Geospatial assessment of soil erosion risk using the RUSLE model in lower Krishna Lanka areas of Andhra Pradesh, India

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***Abstract*—Soil erosion is a major environmental challenge that threatens land productivity and long-term sustainability, particularly in dynamic floodplain environments. The Lower Krishna Lanka region, situated downstream of the Krishna River in Andhra Pradesh, India, is especially prone to erosion due to intense rainfall, fluctuating river regimes, diverse land use practices, and subtle topographic variations. This study evaluates the spatial distribution of soil erosion risk in the region using the Revised Universal Soil Loss Equation (RUSLE) integrated with geospatial techniques. The RUSLE model was implemented within a Geographic Information System (GIS) framework to estimate annual soil loss across the study area. Five key parameters—rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C), and conservation practice (P) were generated using rainfall records, soil datasets, satellite imagery, and digital elevation models processed in ArcGIS. The computed soil loss values were classified into five erosion risk categories: very low (0–5 t/ha/year), low (5–10 t/ha/year), moderate (10–25 t/ha/year), high (25–50 t/ha/year), and very high (>50 t/ha/year). The results reveal that annual soil loss in the study area ranges from negligible values to as high as 11,631.79 t/ha/year, with an average soil loss of 23.57 t/ha/year. For the total area of 1032.61 hectares, the estimated annual soil loss is approximately 24,340 tons. Spatial analysis indicates that a significant portion of the region falls under moderate erosion risk, while high and very high erosion zones are primarily associated with steeper slopes, exposed soils, and sparse vegetation cover. The study demonstrates that integrating RUSLE with GIS provides a reliable and effective approach for identifying erosion-prone areas. The findings offer valuable insights for planning targeted soil conservation strategies and support sustainable land management practices in the Lower Krishna Lanka region.**

***Index Terms*—GIS, Remote Sensing, Soil Erosion, RUSLE, Krishna River Delta, ArcGIS, Andhra Pradesh**

I. INTRODUCTION

Soil erosion is a serious environmental issue that significantly affects land productivity, ecosystem stability, and socio-economic conditions, particularly in agriculturally intensive and floodplain regions (Borrelli et al., 2017; Bewket and Teferi, 2009). In India, soil erosion has emerged as a major form of land degradation, driven by factors such as intense monsoonal rainfall, improper land management practices, and increasing anthropogenic pressure (Dabral et al., 2008; Balabathina et al., 2020). The problem is especially pronounced in river delta and floodplain areas, where periodic flooding and land use changes accelerate soil loss. The Lower Krishna River region in Andhra Pradesh, characterized by fertile alluvial soils and intensive agriculture, is highly vulnerable to such erosion processes.

Soil erosion leads to loss of fertile topsoil, reduction in agricultural productivity, and increased sedimentation in rivers and reservoirs, thereby affecting both environmental quality and food security (Alemayehu et al., 2020; Aneseyee et al., 2020). Changes in land use and land cover significantly influence erosion intensity, particularly in regions with sparse vegetation and exposed soils (Aneseyee et al., 2020; Chakrabortty et al., 2020). In deltaic regions like the Krishna basin, frequent flooding combined with cultivation practices further accelerates soil detachment and transport.

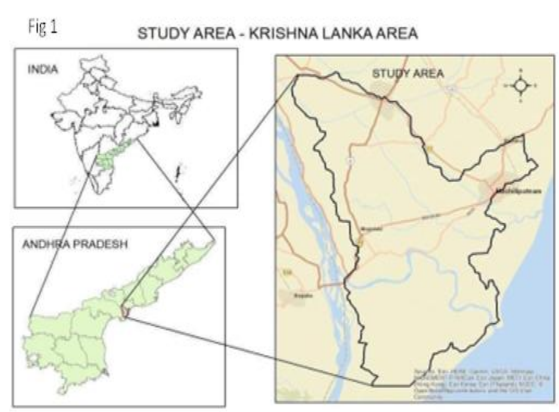
Accurate estimation and spatial assessment of soil erosion are essential for effective land management and conservation planning. Several empirical models such as the Universal Soil Loss Equation (USLE) and its revised version (RUSLE) have been widely used for predicting soil loss (Abdo and Salloum, 2017; Addis and Klik, 2015). Among these, the RUSLE model is preferred due to its simplicity, reliability, and ability to integrate with Geographic Information Systems (GIS) and Remote Sensing (RS) techniques (Amsalu and Mengaw, 2014; Belayneh et al., 2019). The integration of GIS with RUSLE enables spatial mapping of erosion risk and identification of critical areas requiring conservation measures (Andualem et al., 2020; Balabathina et al., 2020).

Although several studies have been conducted on soil erosion assessment in different regions, there is limited research focusing specifically on the Lower Krishna Lanka areas at a detailed spatial scale. Therefore, quantifying soil loss and identifying erosion-prone zones using geospatial techniques is essential for sustainable land use planning. In this context, the present study aims to assess the spatial distribution of soil erosion risk using the RUSLE model integrated with GIS, providing a scientific basis for soil conservation and management in the Lower Krishna River region.

II. MATERIALS AND METHODS

2.1 Study Area

The Lower Krishna Lanka region, located (Fig 1) downstream of the Krishna River in Andhra Pradesh, is well connected by a network of rural and district roads linking major settlements such as Avanigadda, Koduru, and nearby coastal habitations, facilitating agricultural transport and market accessibility. The region experiences a tropical humid climate characterized by hot summers, moderate winters, and significant rainfall primarily from the southwest and northeast monsoons, with annual precipitation ranging between 900–1100 mm (IMD, 2020). The area supports a dense rural population largely dependent on agriculture, aquaculture, and allied activities, reflecting high land-use pressure on fertile deltaic soils (Census of India, 2011). The drainage system is dominated by the Krishna River and its distributaries, forming an intricate network of natural channels, backwaters, and floodplain depressions that frequently influence sediment transport and erosion processes (CGWB, 2013). Additionally, the region is served by an extensive canal irrigation system derived from the Prakasam Barrage, including major canals such as the Eluru and Bandar canals, along with numerous distributaries and field channels that ensure water availability for intensive paddy cultivation (Irrigation Department, Andhra Pradesh, 2015). This combination of dense drainage, irrigation infrastructure, and climatic variability makes the Lower Krishna Lanka region highly dynamic and susceptible to soil erosion and sediment redistribution.



The graph (Fig 2) clearly shows that rainfall is very low from January to May, and then it increases sharply from June with the onset of the monsoon. The highest rainfall is observed in July and August, which indicates strong monsoon influence in the Krishna Lanka study area. Temperature increases steadily from January and reaches its peak in May, after which it slightly decreases during the rainy season due to cloud cover. From October to December, rainfall reduces again and temperatures remain moderate, showing a shift towards dry conditions.

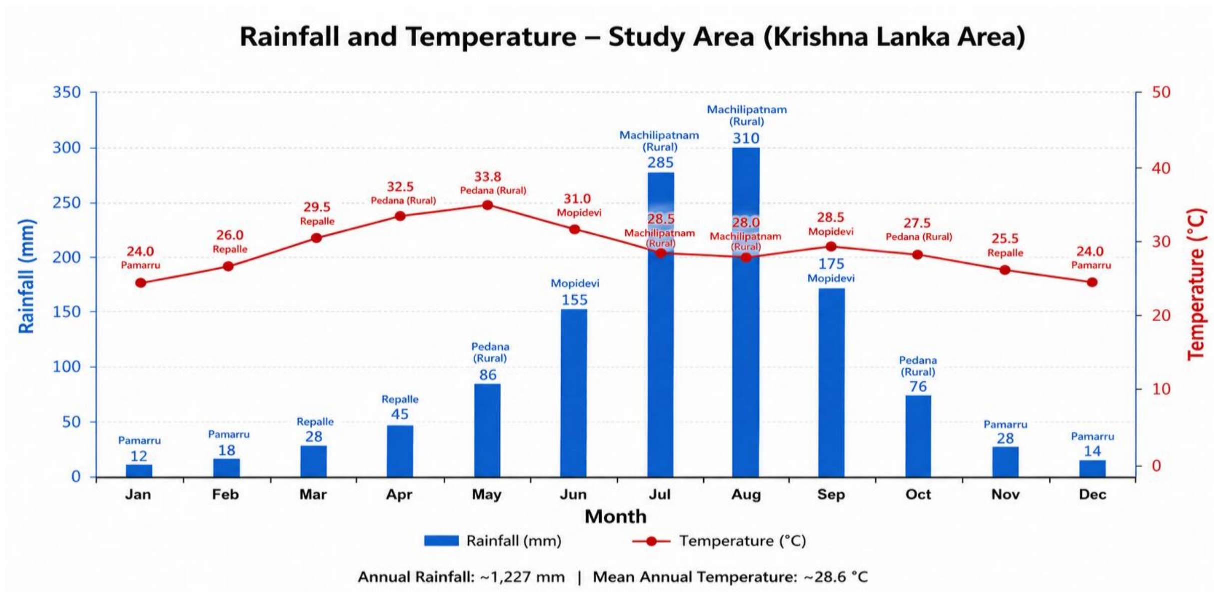


Fig 2. Rainfall and Temperature of the study area

2.2 The Revised Universal Soil Loss Equation (RUSLE)

Soil erosion can be quantitatively estimated as the combined effect of six major controlling factors climatological, pedological, topographical, land cover, and anthropogenic influences expressed through the widely used Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978).

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

where A represents the average annual soil loss per unit area (t ha^{-1} yr^{-1}). R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}), reflecting the impact of raindrop intensity and runoff. K denotes the soil erodibility factor (t h MJ^{-1} mm^{-1}), indicating the susceptibility of soil particles to detachment and transport. LS is the topographic factor (dimensionless), which combines slope length (L) and slope steepness (S). C is the cover and management factor (dimensionless), representing the effect of vegetation and cropping practices, while P is the support practice factor (dimensionless), accounting for conservation measures such as contouring and terracing (Renard et al., 1997; Morgan, 2005).

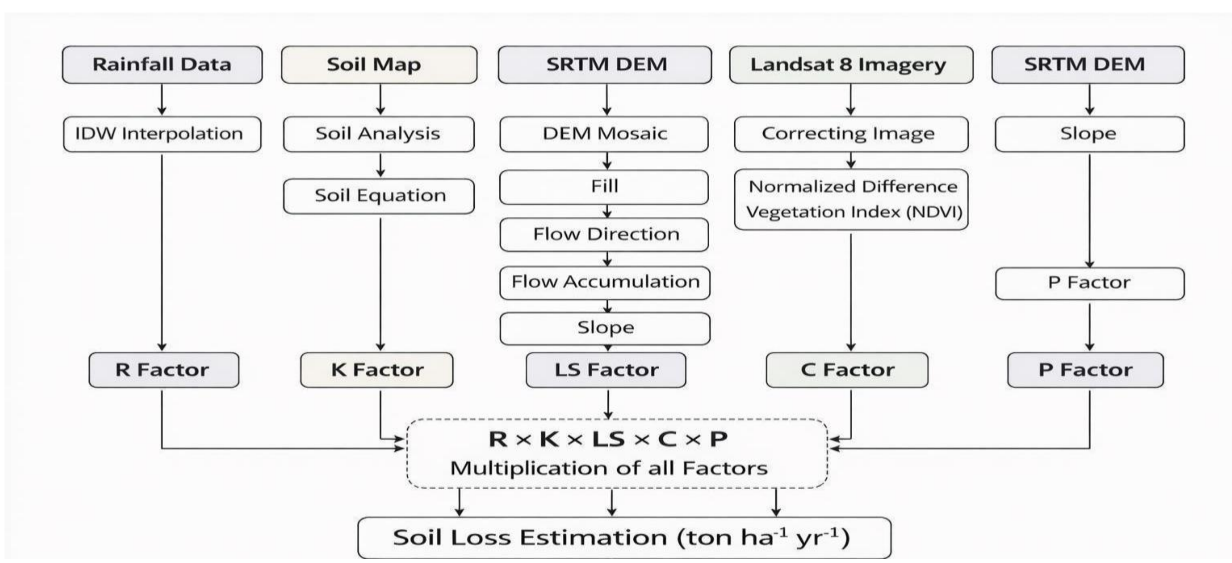


Fig 3. RUSLE Flow chart of the study area

The flowchart (Fig. 3) represents the procedure adopted to estimate soil loss using the RUSLE model integrated with GIS techniques. Rainfall, soil, topography, and satellite data are processed separately to derive R, K, LS, C, and P factors. DEM-based analysis provides slope and flow characteristics, while NDVI from satellite imagery is used to represent vegetation cover. Each factor map is generated and then combined through multiplication to calculate soil erosion spatially. This integrated approach using remote sensing and GIS is widely applied for soil erosion assessment in different watersheds (Getu et al., 2022; Ganasri and Ramesh, 2016; Kiruthika et al.; Oued Laou Basin study, 2021).

2.2.1 Rainfall Erosivity Factor (R)

In the present study area, the R-factor values range from approximately 811.96 to 982.97 MJ mm ha^{-1} h^{-1} yr^{-1}, indicating a moderate to relatively high erosive potential. The southern portion of the region shows comparatively higher values, suggesting that these areas experience more intense rainfall events and are therefore more susceptible to soil erosion. In contrast, the northern parts exhibit slightly lower erosivity values, indicating comparatively reduced rainfall impact.

2.2.2 Soil Erodibility Factor (K)

The Soil Erodibility Factor (K) map (Fig 4) shows how easily the soil in your study area can be detached and transported by rainfall and runoff. In this map, K values range from about 0.235 to 0.329, indicating moderate soil erodibility across the region. Higher K values (darker orange areas, mainly in the northern part) suggest soils that are more vulnerable to erosion due to weaker structure or finer particles. Lower values (lighter shades in the southern region) indicate relatively stable soils with better resistance to erosion.

2.2.3 Slope Length and Steepness Factor (LS)

The LS factor map (Fig 4) represents the influence of slope length and slope steepness on soil erosion in the study area. Higher LS values (shown in darker tones along drainage lines) indicate areas where runoff flows over longer distances and steeper slopes, increasing erosion potential. Lower LS values in flatter regions suggest less runoff energy and therefore lower chances of soil loss. The pattern clearly follows the drainage network, showing that erosion is more likely along streams and flow paths. The areas with higher LS values are more prone to erosion and require proper soil conservation measures.

2.2.4 Cover Management Factor (C)

This land use map (Fig 4) shows different surface features in the study area such as water bodies and vegetation types.The blue color represents water features, mainly the river flowing through the central part of the area. Light green indicates moderate vegetation, which is spread across most of the region and represents agricultural or mixed land cover. Dark green shows dense vegetation, mostly concentrated near the river and southern parts. Low vegetation areas are scattered in small patches, indicating less plant cover and possible open or fallow land.

2.2.5 Support Practice Factor (P)

The P factor map (Fig 4) shows the effect of conservation practices on soil erosion in the study area. Green shades represent very low and low values, which indicate better protection due to practices like contouring or vegetation cover. Yellow areas show moderate values where protection is limited and some erosion risk exists. Orange and red patches indicate high and very high values, meaning little or no conservation measures and higher chances of soil loss. Most parts of the area fall under low to moderate categories, while scattered high value zones need improved management practices.

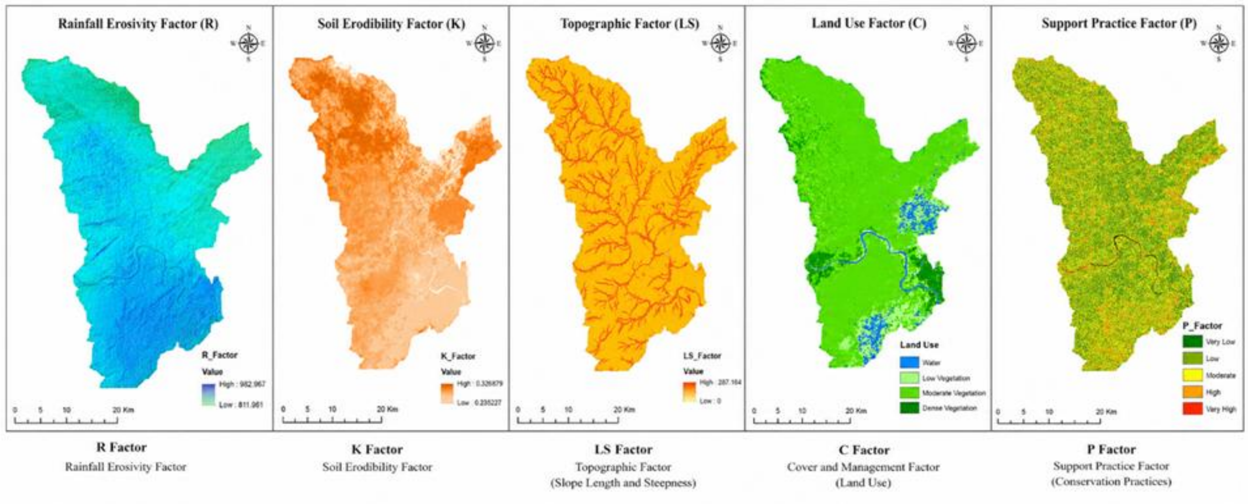


Fig .4 RUSLE Spatial maps of the study area

III. RESULTS AND DISCUSSION

The estimated soil loss results from 2020 to 2025 indicate (Table 1) noticeable variation mainly due to changes in rainfall erosivity and vegetation cover conditions. Higher soil loss values observed in years such as 2022 and 2024 can be linked to increased rainfall intensity, which enhances the detachment and transport capacity of runoff. Similar findings have been reported in watershed-based studies where rainfall plays a dominant role in controlling annual soil erosion rates. The relatively stable values of K, LS, and P factors suggest that soil characteristics, topography, and conservation practices remain unchanged over time, while temporal variability is primarily driven by climatic and land cover dynamics. This trend is consistent with studies that emphasize the combined influence of rainfall and vegetation cover in erosion processes.

The results also show that areas with reduced vegetation cover tend to experience higher soil loss, highlighting the importance of land management practices. Previous research using GIS and RUSLE models has demonstrated that vegetation acts as a protective layer, reducing runoff velocity and soil detachment. These findings align with studies conducted in different watersheds, where integrated use of remote sensing and GIS with the RUSLE model has proven effective for estimating spatial and temporal soil erosion patterns and identifying vulnerable zones for conservation planning (Getu et al., 2022; Ganasri and Ramesh, 2016; Kiruthika et al.; Oued Laou Basin study, 2021).

Table 1: Annual Results

Year	R Factor	K Factor	LS Factor	C Factor	P Factor	Soil Loss A ($t\ ha^{-1}\ yr^{-1}$)
2020	845.20	0.28	145.00	0.32	0.55	598.45
2021	872.10	0.28	145.00	0.30	0.55	603.88
2022	910.35	0.28	145.00	0.34	0.55	671.92
2023	888.60	0.28	145.00	0.31	0.55	622.17
2024	925.80	0.28	145.00	0.35	0.55	703.54
2025	901.45	0.28	145.00	0.33	0.55	650.28

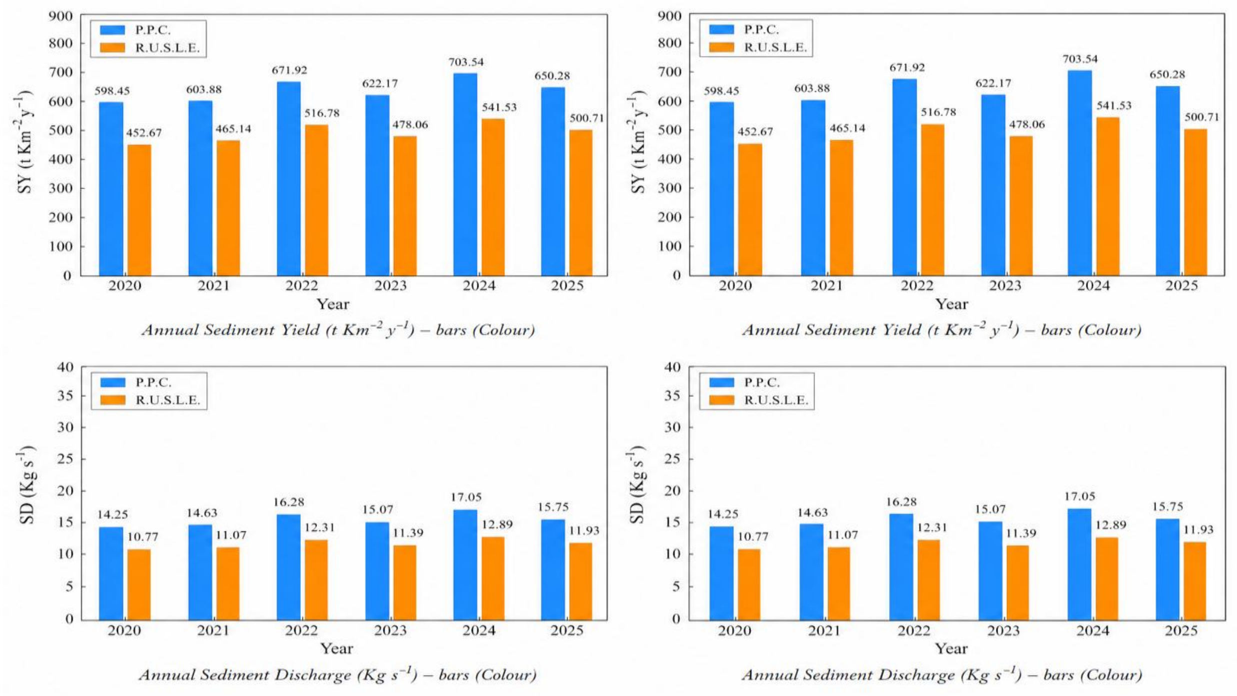


Fig. 5 Annual Results

The bar graphs illustrate the variation of annual sediment yield and sediment discharge for the period 2020 to 2025 using both PPC and RUSLE approaches. In all years, the PPC values are consistently higher than the RUSLE estimates, indicating that PPC tends to predict greater sediment output compared to the model-based RUSLE method. Sediment yield shows an increasing trend from 2020 to 2022, followed by a slight decrease in 2023, and then reaches a peak in 2024 before declining again in 2025. A similar pattern is observed in sediment discharge, where the highest values occur in 2024, suggesting a strong influence of rainfall and runoff during that year.

The comparative behaviour between the two methods remains consistent across both sediment yield and discharge graphs, with RUSLE providing relatively conservative estimates. The fluctuations observed over the years can be linked to variations in rainfall intensity and vegetation cover, which directly influence erosion processes. The close agreement in trend between PPC and RUSLE indicates that both approaches effectively capture temporal variations in soil erosion, while the differences in magnitude highlight methodological variations in estimation.

IV. DISCUSSION

The objective of this study was to quantify soil erosion and sediment yield in the study area using the RUSLE model integrated with GIS. A GIS based evaluation was adopted to efficiently handle spatial datasets such as rainfall, soil, topography, and land use. Each factor was derived systematically: the R factor from interpolated rainfall data, the K factor from soil properties, the LS factor from DEM based slope and flow accumulation, the C factor from NDVI derived using satellite imagery, and the P factor from slope and conservation practice information. These factor maps were prepared as raster layers and multiplied within the GIS environment to estimate spatial soil loss. This approach enables accurate representation of spatial variability and is widely used for erosion assessment in watershed studies.

The results show that sediment yield varies from year to year, mainly influenced by rainfall intensity and vegetation conditions. Higher sediment yield values observed in certain years indicate increased runoff and erosion activity, while lower values reflect better vegetation cover and reduced rainfall impact. The model execution demonstrates that RUSLE can effectively identify erosion prone areas and temporal variations in soil loss. The application of RUSLE in this study highlights its usefulness as a decision support tool for soil conservation planning, helping to prioritize areas that require management practices and reducing land degradation in the study region.

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