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Modelling Soil Erosion Using RUSLE and GIS for Kadalundi River Basin in Kerala, India

Akhina P. [a++*], Rema K. P. [a], Anu Varughese [a], Divya Vijayan [b] and Asha Joseph [a]

[a] Department of Irrigation and Drainage Engineering, KCAET, Tavanur, Malappuram, India.
[b] Department of RS&GIS, College of Forestry, Thrissur, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The main objective of the study was to estimate the potential average annual soil loss from Kadalundi river basin using RUSLE model and to prepare the spatial distribution map of soil erosion hazard using GIS to suggest suitable soil conservation and management measures for the basin. The individual factor maps for each factor in the RUSLE equation were prepared and multiplied in raster calculator to obtain the spatial distribution map of soil erosion with the help of ArcGIS. The daily rainfall data, basic soil data, Digital Elevation Model (DEM) and satellite imageries were used as the input data for the calculation of rainfall erosivity factor, soil erodibility factor, topographic factor, cover management factor and conservation practice factor. The results indicated an average annual erosion of 5.48 $t \cdot ha^{-1} \cdot yr^{-1}$ in the basin during the period of 2001 to 2021. The total quantity of soil washed away from the basin was 694836.60 $t \cdot yr^{-1}$. The estimated values of R-factor ranged from 938.97 $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot yr^{-1}$ to 1102.65 $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot yr^{-1}$, and the computed erodibility factor

[++] *Post Graduate Student;*
**Corresponding author: E-mail: akhinaajith17@gmail.com;*

values varied between 0.0075 to 0.025 $t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$. The topographic factor value of the basin was found between 0 to 9.07. The basin had C-factor values of 0.08 to 1.10 and the P-factor values varied from 0.1 to 1. The spatial distribution map of erosion suggest that major part of the basin is under slight erosion class and only a minor part is under very severe erosion class. Areas in the very severe erosion class is characterised by moderate to steep slopes, or in other words areas with less slope is having slight erosion. As most of the area of the basin is having slight erosion, simple agronomical measures can be adopted for the mitigation purposes.

Keywords: Modelling; RUSLE; GIS; soil erosion; Kadalundi river basin; India.

1. INTRODUCTION

Soil and water are the foundation of life, and the sustainable management of these natural resources is inevitable. Soil is the key resource to achieving planet sustainability [1]. All living beings benefit from the top 30 cm of soil. The detachment transportation and deposition of nutrient rich top soil is termed as soil erosion. It is usually a natural phenomenon caused by natural forces like water, wind and glaciers. However, it can be accelerated by anthropogenic actions like deforestation, intensive agriculture and others. Erosion caused by water is more common in most of the places. The impact of rainwater touching the ground initiates the erosion process and further it removes a sheet of soil which is known as sheet erosion.

Soil erosion reduces the quality of soil which will results in decline in agricultural productivity. Apart from reduction in soil quality, soil erosion has other detrimental effects like land degradation, desertification, sedimentation in rivers and reservoirs, reduction of water holding capacity of the soil, water pollution and even ecological collapse. According to estimates, erosion causes the loss of 24 billion tonnes of fertile soil annually. Moving just across the border from one country to the next changes the rate of soil erosion by 1.4 $t \cdot ha^{-1} \cdot yr^{-1}$ [2]. About 26.50%, 22%, 5% and 9% of Total Geographical Area (TGA) of Andhra Pradesh, Karnataka, Kerala and Tamil Nadu states, respectively, experiences moderate or moderate to severe soil loss [3]. Soil erosion is affecting 15.12 per cent of Kerala's TGA, with erosion rates of more than 10 $t \cdot ha^{-1}$ [4]. Additionally, the elimination of wetlands has led to increased soil erosion and flooding in Kerala [5]. According to Chinnasamy et al. [6], floods expose the vulnerable saturated soil and erode the topsoil, which causes further soil erosion and flooding in the future due to less soil available for recharge. From the study, they found that the 2018 floods in Kerala significantly boosted soil erosion rates by 80 per cent.

Assessment of soil erosion in large scale by traditional methods has always been a challenge to the researchers. Models integrated with Geographic Information System (GIS) has emerged as an alternative to tedious conventional methods. Empirical models such as Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE) are most commonly used for the estimation of soil erosion. The USLE is an empirical model used for a given combination of crop system, management practice, soil type, rainfall pattern, and topography [7]. The equation was later updated to overcome its disadvantages, and is known as RUSLE. High compatibility of the empirical models, such as USLE and RUSLE, with GIS has made the erosion assessment much more effortless.

Kadalundi river is one of the four major rivers flowing through the Malappuram district of Kerala. The major part of Malappuram district is covered by the Kadalundi river basin, which is often prone to soil erosion problems. The climatic conditions and topographic characteristics of the basin make it susceptible to water erosion and sedimentation at various locations in the basin. Even though different studies concentrated on the land use change in the Kadalundi river basin, the groundwater scenario of the basin and the biodiversity of the basin, studies still needed to address the erosion problems in the basin. This study is the first endeavour to integrate the RUSLE model with GIS to quantify the annual rate of soil erosion in the Kadalundi river basin.

In light of the above mentioned facts, the present study estimates soil loss from the Kadalundi river basin using RUSLE with the assistance of GIS, anticipating to accomplish the objective of modelling the potential annual average soil loss from the Kadalundi river basin using RUSLE and mapping the spatial distribution of soil erosion hazard using GIS to suggest suitable soil conservation and management protocols for the watershed.

The Kadalundi river basin, which extends through three districts of Kerala; Kozhikode, Malappuram and Palakkad, is the area selected for the study. The location map of the study area is shown in Fig. 1. Kadalundi river originates from the Western Ghats of Palakkad district and has two principal tributaries, Olipuzha and Veliyar rivers. The river has a total length of nearly 120 km, with a drainage area of 1274 km². The river drains into the Arabian sea at Kadalundi Nagaram in Vallikkunnu on the North-Western border of Malappuram district. The Kadalundi river basin is located between 10°51’42’’ to 11°10’42’’ north latitude and 75°48’21’’ to 76°24’30’’ east longitude. Topographically this basin exhibits undulating terrain with steep slopes with an elevation ranging from 0 to 1348 m above MSL. Based on the physiographic condition, the study area constitutes the three well defined natural divisions of Kerala: lowland, midland and highland.

The river basin has a typical tropical climate, with notable influence from the southwest monsoon season. The Kadalundi river basin receives 3610 mm of rain on average each year. The climate is typically hot and humid, with maximum and minimum temperatures of 28.9 to 36.2°C and 17.0 to 23.4°C respectively. The geology, soil and LULC in the river basin indicate a fertile land. The primary soil types in the basin include laterites, riverine alluvium, coastal alluvium and loamy soil. The major economic activity is agriculture, even though no considerable irrigation schemes are present in the river basin. With diverse agro climatic conditions encountered in different physiographic zones, a wide range of crops, such as coconut, paddy, tapioca, cashew nuts, pepper, rubber, areca nuts and others are cultivated in this basin. The significant land use land cover in the basin are waterbody, cropland, built-up land, fallow land, forest land and barren rocky areas. The Kadalundi river basin is blessed with rich biodiversity, including both flora and fauna. The Kadalundi estuary, a remarkable wetland, is situated at the mouth of the river and is renowned for its extensive mangrove forest distribution and presence of migratory birds.

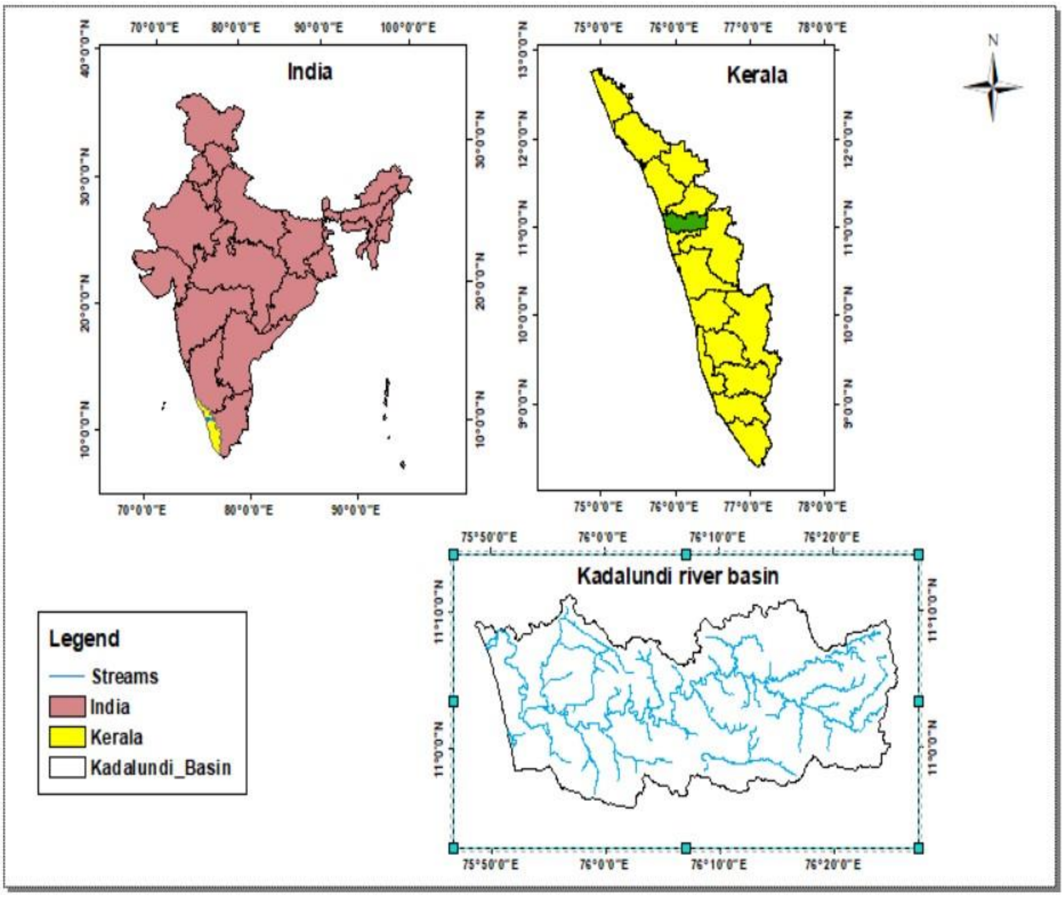

Fig. 1. Location map of the study area

Table 1. Input data used and corresponding source

Input data	Source
Daily rainfall data	IMD stations and WRD stations (https://dsp.imdpune.gov.in/)
Soil data	SoilGrids (https://soilgrids.org/)
Digital Elevation Model	USGS Earth Explorer (https://earthexplorer.usgs.gov/)
Satellite Imageries	USGS Earth Explorer (https://earthexplorer.usgs.gov/)

1.1 Data

The study area consists of six rain gauge stations, including stations under Indian Meteorological Department (IMD) and Kerala Water Resource Department (WRD). The daily rainfall data of the IMD stations were directly downloaded from their official website (https://dsp.imdpune.gov.in/). The available data from WRD stations were obtained from Irrigation Design and Research Board (IDRB), Thiruvananthapuram. The soil data were downloaded from the Soil Grids website (https://soilgrids.org/) as GIS layers, which are publically available. The present study used SRTM Digital Elevation Model (DEM) downloaded from United States Geological Survey (USGS) Earth Explorer (https://earthexplorer.usgs.gov/) with a resolution of 30 m. To prepare the land use land cover map and NDVI map, Landsat 8 imageries of the year 2021 were downloaded from the USGS earth explorer. Table 1 indicates the input data used for the study and its corresponding sources.

2. METHODOLOGY

Assessment of soil erosion by conventional method has always been a strenuous work to the scientists and researchers. Empirical models like USLE and RUSLE created a revolution in the estimation of soil erosion. The RUSLE, proposed by Renard et al. [8] deals with empirical data for the estimation of annual average rate of soil erosion. The average annual soil erosion in the Kadalundi river basin was estimated using the equation (1).

$$\mathrm{A} = \mathrm{R} \times \mathrm{K} \times \mathrm{L} \times \mathrm{S} \times \mathrm{C} \times \mathrm{P} \quad (1)$$

Where, A=Average annual soil loss ($t \cdot ha^{-1} \cdot yr^{-1}$), R=Rainfall erosivity factor ($MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot yr^{-1}$), K=Soil erodibility factor ($t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$), L=Slope length factor (dimensionless), S=Slope steepness factor (dimensionless), C=Cover management factor (dimensionless), and P=Soil conservation practices factor (dimensionless).

2.1 Creation of RUSLE Factor Maps

2.1.1 Rainfall erosivity (R) factor map

Rainfall erosivity is the ability of rainfall to remove the topsoil. In the RUSLE equation, when factors other than rainfall are held constant, soil losses from cultivated fields are the product of total storm energy (E) and the maximum 30-min intensity (I_{30}). The study area lacks recording type rain gauge stations, and hence intensity data could not be drawn. So, in this study the erosivity factor was computed by using equation (2) developed especially for Indian conditions [9].

$$\mathrm{R} = 81.5 + 0.375 \times \mathrm{P} \quad (340 > \mathrm{P} \leq 3500) \quad (2)$$

Where, R= Rainfall erosivity factor ($MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot y^{-1}$) and P= Annual rainfall (mm).

Daily rainfall data for 21 years (2001-2021) from six rain gauge stations in the study area were used as the input data to prepare the R-factor map. The map was prepared by the using Inverse Distance Weighted (IDW) interpolation method using IDW tool in ArcGIS.

2.1.2 Soil erodibility (K) factor map

Soil erodibility factor is an important factor that affects soil erosion along with the R-factor. It is the vulnerability of soil to be detached and transported during a storm event. The soil properties which influence erodibility are soil texture, soil structure, organic matter content in the soil, permeability of the soil, the surface roughness of soil particles and the moisture content present in the soil. A number of mathematical equations are available to find out the K-factor; nonetheless, the globally accepted method is using a nomograph [10] or the equation developed by Wischmeier and Smith [11]. Erodibility factor was found using the well-known equation (3) developed by Wischmeier et al. [10].

$$K = \frac{2.1\times10^{-4}\times(12-OM)\times M^{1.14}+3.25\times(s-2)+(p-3)}{759} \quad (3)$$

Where, K= Soil erodibility factor ($t{\cdot}ha{\cdot}h{\cdot}ha^{-1}{\cdot}MJ^{-1}{\cdot}mm^{-1}$), OM= Organic matter (%), M= A function of soil primary particle size fraction

$$\mathrm{M} = (\%\text{silt} + \%\text{very fine sand}) \times (100 - \%\text{clay}) \quad (4)$$

s= Soil structure code (1-Very fine granular, 2-Fine granular, 3-Medium or coarse granular, 4-Blocky, platy or prismatic), p= Soil permeability code. Soil permeability codes (p) based on textural classes include 1-rapid, 2-moderate to rapid, 3-moderate, 4-moderate to slow, 5-slow, and 6-very slow.

The required data like sand, silt and clay content ($g{\cdot}kg^{-1}$) and organic carbon ($dg{\cdot}kg^{-1}$) layers were downloaded as GIS layers from the SoilGrids website. Soil structure code and soil permeability code were obtained from Bench mark soils of Kerala by SSO (Soil Survey Organisation) [12] published by the Government of Kerala. Erodibility factor was computed by using equation (3) with the help of raster calculator in ArcGIS platform.

2.1.3 Topographic (LS) factor map

Slope length and slope steepness factors together is known as topographic factor. The topography of an area plays a significant role in generating runoff and soil erosion. Steep slope results in high flow velocity, increasing the capability of surface runoff or overland flow to detach and transport more soil particles. Slope length and the steepness of the slope were calculated separately using equation (5) and equation (7) or equation (8), put forward by Smith and Wischmeier [13] and Mccool et al. [14] and then multiplied to get the topographic factor.

$$\mathrm{L} = (\lambda/22.13)^{\mathrm{m}} \quad (5)$$

Where, L= Slope length factor (dimensionless), λ= Slope length (m) and m=Slope length exponent (dimensionless). Flow accumulation raster was created in ArcGIS from DEM and the. Slope length was calculated using equation (6) by considering the resolution of DEM as cell size. Here a globally accepted standard slope length exponent (m) value of 0.14 was used to calculate the slope length factor using equation (5).

$$\lambda = \text{Flow accumulation} \times \text{Cell size} \quad (6)$$

A slope map was needed to calculate the slope steepness factor. It was prepared in ArcGIS using slope tool in the spatial analyst tool of Arc toolbox, the input was DEM. The slope map in degree and percentage was created and converted into radians.

$$\mathrm{S} = 10.8 \times \sin\theta + 0.03 \qquad \mathrm{S} < 9\% \quad (7)$$

$$S = \left(\frac{\sin\theta}{\sin 5.143}\right)^{0.6} \qquad S \geq 9\% \quad (8)$$

Where, S=Slope steepness factor (dimensionless) θ= Slope angle (radian). After generating L-factor and S-factor maps, their product was found with the help of raster calculator in the Arc toolbox to get the topographic factor.

2.1.4 Cover management (C) factor layer

Another important factor influencing soil erosion rate is vegetation. If the soil is covered with vegetation, there will be enough time for infiltration thus, runoff will be less and chances of erosion will be minimized. In the RUSLE model, the effect of vegetation cover is incorporated in the cover management factor. In this study C-factor map was prepared with the help of NDVI map. According to Van et al. [15], for a large basin, it is hardly possible to estimate C-factor using the RUSLE guidelines due to the lack of sufficiently detailed data. After performing many experiments, he derived a nonlinear relationship between C-factor and NDVI, which seemed to be adequate.

$$\mathrm{C} = \exp\left(-\alpha \times \frac{\mathrm{NDVI}}{\beta-\mathrm{NDVI}}\right) \quad (9)$$

Where, C= Cover management factor (dimensionless), α= 2, β=1 and NDVI= Normalized Difference Vegetation Index.

NDVI is the measure of vegetation health on the land surface. In general, NDVI values range from -1.0 to 1.0, with negative values indicating clouds and water, positive values near zero indicating bare soil, and higher positive values of NDVI ranging from sparse vegetation (0.1 - 0.5) to dense green vegetation (0.6 and above). It was calculated by using equation 10.

$$\mathrm{NDVI} = \frac{\mathrm{NIR-R}}{\mathrm{NIR+R}} \qquad (10)$$

Where, NDVI= Normalized Difference Vegetation Index, NIR=Reflection in the Near Infrared region of the electromagnetic spectrum and R=Reflection in the visible red region of the electromagnetic spectrum.

For the preparation of NDVI map, B4 and B5 bands of Landsat 8 images of the year 2021 were used. NDVI was calculated in raster calculator using equation 10. Using this NDVI map, C-factor was calculated with the help of raster calculator using equation (9).

2.1.5 Conservation practice (P) factor map

Various agronomic and engineering measures are there to minimise the chances of erosion; the conservation practice factor accounts for the effect of soil and water conservation measures on soil erosion in an area. The P-factor values given by Wischmeier and Smith [11] on the basis of land use and field slope in percentage were employed in the present study. The P-factor values range from 0.1 to 1, such that areas having conservation measures will have less P-factor value, and areas with no conservation measures will have P-factor value of 1. Land use map prepared by using supervised classification in the ArcGIS platform and slope map was used for the creation of P-factor map. The land use map and slope map were combined using the union tool in overlay section in the analysis tools of arc tool box. The P-factor values were added to the attribute table of the union map according to Table 2.

Table 2. P-factor values based on slope and land use

Land use	Slope (%)	P-factor
Agricultural areas	0-5	0.10
	5-10	0.12
	10-20	0.14
	20-30	0.19
	30-50	0.25
	50-100	0.33
Non-agricultural areas	-	1

2.1.6 Estimation of average annual soil erosion

After preparing the individual factor maps, it was made sure that each map was projected in the WGS_1984_UTM_43N coordinate system. The spatial resolution of the datasets was resampled to 30 m, in order to derive uniform spatial variation of soil loss within the study area in ArcGIS 10.7.1. Average annual soil erosion in $t \cdot ha^{-1} \cdot yr^{-1}$ was calculated using equation 1 in raster calculator. The flow chart (Fig. 2) shows the overall methodology adopted for RUSLE modelling using GIS in this study.

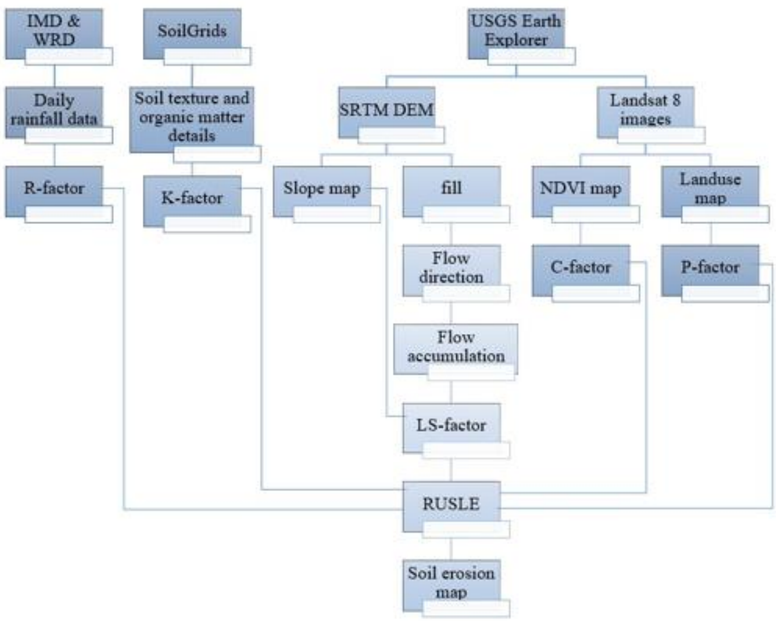

Fig. 2. Flow chart of estimation of soil loss using RUSLE and GIS

2.1.7 Statistics of soil erosion with respect to slope and land use

The distribution of erosion in various slope classes and land use classes were assessed with the help of zonal statistics tool in ArcGIS. The spatial similarities based on specific attributes like areas with similar soil, slope, land use, elevation etc. defines a zone. Zonal statistics in the ArcGIS is a tool to calculate the statistics of raster values which falls in particular zones defined by another raster or vector dataset. Zonal statistics were calculated as table which gives statistical values like minimum value, maximum value, range, mean, standard deviation and sum.

3. RESULTS AND DISCUSSION

3.1 Rainfall Erosivity Factor

The amount of rainfall is an important parameter in the generation of sediment particles, therefore it greatly affects the soil erosion rate. The amount of rainfall and its intensity is directly related to soil erosion. The current study made use of annual rainfall for the calculation of erosivity factor. Similar equation to estimate the R-factor was used by [16]. The estimated R-factor ranges from 938.97 $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot yr^{-1}$ to 1102.65 $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot yr^{-1}$. Fig. 3 shows the spatial distribution of R-factor over Kadalundi river basin. The interpolated values of R-factor have varying values in each pixel. The higher values of R-factor were found at Karippur and Perinthalmanna regions where average annual rainfall was high. The spatial distribution map of the erosivity factor indicated that the erosivity factor has an increasing trend in highly elevated areas. The results of R-factor of the present study were comparable with the R-factor calculated by Thomas et al. [17] for Muthirapuzha river basin in Kerala.

3.2 Soil Erodibility Factor

The erosion susceptibility of the soil is invariably denoted by soil erodibility factor. The soil data downloaded from the SoilGrids website indicated 0 to 54 per cent sand content, 0 to 32 per cent silt content, 0 to 39 per cent clay content and 0 to 12.56 per cent organic matter content in the Kadalundi river basin. The overall permeability

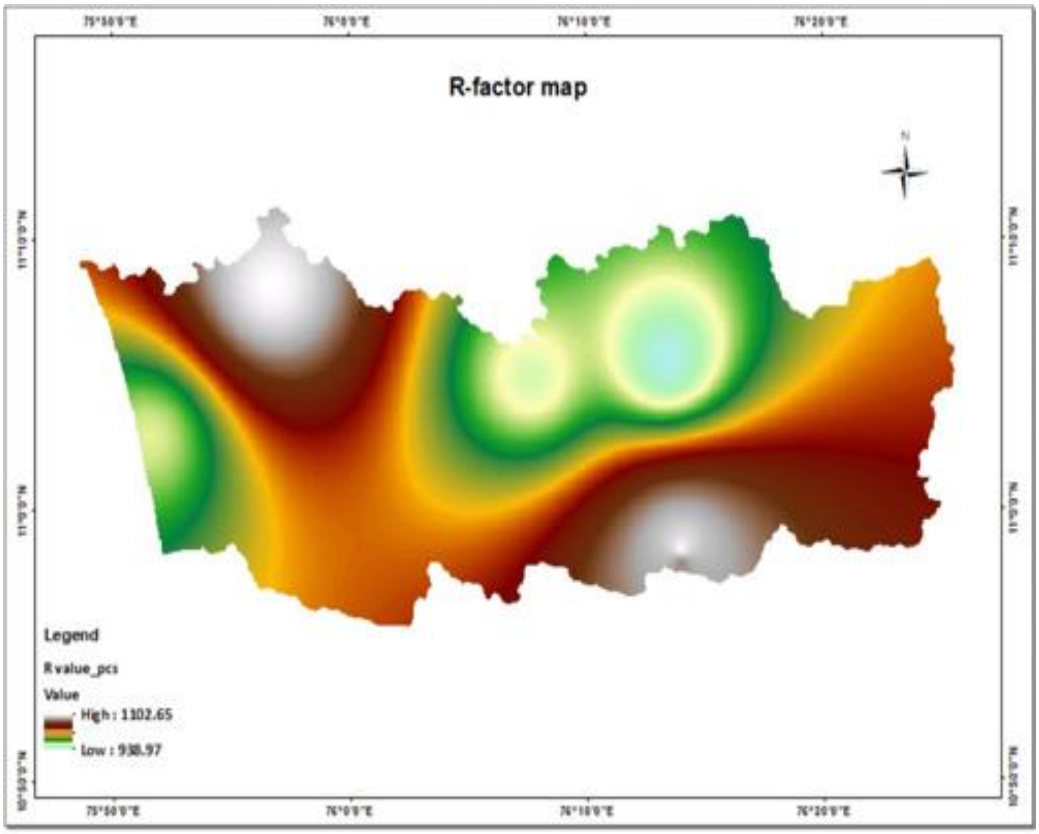

Fig. 3. Spatial distribution map of R-factor

code and structural code of the Kadalundi river basin was taken as 3 and 4 respectively. The erodibility factor computed using these data using equation (3) extended from 0.0075 to 0.0256 $t{\cdot}h{\cdot}MJ^{-1}{\cdot}mm^{-1}$ with a mean value of 0.0183 $t{\cdot}h{\cdot}MJ^{-1}{\cdot}mm^{-1}$. The areas characterised mainly by high slopes and barren rocky regions had high soil erodibility. Fig. 4 represents the spatial variability of erodibility factor in the Kadalundi river basin. In general, the low values of K-factor refer to the reduced erosion in the basin. The research carried out by Georage et al. [18] used the soil data from SoilGrids website to get K-factor values of 0.017 to 0.054 $t{\cdot}h{\cdot}MJ^{-1}{\cdot}mm^{-1}$with a mean value of 0.03 $t{\cdot}h{\cdot}MJ^{-1}{\cdot}mm^{-1}$.

3.3 Topographic Factor

Topography of an area plays an important role in runoff generation and soil loss estimation. To create the LS-factor map, the slope length factor map and the slope steepness factor map were prepared separately by using flow accumulation raster and slope map respectively. The slope map prepared for Kadalundi river basin is displayed in Fig. 5. Major part of the basin (29.31%) has slope values between 0 to 5 per cent, a reasonable per cent of the area (53.38%) comes under 5 to 20 per cent slope and only less than 3 per cent of the total area falls under slope per cent greater than 50. The L-factor values ranged between 0 to 2.34, whereas the values of S-factor ranged from 0.03 to 4.15. The LS-factor values of the basin were found between 0 to 9.07 with a mean value of 0.88. It was observed that the pixels with high slope was characterised by high LS-factor values. Fig. 6 shows the LS-factor map of Kadalundi river basin, which clearly indicates that the north-eastern part and central portions of the basin has high LS-factor value. Areas with steep slopes trigger more runoff, and hence, soil loss will be greater in these areas.

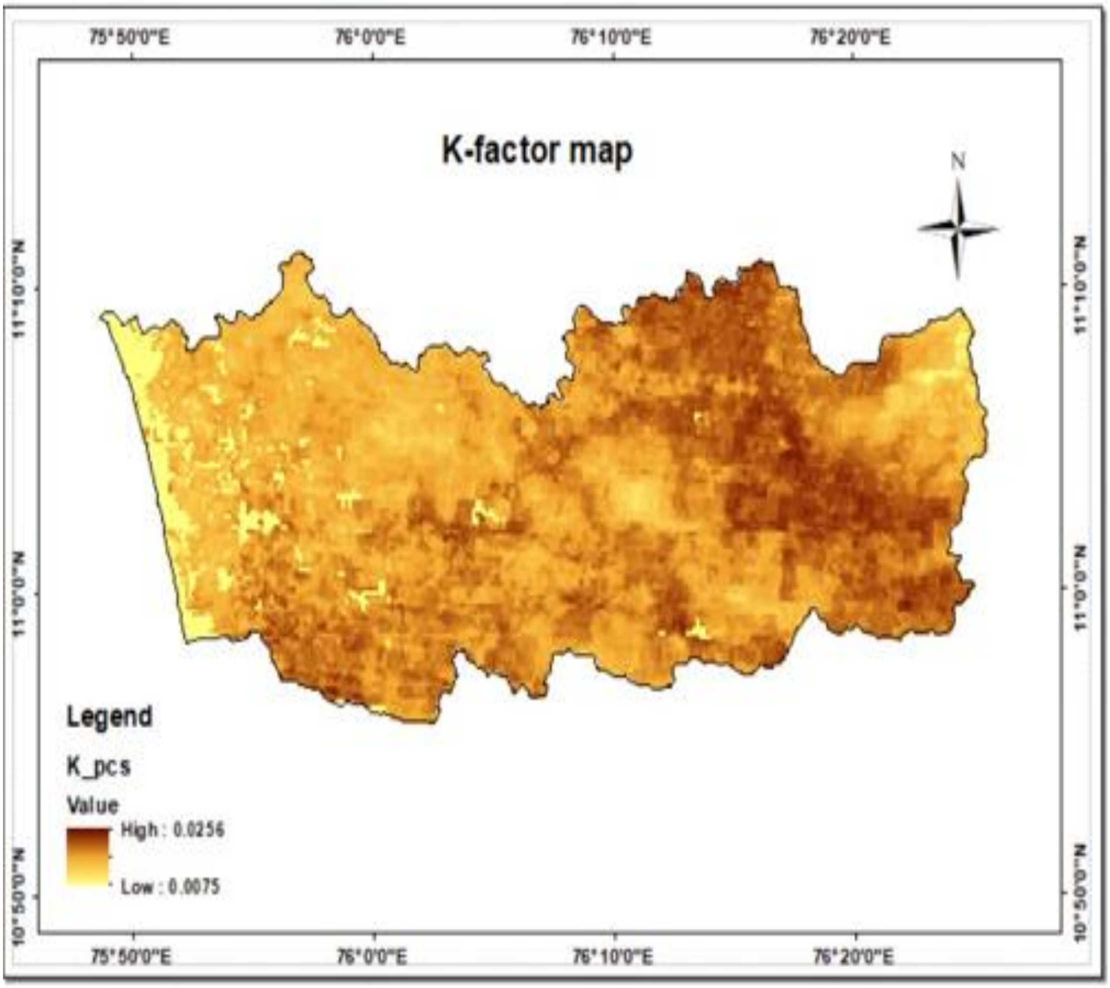

Fig. 4. Soil erodibility factor map of Kadalundi river basin

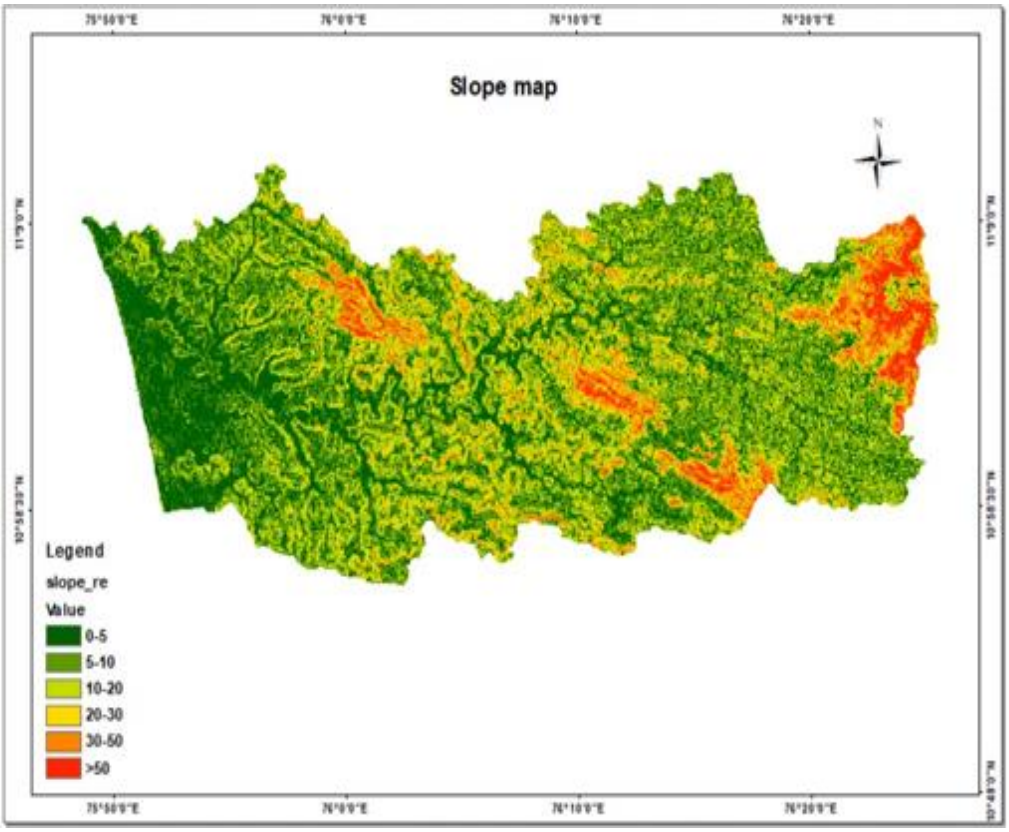

Fig. 5. Slope map of Kadalundi river basin

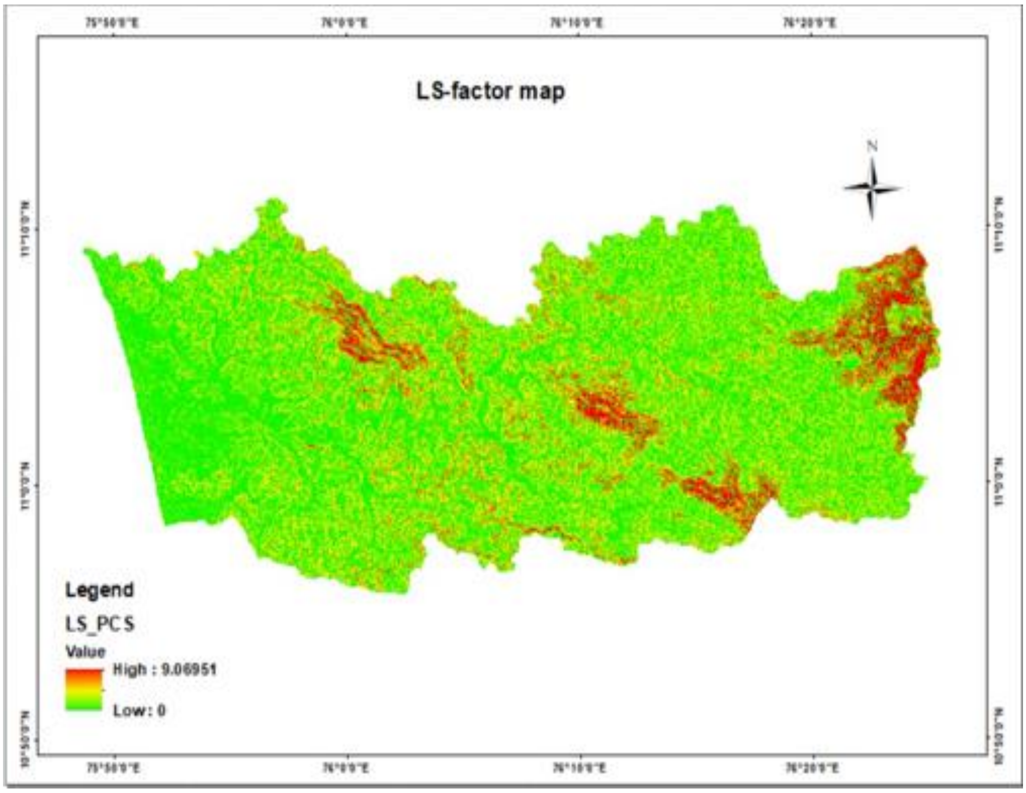

Fig. 6. Topographic factor map of Kadalundi river basin

3.4 Cover Management Factor

The C-factor reflects the effect of surface cover, and practices that change the amount of surface cover, on erosion [19]. In the present study, the C-factor map was generated from the NDVI map prepared with the aid of satellite images. The NDVI values of the basin varied between -0.05 to 0.55, the moderate value is an indication of sparse vegetation in the basin the negative value indicates waterbodies and built-up lands. The higher values of NDVI in the basin were observed in highly vegetated areas. The basin has C-factor values of 0.08 to 1.10 which is shown in Fig. 7. In contrast with NDVI values high C-factor values were noted in areas with waterbodies and built-up and low C-factor values were found in areas with vegetation cover.

3.5 Conservation Practice Factor

The effect of various conservation measures adopted in the agricultural land is shown in the P-factor map. The present study made use of slope map and land use map to create P-factor map, as the P-factor values considered in the study depended on the slope per cent and land use of the basin [11]. The slope map and land use map were combined to assign the P-factor values. It was assigned such that values less than 1 represented the agricultural lands and 1 designated all non-agricultural lands. As per Table 2, the P-factor values ranged from 0.1 to 1. The land use land cover map of the basin prepared by supervised classification is displayed in Fig. 8. Analysis of the land use land cover map revealed that 52.87 per cent of the basin area is covered by dense vegetation, while the barren land constitutes only 0.21 per cent. Significant amount of the area comes under built-up land and crop land with representative area per cent of 18.70 and 13.35 respectively. The P-factor map of the basin is shown in Fig. 9. The major part of the basin had a high P-factor due to the absence of conservation practices. Only 13.35 per cent of the total basin area has cropland, therefore lower values of P-factor are limited in the basin.

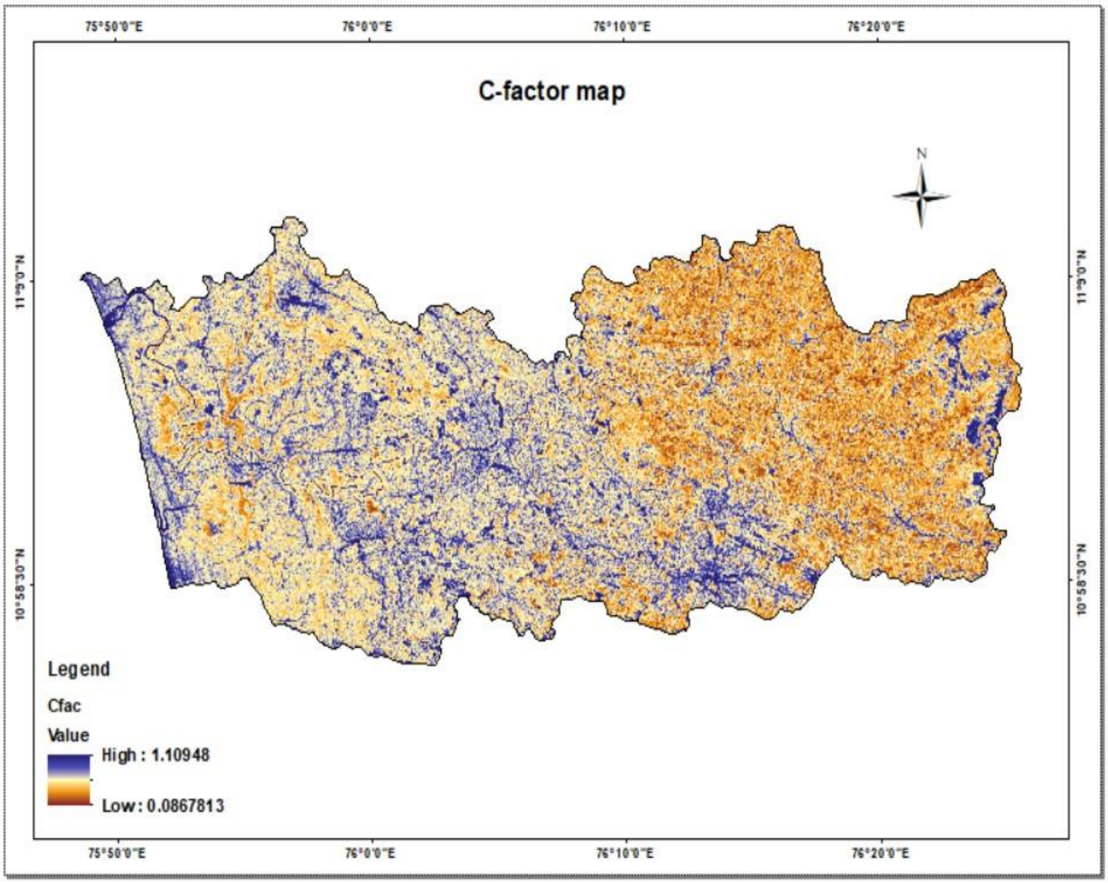

Fig. 7. Spatial distribution of C-factor in Kadalundi river basin

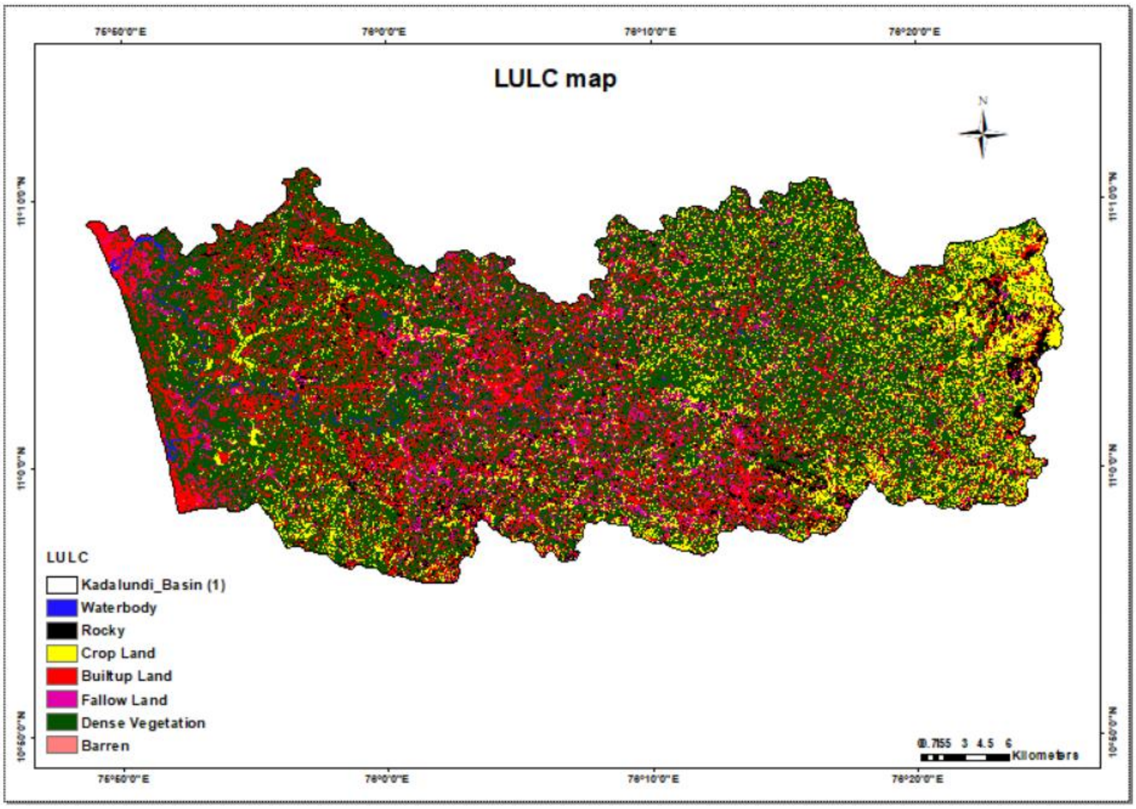

Fig. 8. Land use map of Kadalundi river basin

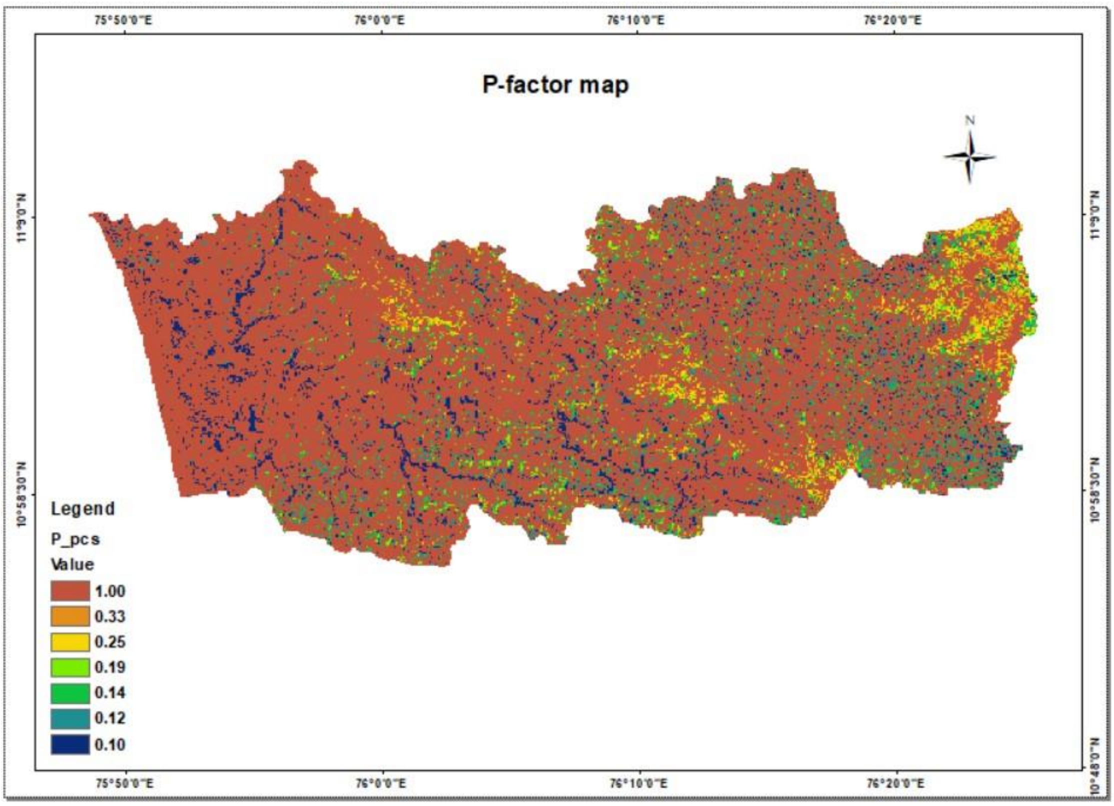

Fig. 9. P-factor map of Kadalundi river basin

3.6 Estimation of Average Annual Soil Erosion

The map obtained by multiplying the above mentioned individual factor maps in raster calculator of ArcGIS, demonstrates the spatial distribution of soil erosion in Kadalundi river basin (Fig. 10). The values of the estimated soil erosion by RUSLE model in the basin ranges from 0 to 100.33 $t \cdot ha^{-1} \cdot yr^{-1}$ with a mean value of 5.48 $t \cdot ha^{-1} \cdot yr^{-1}$. The total quantity of eroded soil from the basin was 694836.60 $t \cdot yr^{-1}$. Table 3 shows the categorised values of soil erosion and corresponding area covered. Major portion of Kadalundi river basin (60.66%) is subjected to slight erosion (<5 $t \cdot ha^{-1} \cdot yr^{-1}$) and only 0.45 per cent has very severe erosion (>40 $t \cdot ha^{-1} \cdot yr^{-1}$). These values showed strong agreement with the results obtained by Naidu et al. [20] for soil erosion estimation in Malappuram district of Kerala (59.17% in slight erosion class and 0.40% in very severe erosion class). Other classifications are, 15.96 per cent of area under moderately slight erosion class (5-10 $t \cdot ha^{-1} \cdot yr^{-1}$) moderate erosion (10-15 $t \cdot ha^{-1} \cdot yr^{-1}$) consists of 13.28 per cent of the area, moderately severe erosion class (15-20 $t \cdot ha^{-1} \cdot yr^{-1}$) includes 5.92 per cent of the total area and nearly 4 per cent (3.70%) comes under severe erosion class (20-40 $t \cdot ha^{-1} \cdot yr^{-1}$).

3.7 Statistics of Soil Erosion with Respect to Slope and Land Use

The effect of slope and land use on soil erosion can be comprehended from the zonal statistics. The mean value of erosion is low (1.40 $t \cdot ha^{-1} \cdot yr^{-1}$) in less than 5 per cent slope class and a high mean erosion value of 20.52 $t \cdot ha^{-1} \cdot yr^{-1}$ was observed in greater than 50 per cent slope class (Table 4). Slope ranging between 30-50 per cent had a mean erosion value of 11.56 $t \cdot ha^{-1} \cdot yr^{-1}$.

Table 3. Soil erosion risk classification and area coverage

Sl. No.	Soil loss ($t \cdot ha^{-1} \cdot yr^{-1}$)	Erosion class	Area (ha)	Area (%)
1.	<5	Slight	76214.07	60.66
2.	5-10	Moderately slight	20060.82	15.96
3.	10-15	Moderate	16684.83	13.28
4.	15-20	Moderately severe	7439.22	5.92
5.	20-40	Severe	4660.56	3.70
6.	>40	Very severe	570.96	0.45

Table 4. Variation of erosion in each slope class in Kadalundi river basin

Slope classes (%)	Minimum value of erosion ($t \cdot ha^{-1} \cdot yr^{-1}$)	Maximum value of erosion ($t \cdot ha^{-1} \cdot yr^{-1}$)	Mean value of erosion ($t \cdot ha^{-1} \cdot yr^{-1}$)	Standard deviation of erosion ($t \cdot ha^{-1} \cdot yr^{-1}$)
0-5	0	32.44	1.40	2.31
5-10	0	37.07	4.33	4.84
10-20	0	54.34	6.99	6.63
20-30	0	75.95	9.19	8.28
30-50	0	81.19	11.56	10.48
>50	0	100.33	20.52	17.09

Table 5. Variation of erosion in each land use class in the basin

Land use classes	Minimum value of erosion ($t \cdot ha^{-1} \cdot yr^{-1}$)	Maximum value of erosion ($t \cdot ha^{-1} \cdot yr^{-1}$)	Mean value of erosion ($t \cdot ha^{-1} \cdot yr^{-1}$)	Standard deviation of erosion ($t \cdot ha^{-1} \cdot yr^{-1}$)
Waterbody	0	68.44	4.57	8.29
Rocky	0	100.33	10.82	14.55
Crop land	0	59.53	3.47	5.11
Built-up land	0	76.37	6.03	7.79
Fallow land	0	67.48	3.69	6.22
Dense vegetation	0	70.19	5.47	6.38
Barren land	0	75.39	12.43	16.24

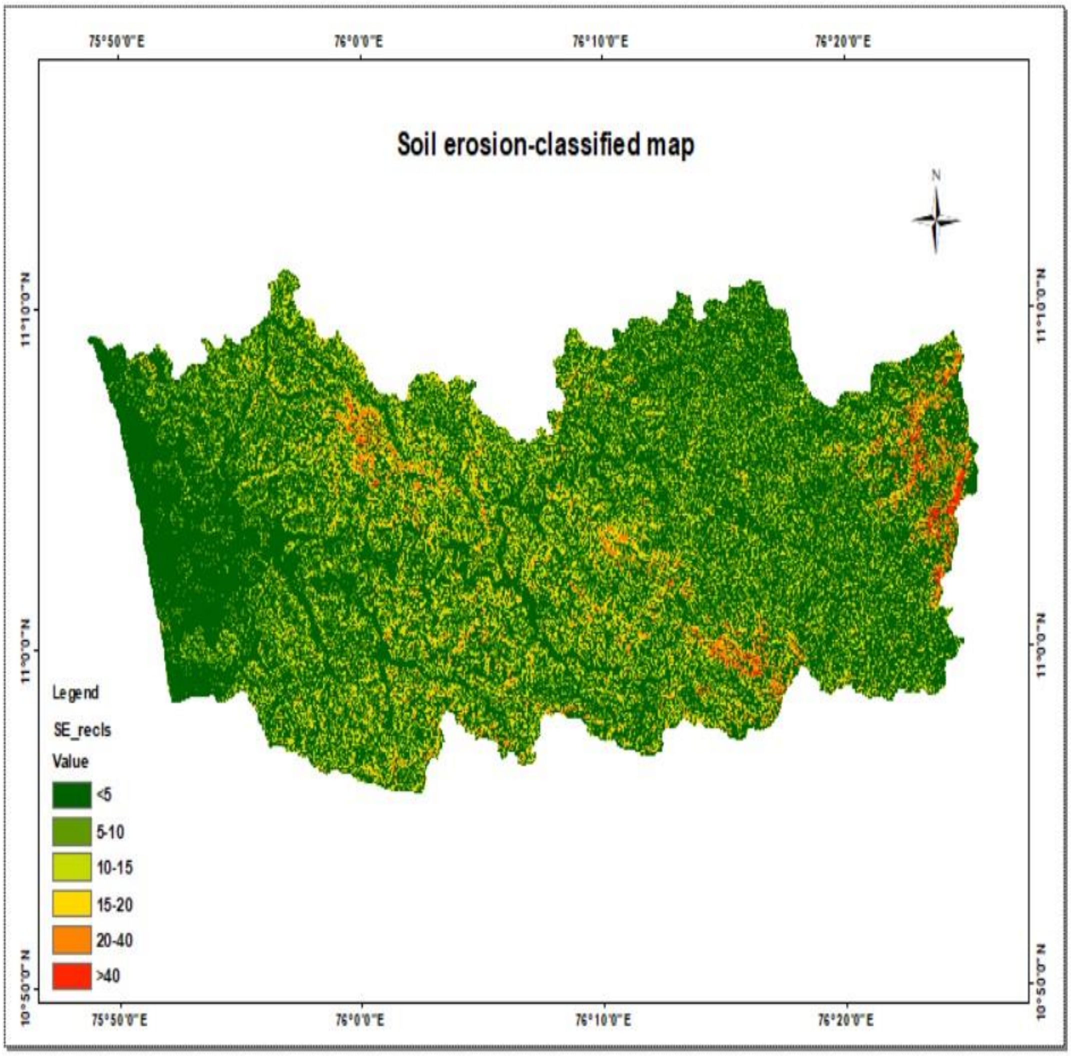

Fig. 10. Classified map of soil erosion for Kadalundi river basin

This indicates that the slope is directly related to soil erosion, or in other words, soil erosion increases with an increase in slope. While, considering the land use, the mean value of erosion is less in crop land (3.47 $t \cdot ha^{-1} \cdot yr^{-1}$) and high in barren land with an erosion rate of 12.43 $t \cdot ha^{-1} \cdot yr^{-1}$ (Table 5). Densely vegetated areas and fallow lands also have low mean erosion, denoting that the vegetation and conservation measures in the cultivable lands minimize erosion.

5. CONCLUSION

The proper river basin management demands quantification of soil erosion from the basin catchment. In light of this fact, the present study attempted to assess the soil erosion of the Kadalundi river basin by using RUSLE model incorporated with GIS. Individual maps of the RUSLE factors were developed and soil erosion map of Kadalundi river basin was prepared. The interpolated R-factor values for 21 years (2001-2021) ranged from 938.97 $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot yr^{-1}$ to 1102.65 $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot yr^{-1}$ in Kadalundi river basin. The estimated values of K-factor varied from 0.0075 to 0.0256 $t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$ with a mean value of 0.0183 $t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$. The average value of LS-factor was very less (0.88) while high LS-factor values were identified in high elevation ranges (9.07). The C-factor determined using NDVI values ranged from 0.08 to 1.10, in which higher values were observed in built-up land, water bodies and barren lands and low values in densely vegetated areas. The P-factor values assigned based on the slope and land use varied from 0.1 to 1, where 1 represents all non-agricultural lands.

Multiplication of the raster layers of the individual factors in RUSLE model in raster calculator generated the spatial distribution map of soil erosion in Kadalundi river basin. The estimated soil erosion ranged from 0 to 100.33 $t \cdot ha^{-1} \cdot yr^{-1}$ with an average value of 5.48 $t \cdot ha^{-1} \cdot yr^{-1}$. The total quantity of soil washed away from the basin was 694836.6 $t \cdot yr^{-1}$. Based on the classified erosion map, 60.66 per cent area of the basin came under slight erosion class. Moderately slight erosion class covered 15.96 per cent of area whereas moderate erosion class covered 13.28 per cent of the area. Around 6 per cent of the total area belonged under moderately severe erosion class and nearly 4 per cent under severe erosion class. However, 0.45 per cent of the total basin area experienced very severe erosion with soil loss greater than 40 $t \cdot ha^{-1} \cdot yr^{-1}$.

Altogether, the study concluded that, the soil erosion values of Kadalundi river basin comes in agreement with the soil erosion estimated for Malappuram district by Naidu et al. [20] with 59.17 per cent area in the slight erosion class and 0.40 per cent of area under very severe erosion class. Higher erosion ranges are found in higher elevation (>50% slope) areas and barren land possesses more erosion considering land use, while slight erosion is characterized by lower elevation ranges and crop lands. Since majority of the area in the basin comes under slight erosion class, simple agronomical measures can be adopted for reducing the effect of erosion and contour bunds, trenches and terraces can be used according to slope to prevent the soil erosion problems in the elevated areas.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Sample calculation of R-factor for Anakkayam station for the year 2001 to 2021

Year	Annual rainfall, mm (P)	R-value
2001	2470.40	1007.90
2002	2092.20	866.08
2003	2342.00	959.75
2004	2293.60	941.60
2005	2533.90	1031.71
2006	3326.90	1329.09
2007	3464.10	1380.54
2008	2176.30	897.61
2009	2509.80	1022.68
2010	2217.30	912.99
2011	2552.20	1038.58
2012	1379.40	598.78
2013	2622.60	1064.98
2014	2524.30	1028.11
2015	1816.90	762.84
2016	1203.40	532.78
2017	1871.70	783.39
2018	2435.50	994.81
2019	2531.70	1030.88
2020	2227.50	916.81
2021	2440.00	996.50

Consider the year 2021,
To calculate the R-factor according to the equation

$$R = 81.5 + 0.375 \times P$$

$$R = 81.5 + 0.375 \times 2440$$

$$R = 996.50\ MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot yr^{-1}$$

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