Universal Soil Loss Equation (RUSLE) model forestimation of potential soil erosion.

Revised Universal Soil Loss Equation (RUSLE) model

In the present study, the Revised Universal Soil Loss Equation (RUSLE) model, as proposed by McCool and Rendard (1990), was employed to estimate soil loss in the study area. The RUSLE model, which builds upon the framework of the Universal Soil Loss Equation (USLE), is particularly applicable in predicting soil erosion in agricultural, pasture, and forested watersheds. It represents a software-based enhancement of the USLE.

Using the RUSLE model, the study calculated the spatial average soil loss per unit area (A) by considering several factors. The equation used is as follows:

$$A = RKLSCP$$

Where,

A represents the computed spatial average soil loss per unit area (t ha^{-1} yr^{-1})

R denotes the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1})

K signifies the soil erodibility factor (ton h ha MJ^{-1} $ha^{-1}mm^{-1}$)

LS corresponds to the slope length and steepness factor (dimensionless)

C represents the cover management factor (dimensionless)

P denotes the conservation practice factor (dimensionless)

Preparation of map Layers for RUSLE Model

Rainfall Erosivity (R) factor was calculated via RUSLE model, using monthly data from Karipur, Manjeri, and Nilambur stations (2000-2020). Nilambur station data, near the study area outlet, were employed. R = EI30, where E is storm energy, I30 is 30-min rainfall intensity. Fournier Index (FI) gauges rainfall aggressiveness, while the modified Fournier Index (MFI) by Arnoldus considers monthly distribution. MFI and annual precipitation at Nilambur were used to calculate the R-factor, assessing erosive power of rainfall for land management

Preparation of K Factor Layer

The soil association map of the Chaliyar river basin was provided by the Department of Soil Survey and Soil Conservation, Kerala. The map was geo-referenced and clipped to obtain the study area map, which was used to prepare the K factor layer. The highest K factor series was selected from each soil association group, and a nomograph for the USLE K factor was used to validate the estimated values.

Creation of LS factor layer

The LS factor, which represents the combined effect of slope length (L) and slope steepness (S), plays a crucial role in determining total erosion in a watershed. To calculate the LS factor, CartoSat DEM imagery with a 30m resolution was utilized, along with spatial analyst and hydrology toolkits in ArcGIS software. The methodology described by Moore Burch (1986) and Mitasova *et al.* (1996) was followed.

Creation of C Factor Layer

In this study, an NDVI map was generated from a Landsat 8 satellite image obtained from USGS Earth Explorer using ArcGIS image analysis. Band 4 represented red, while band 5 represented NIR.

Creation of P Factor Layer

The P-factor values for different land uses and slope percentages, as provided by Wischmeir and Smith (1978), are used to create a P-factor layer based on a land use/land cover (LULC) map. This method helps assess the impact of conservation practices on soil erosion.

Estimation of Average Annual Soil Erosion using RUSLE

The final soil erosion map for the subwatershed was obtained by applying the RUSLE model, multiplying all the raster layers such as R factor value, K_factor, LS_factor, C_factor and P_factor using a raster calculator by maintaining a cell size of 30m for each layer. After integrating all the layers in ArcGIS, environment final erosion map was obtained. The WGS_1984_UTM_43N coordinate system and transverse Mercator projection were used to create all of the map layers.

Soil Conservation and Management Protocol for the Watershed

The suitability of conservation measures depends on factors such as topography, rainfall, soil characteristics, and current agricultural practices. For slopes below 2%, agronomic practices are usually sufficient, while slopes between 2% and 10% can benefit from narrow or broad-based terraces. In this study, the erosion risk of different land uses and slope classes was determined using ArcGIS. The soil loss map was spatially joined with slope and land use maps, and average soil loss values were calculated. Based on the erosion risk and slope classes, conservation measures were recommended following guidelines from the NBSSLUP and CSWCRTI.

Results and Discussion

Digital Elevation Model (DEM)

The Kurumanpuzha sub-watershed in the Chaliyar river basin was delineated using ArcGIS. The outlet point of the watershed is situated at Conolly plot near Nilambur, where the Kurumanpuzha River joins the Chaliyar River. The total area of the watershed is 10,359.05 hectares. The basin length, width, and perimeter were calculated to be 19.19 km, 9.2 km, and 60.63 km, respectively.

Slope Map

The slope map was created using the DEM of the study area. The DEM and slope map of study area are shown in Fig. 1 and 2 respectively. The entire watershed was divided into five distinct slope classes, ranging from 0% to more than 50%. According to the slope analysis data, around 50.67%of the area has a slope of 10-25%, while only 5.09%of the land has less than 3%. Slope classes listed in Table 1.

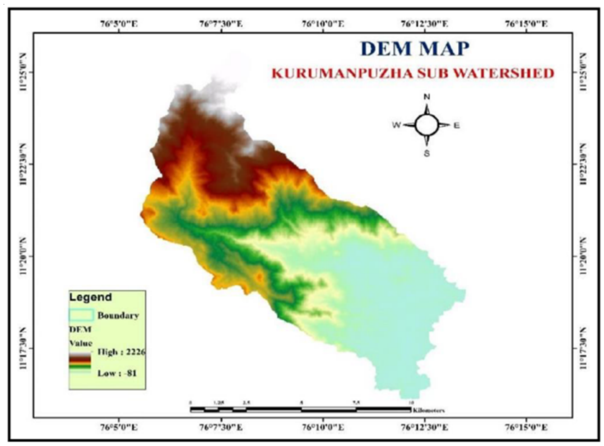

Fig. 1. DEM map of the watershed

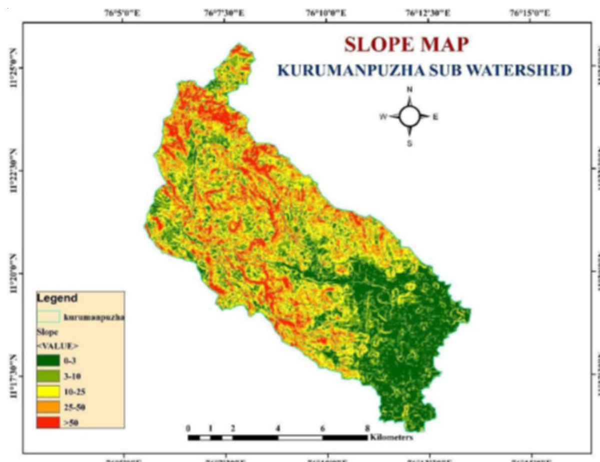

Fig. 2. Slope map of the watershed

Land use/Land cover

Using unsupervised classification in ERDAS imagine 2015 software land use land cover map of the study area was generated (Fig. 3). The water bodies, Forest/dense vegetation, rubber, coconut/areca nut, cropland, scrubland, and bare land are the type of land uses identified in the study area. The obtained raster map was digitally vectorized and then rasterized for spatial GIS analysis. Forest/dense vegetated area (56.46%) were estimated as the major land use with the Rubber plantation (20.06%). Rubber, coconut and areca nut were identified as the major crops in the study area. Some ground truth values identified the selected areas for classifying using the unsupervised method. Area under Differ-

Table 1. Slope classes identified in the watershed

Slope classes	Slope values in %	Area in ha	% of total area
Very gently sloping	0-3	527.08	5.09
Gently sloping	3-10	2298.635	22.20
Strongly sloping	10-25	5245.74	50.67
Steeply sloping	25-50	2279.858	22.02
Very steeply sloping	>50	4.97	0.04

ent Land Use/Land Cover is shown in Table 2.

Modelling of Soil Erosion

Generation of maps for the RUSLE model

Rainfall Erosivity Factor (R)

Soil erosion in the watershed area is influenced by rainfall distribution and erosivity. Due to a lack of rainfall intensity data, the erosivity index factor (R) was calculated using monthly rainfall amounts. The average R value for the years 2000 to 2020 was determined to be 9310.538 MJ mm ha^{-1} h^{-1} yr^{-1}. The findings align with previous studies, indicating a similar erosivity factor range. The R values were applied uniformly throughout the watershed due to limited data availability and a small study area.

Table 2. Area under Different Land Use/Land Cover

Land use/Land Cover	Area in ha	Area in %
Forest/Dense vegetation	5849.19	56.46
Rubber	2078.64	20.06
Coconut/Arecanut	993.15	9.5
Scrub land	923.22	8.91
Crop land	279.45	2.69
Bare land	138.96	1.34
Water bodies	67.23	0.64
Built up/Urban areas	28.35	0.27

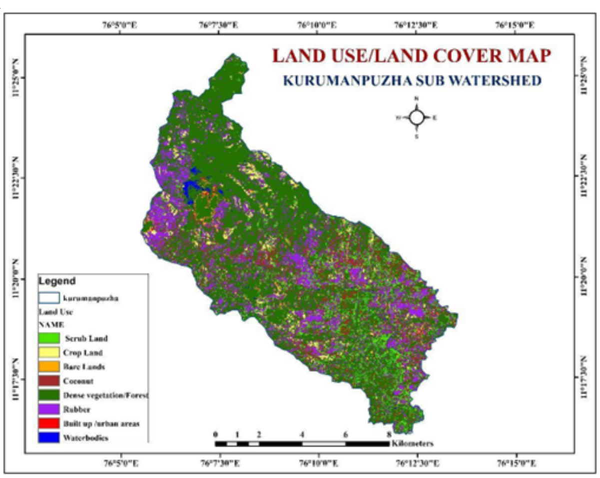

Fig. 3. Land use land cover map of the study area

Soil Erodibility Factor (K)

From the soil map, seven textural categories were identified, and the K values ranged from 0.25 to 0.53 t ha h ha^{-1} MJ^{-1} mm^{-1}. The obtained K values were consistent with the findings of Wischmeier and Smith (1978). The soil association Vettekode-koramala-vazhikad, with lower clay content, had a higher K value (0.53 t ha h ha^{-1} MJ^{-1} mm^{-1}) compared to the Mannamkulam-kuttil-Angadipuram soil association, which had higher clay content and a lower K value (0.28 t ha h ha^{-1} MJ^{-1} mm^{-1}). K mapis shown in Fig. 5 and values listed in Table 3.

Slope Length and Slope Steepness Factor (LS)

The obtained LS values using DEM ranged from 0 to 24.59, with a mean of 0.158 and a standard deviation of 0.523. The LS values were influenced by the elevation, with higher values associated with higher elevations. Similar methodologies were employed by Prasannakumar *et al.* (2011b), Thomas *et al.* (2017a, 2017b), and Praveen *et al.* (2012) in different regions of Kerala, providing validation and comparability to the LS values obtained in this study.

Crop Cover Management Factor (C)

NDVI maps derived from Landsat imageries were

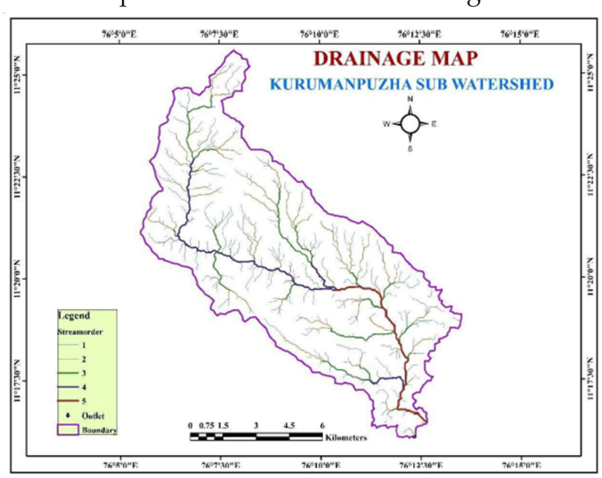

Fig. 4. Drainage network map of the watershed

used to calculate the C, considering changes in vegetation and urbanization. The exponential scaling method was employed, resulting in C values ranging from 0.0699 to 0.87. The C map was integrated with the land use/land cover (LULC) map to determine C for different land uses. Water bodies, built-up areas, and bare land exhibited higher C values due to lower NDVI values, indicating less vegetation cover. Conversely, areas with vegetation had lower C due to higher NDVI values and greater canopy cover. The findings align with previous studies conducted by Bayramov *et al.* (2013) and Thomas *et al.* (2017a).

Conservation Practice Factor (P)

Most of the earlier studies related to RUSLE model gave the P for the entire watershed as '1' (Shiono *et al.*, 2002; Alexakis *et al.*, 2013). The current study considered slope and land use characteristics while calculating the P, as Wischmeier and Smith (1978) indicated. By combining both slope and Land use/land cover map by using the union tool in ArcGIS, the P map was generated. For agricultural areas, the P was assigned based on the slope of the land according to the guidelines by Wischmeier and Smith (1978) and for other land uses, the P was considered one. The P map obtained for the watershed is shown in Fig 3.7.

Soil Erosion Risk Assessment

The RUSLE model was utilized in a study of soil erosion in a Kerala watershed with a tropical climate and steep terrain. By layering various factor maps, including R-factor, K, LS, C, and P, the average annual soil loss (A) was determined to be 8.00 $tha^{-1}yr^{-}$

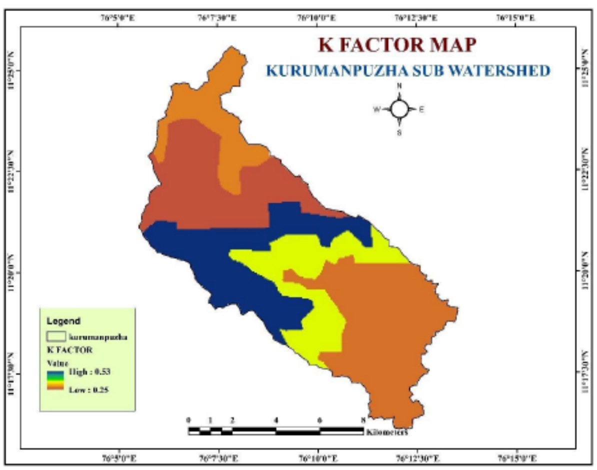

Fig. 5. Spatial distribution of soil erodibility factor(K factor)

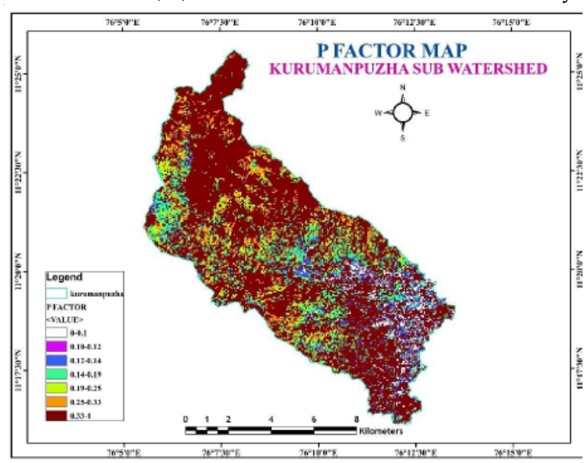

Fig. 7. Spatial distribution of P factor for the watershed

Table 3. K factor values for the Kurumanpuzha sub watershed

Soil association	Soil texture			Organic	Organic	Structural	Permeability	K
	Sand (%)	Silt (%)	Clay (%)	Carbon (%)	matter (%)	code b	c	factor
Mannamkulam	22	20	58	2	2	3	5	0.19
Kuttil	52	6	42	2	2	2	5	0.16
Angadipuram	58	15	27	2	1.2	2	5	0.28
Vettekode	52	6	42	2	2	4	5	0.25
Koramala	58	15	27	2	2	4	5	0.35
Vazhikad	32	34	34	2	2.76	4	5	0.37
Arimbra	43	39	18	2	2.07	4	5	0.53
karuvarakundu	22	20	58	2	2	4	5	0.23
churathinmel	32	34	34	2	2.43	4	5	0.38
Nadukani	22	20	58	2	0.83	4	5	0.24
Kalvarikunnu	52	6	42	2	2.21	4	5	0.25
Pullangod	52	6	42	2	2	4	5	0.25
Walakkad	32	34	34	2	4.22	3	5	0.29
kurumbramala	32	34	34	2	4.22	3	5	0.29

[1], resulting in a total soil erosion quantity of 82,872.4 t yr^{-1}. The findings were consistent with prior research in similar regions. The study categorized the area into five erosion risk zones based on soil loss: very slight (<5 t ha^{-1} yr^{-1}), slight (5-15 t ha^{-1} yr^{-1}), moderate (15-30 t ha^{-1} yr^{-1}), severe (30-50 t ha^{-1} yr^{-1}), and very severe (>50 t ha^{-1} yr^{-1}). The majority of the watershed (78.79%) experienced very slight erosion, while smaller percentages were classified as slight (16.29%), moderate (4.55%), severe (0.28%), and very severe (0.07%) shown in Table 4. Kurumanpuzha sub-watershed study in Western Ghats matched earlier research. Similar soil loss results from multiple studies, attributed to rainfall and land use differences. Geomorphology indicates slight erosion risk, supported by RUSLE modeling across the watershed.

Suggestion of Suitable Soil Conservation and Management Protocol for the watershed

Table 5 illustrates the relationship between land use/cover types and average annual soil loss. Bare lands had the highest erosion (8.55 t/ha/yr), attributed to limited vegetation and conservation practices. Scrublands followed (5.27 t/ha/yr). Forests, rubber, coconut/areca nut, and crop lands had lower soil loss due to canopy cover and conservation efforts. Table 6 combines slope and soil loss data, showing variation across slope categories. The watershed included very gentle, gentle, strong, steep, and very steep slopes. RUSLE model determined average soil loss: 4.215, 6.830, 7.826, 5.248, and 1.566 t/ha/yr for respective slope categories. The study suggests specific soil conservation measures based on these findings:

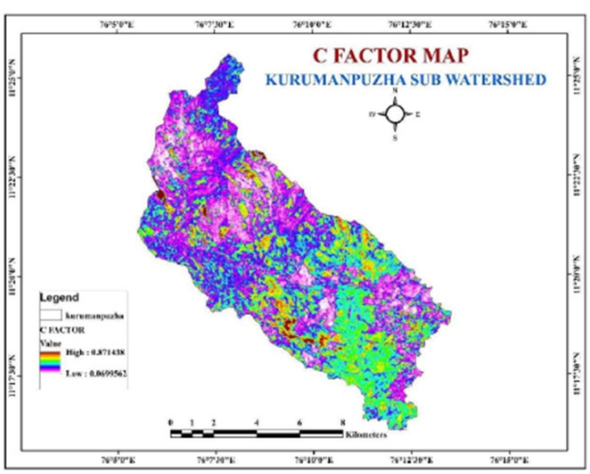

Fig. 6. Spatial distribution of C factor of Kurumanpuzha sub watershed

Soil conservation measures for the watershed include: 1) For 0-3% slopes with slight erosion, use agronomical measures like contour farming, inter-

Table 4. Soil erosion risk classification and area coverage

Soil erosion class	Soil loss (in t $ha^{-1}yr^{-1}$)	Area (in ha)	Area (%)
Very slight	<5	8162.40	78.8
Slight	10-15	1687.67	16.3
Moderate	15-30	471.632	4.5
Severe	30-50	29.60	0.3
Very severe	>50	7.73	0.07

Table 5. Average annual soil loss (A in t $ha^{-1}yr^{-1}$) in different land uses

Land use/Land cover	Area (ha)	Area %	A
Bare land	138.96	1.34	8.55
Forest/Dense vegetation	5849.19	56.46	3.10
Rubber plantations	2078.64	20.06	3.94
Built/urban areas	28.35	0.27	3.60
Coconut	993.15	9.5	3.35
Scrub land	923.22	8.91	5.27
Crop land	279.45	2.69	2.72

Table 6. Average annual soil loss (A) corresponds to different slope lands

Slope range in %	Area in ha	A in t ha^{-1} yr^{-1}
0-3	527.08	4.215
3-10	2298.635	6.830
10-25	5245.74	7.826
25-50	2279.858	5.248
>50	4.97	1.566

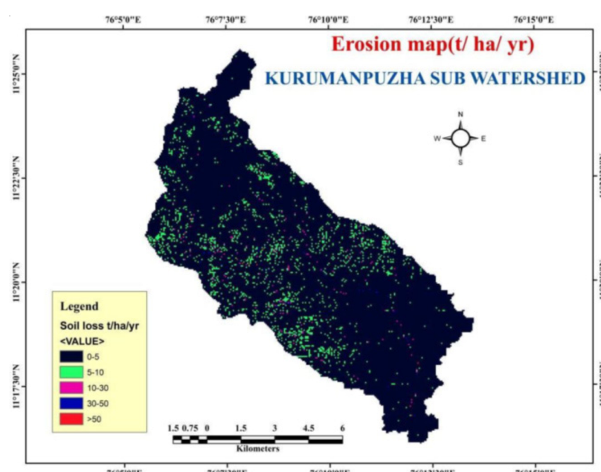

Fig. 8. Spatial distribution of soil erosion in Kurumanpuzha sub watershed

cropping, strip cropping, tillage, and mulching. 2) For 3-10% slopes with moderate erosion, implement mechanical measures such as contour bunds. 3) Given annual rainfall of 2419 mm, graded bunds are advised. 4) For 10-25% slopes, use inward sloping bench terracing and graded bunds in areas with lower erosion rates. 5) Slopes of 25-50% already have terracing in place due to forest or rubber areas. 6) No specific measures are needed for slopes >50% with negligible erosion. 7) Due to predominant channel flow and shorter overland flow, implement drainage line treatments, despite RUSLE not estimating channel or gully erosion. 8) First-order streams require check dams, loose stone brushwood, and log brushwood dams. 9) Higher-order streams benefit from permanent check dams along drainage lines. 10) Steep slopes can be stabilized using logwood crib structures filled with stone or brushwood. 11) These measures aim to address erosion risksand stabilize the watershed based on slope characteristics and land cover.

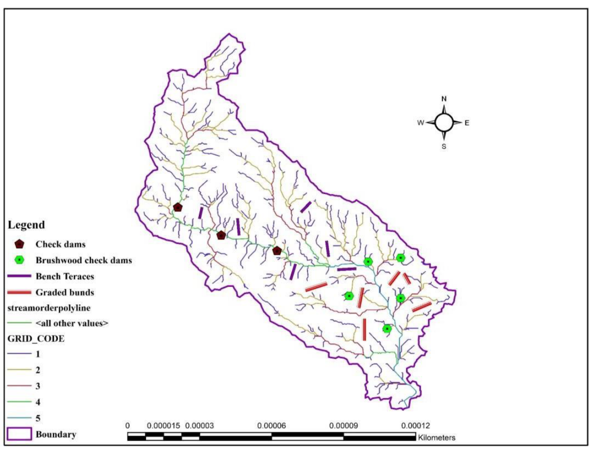

Fig. 9. Soil conservation measures suggested for the study area

Conclusion

Based on the erosion classes and slope of the watershed, soil conservation measures were suggested. For slopes ranging between 0-3% with slight erosion, agronomical measures like contour farming, intercropping, and mulching were recommended. Slopes of 3-10% with moderate erosion required mechanical measures such as contour bunds, with graded bunds for the area's high rainfall. Slopes of 10-25% needed inward sloping bench terracing and graded bunds. Slopes of 25-50% were already managed with terracing due to forest or rubber plantations. No measures were suggested for slopes >50%. Drainage line treatments, including check dams and logwood crib structures, were advised due to predominant channel flow. Future work should involve comparing erosion using different slope maps, using gridded rainfall and soil data, and validating the model's performance through field measurements. These measures provide targeted strategies for effective soil conservation in the watershed, considering erosion classes and slope ranges.

Acknowledgements

We express our sincere regards, to KCAET, Tavanur, for providing us necessary facilities for completion of this study and our heartfelt gratitude to Dr.Rema K. P. Professor, Department of Irrigation and Drainage Engineering, KCAET, Tavanur, for her valuable suggestionsand insightful decision provided for entire work.

We avail this opportunity to express our sincere thanks to Dr.DivyaVijayan V, Assistant Professor & PI, STCR, Dept. of Soil Science & Agri. Chemistry, College of Horticulture, Vellanikkara, Dr.Sasikala, Professor, Dept. of IDE KCAET, Tavanur for their valuable suggestions, encouragement and remarks throughout this study.

Conflict of Interest

The authors declare that they have no competing interests related to this manuscript.

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