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Soil erosion modeling by revised universal soil loss equation (RUSLE) - A case study of Kundapura, Udupi district, Karnataka, India

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ABSTRACT

This research explores the use of the revised universal soil loss equation (RUSLE) process and remote sensing (RS) and geographic information system (GIS) techniques to estimate soil erosion in Kundapura taluk, Udupi, Karnataka. The average annual predicted soil loss ranges between 292.16 and 41044.92 t yr^{-1}. The loss of soil <292.16 t yr^{-1} near coastal areas has been recorded, and 1741.86 t yr^{-1} was found intensely plantation (mainly areca nut plantation and paddy field) area and degraded forest area. Soil erosion rate was predicted moderately high (4802.34 t yr^{-1}) for agriculture and slope areas, which needs proper soil conservation measures to reduce erosion. The high, very high, and extreme rate (10601.16-41044.92 t yr^{-1}) of soil erosion was found in the dense forest because of moderate slope value and the high slope length and steepness factor. The computed sediment yield (2010-2018) values range from 137.29-504.65 t yr^{-1}. In the coming years, huge man-made interventions in the Western Ghats region can significantly increase soil erosion. Also, most soil erosion changes happen at the micro-level and need much-localized study for specific regions. The study area belongs to the coastal region of Kundapura, which faces more soil erosion problems. This research may be helpful to understand and quantify soil erodibility rate. This study effectively proves the important role of RS and GIS in understanding geological processes and that the RULSE method can effectively be used for erosion mapping.

1. INTRODUCTION

Soil is the earth's life-sustaining upper surface made up of organic matter, rocks, liquids, gases, and animal debris, or a combination of sand, silt, mud, and humus. The top layer of soil must be protected for vegetation and agricultural production to thrive. Erosion may be caused by a number of causes, such as wind, water, and gravity. Various man-made factors like rapid urbanization and deforestation also lead to an increase in soil erosion. Soil depletion is a major issue due to agricultural intensification, land degradation, and other anthropogenic activities. Therefore, evaluation of soil erosion in a watershed or basin is important in planning and conservation work (Singh *et al.,* 2019). Modeling can provide a quantitative and consistent approach to soil erosion and sediment yield estimation under a wide range of conditions (Ganasri *et al.,* 2016). The sum of soil erosion varies spatially depending on factors such as slope, precipitation, soil condition, plant cover, and so on (Sharda *et al.,* 2019). The negative impacts of extensive soil erosion on soil depletion, agricultural productivity, water quality, hydrological processes, and the environment have long been recognized as major human sustainability issues (Lal, 1998).

According to Dodda Aswathanarayana Swamy *et al.* (2012), approximately 30% of the coastal region experiences mild soil erosion, and 16% experiences severe soil erosion. Annual soil erosion ranges from 5-15 t ha^{-1} to 15-40 t ha^{-1} in mild to extreme soil erosion areas. The condition on the Udupi coasts is more severe. The erosion gets severe during the southwest monsoon due to the combination of high river floods and strong wave action. In the recent study, the RUSLE method in combination with RS and GIS techniques for determining and quantifying soil depletion in the Kundapura taluk has been attempted. The major issues observed in the taluk include improper agricultural land management, soil erosion, crop yield declines, groundwater depletion, deterioration of forest/tree plantation areas, non-availability of drinking water, especially during the summer months, and poor socioeconomic conditions of farmers.

2. MATERIALS AND METHODS

Study Area

The present research work has been carried out for Kundapura taluk of Udupi district of Karnataka (Fig. 1). Kundapura is the northern taluk of the Udupi district and has a geographical area of 1569 sq km. It lies between 74°34′ 40.0″E to 75°4′57.35″E longitudes and 13°28′40.82″N to 13°59′33.26″N latitudes. The region experienced a tropical monsoon climate according to Koppen climate classification. This taluk has many rivers and experiences significant precipitation. The main streams are Venkatapura river, Kollur river (tributaries of Chakra and Souparnika), Haladi-Varahi river, Sita river, Yadamavina hole and Uppunda hole. The soil is of a lateritic type characterized by a high iron and aluminium content.

This variety usually occurs in heavy rainfall zones and is suitable for paddy, sugarcane, areca nut, coconut, cardamom, and plantains. There are different types of soils in the region: i) the sandy soil that covers the beaches and adjacent stretches ii) yellow loamy soil; iii) red lateritic soil. The sandy soils are restricted to a narrow strip of shore with dimensions ranging from 100 m to a km in length. This fine to medium texture sand is distinguished by its extremely high infiltration rate and serves as an honest recharge medium for groundwater. Yellow loamy soils are squarely transported from their source and are primarily found on riverbanks and in the lower reaches of valleys. They are mainly used in the tile industry. This soil type is well suited for irrigation and responds well to irrigation practices. Finally, the most common soil type in the region is red lateritic soil. These soils range in texture from fine to coarse. The soil in valleys and immediate slopes are rich in dirt, while higher slopes and Pedi planes are coarser in nature. The amount of leaching experienced by this soil type is also variable (CGWB, 2012). Studies indicated that the area largely consists of sandy soil; next to this sediments size found in the study area is clay particles (Table 1) (Poojashree *et al.,* 2016). Soil erosion is caused by a range of factors, including precipitation, soil composition, topography, land use trends, and so on.

Using GIS, these variables can be presented on a temporal and spatial scale. The RUSLE model is used in GIS to provide a spatial distribution of soil erosion and classify areas especially vulnerable to erosion. The automated elevation model was developed using 30-meter SRTM data that is commonly available worldwide (Fig. 2). Land use and land cover (LU/LC) maps were generated using

Table: 1
Particle size distribution of surface soil found in the study area

Particle size distribution (ranges) in surface soils of Kundapura	Sand (%)	Silt (%)	Clay (%)
	54.56-71.12	6.44-15.00	20.36-30.44

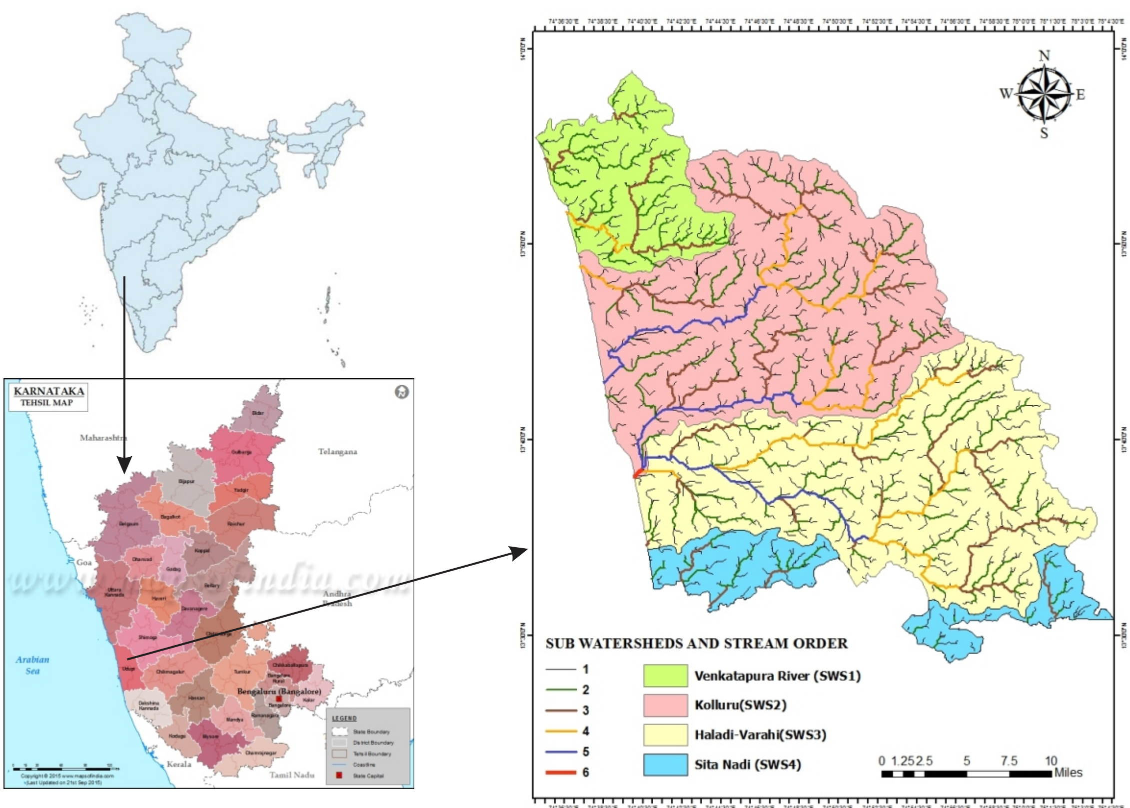

Fig. 1. Location map of Kundapura taluk

Landsat 8 OLI (2019) satellite imagery. The description and source of spatial and non-spatial data used to estimate soil erosion are discussed in Table 2.

Rainfall Map

Rainfall has two distinct effects on soil erosion. The first is caused by the kinetic energy of each raindrop, which causes soil particles to separate from one another as they come into contact. Another is the rainfall intensity, measured by the amount of rain that comes during a given period. Precipitation data from rain gauge stations were obtained from the Karnataka State Natural Disaster Monitoring Centre located in Bengaluru from 2010 to 2018. The mean annual rainfall is estimated from these results, and a spatial distribution map is created using the inverse distance weighted (IDW) interpolation technique (Fig. 3).

Geology and Soil

Geologically area comprises granitic gneisses with laterite capping and unconsolidated river and sea sediments. Gneiss is found in varying degrees in various outcrops, particularly along the river course.

Throughout the field, basic intrusive such as dolerites and gabbro acidic intrusive such as pegmatite and quartz veins and pink porphyritic granites are seen. In addition, current alluvium and colluvial deposits can be found along

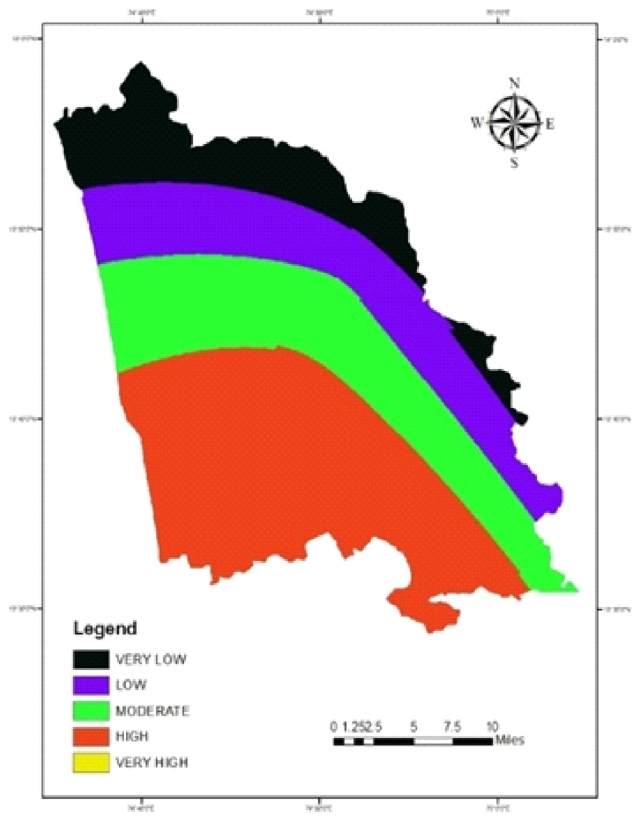

Fig. 3. Average rainfall of Kundapura taluk

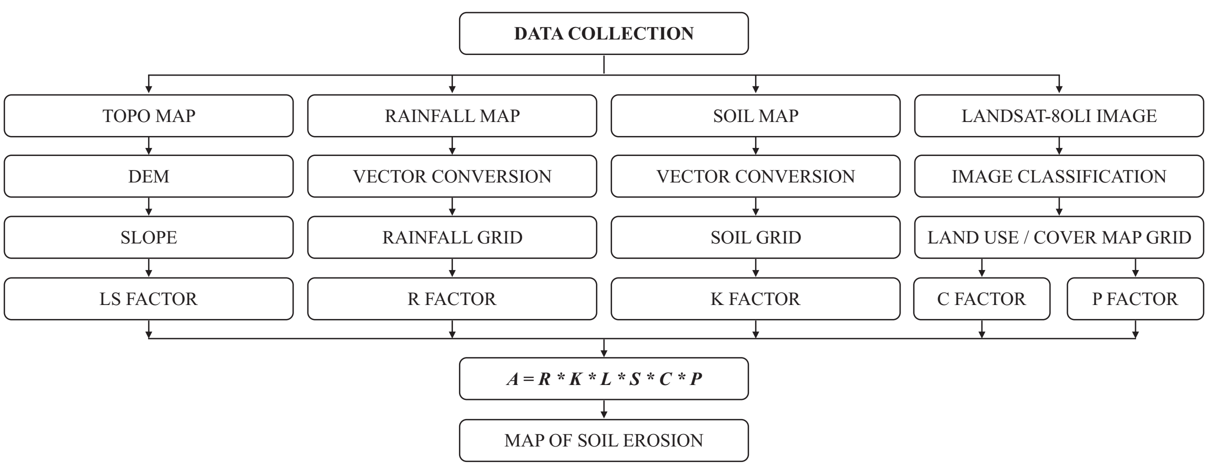

Fig. 2. Flow chart of methodology

Table: 2
Overview of data used

S.No.	Data	Sensor	Source	Usage	Time
1	NASA Shuttle Radar Topographic Mission (SRTM-DEM 30 m)	Interferometric SAR radar	https://earthexplorer.usgs.gov	Digital elevation model (DEM) creation	2019
2	Normalized Difference Vegetation Index (NDVI)	Landsat 8 OLI	https://earthexplorer.usgs.gov	NDVI map creation with red and NIR bands of 30m resolution	2019
3	Land use and Land cover	Landsat 8 OLI	https://earthexplorer.usgs.gov	Red, blue, green and NIR bands	2019
4	Rainfall data	Field data	Karnataka State Natural Disaster Monitoring Centre, Bengaluru	Rainfall information	2010-2018
5	Soil map	Field data	Karnataka State Remote Sensing and Application Centre, Bengaluru	Soil data	2019

the river banks and seashores. The soil map of the study area was derived from the Karnataka state Remote Sensing and Application Centre map, Bengaluru. The soil map was used to extract ten separate soil types - Clay, Clay Loam, Gravely Sandy Clay, Gravely Sandy Loam, Loam, Loamy Sand, Sand, Sandy Clay, Sandy Clay Loam, and Sandy Loam (Fig. 4). The distribution of particle size in the soil is measured by soil texture. Large particles are resistant to transport due to the greater force used to prepare them, and fine particles are resistant to detachment due to their cohesiveness. Since silts and fine sands are the least resistant grains, soils with high silt content are highly erodible.

Land Use / Land Cover (LU/LC) Map

The LU/LC map (Fig. 5) was created using Landsat 8 OLI info, which has 11 spectral bands with a spatial resolution of 30 m. Blue, green, red, and near-infrared (NIR) bands were used to create the stacked signal, which was then used in image classification. Multispectral supervised classification methods, and suitable collateral data were used to generate a thematic map of land cover from remotely sensed data. Dense woods, built-up, open space, beach, agriculture property, and water bodies are among the six broad LU/LC groups identified in the study area.

Revised Universal Soil Loss Equation (RUSLE)

RUSLE is an observational erosion model widely used to quantify the average likelihood of erosion on arable land (www.opennessproject.eu). RUSLE is generally regarded as a standard tool for calculating soil degradation. It is based on erosion phase theory, more than 10,000 years of evidence from natural precipitation plots, and multiple rainfall-simulation plots. The RUSLE was widely used in agricultural and forest watersheds to simulate soil erosion and sediment yield. The RUSLE method is expressed by *Renard et al.* (1997) as:

$$A = R * K * L * S * C * P \qquad ...(1)$$

Where, A = mean (annual) soil loss rate expressed in t $ha^{-1}yr^{-1}$ corresponding to the value of K and a certain period of R.

Rainfall Erosivity (R) Factor

The erosivity factor of rainfall (R) is a function of the falling raindrop and rainfall intensity and is the product of the kinetic energy of the raindrop and the 30-minute maximum rainfall intensity (Pandey *et al.,* 2007). But in the Indian context, detailed meteorological data is less available. Therefore, Singh's (1981) empirical equation has been used for estimating annual and seasonal R-factors in the Indian context. The annual erosion index was as follows:

$$R_a = 79 + 0.363 * P$$

Where, R_a denotes the average annual Rainfall erosivity factor (Mt ha-cm^{-1}), and P represents the rainfall in mm. R

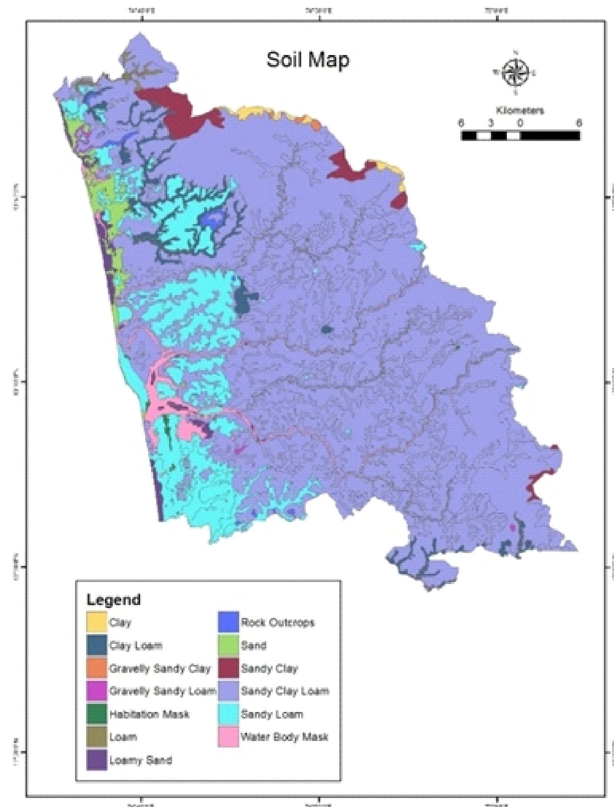

Fig. 4. Soil map of Kundapura taluk

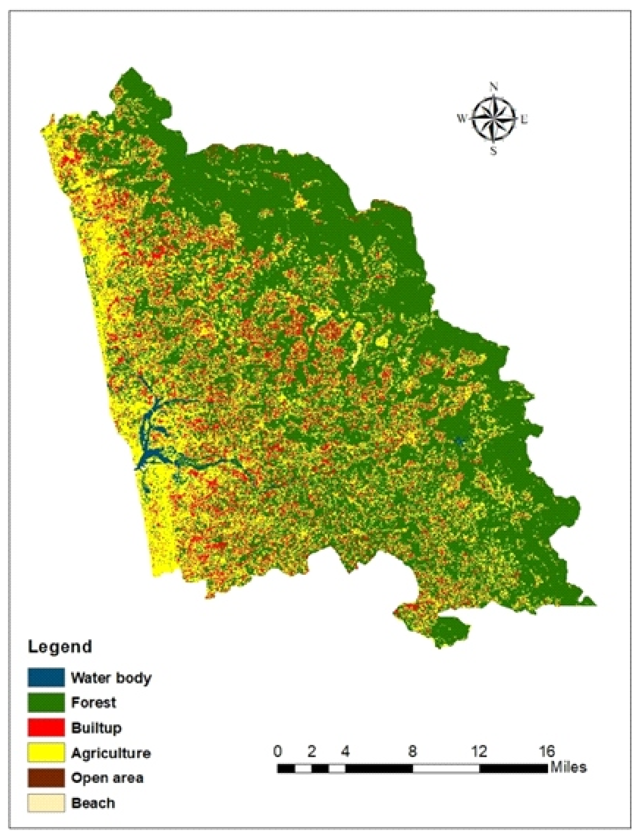

Fig. 5. Land use/Land cover map of Kundapura taluk

was calculated by analyzing rainfall data from 13 rain-gauge stations of the Kundapura taluk and its surrounding area. IDW method of interpolation is used to approximate the spatial distribution of R-factors (Fig. 6) data in the study area. This IDW interpolation process took into account 08 years of rainfall data from 13 rain gauge stations in and around the Kundapura taluk. Table 3 displays the estimated R-factor.

K-factor

This is a soil erodibility factor that indicates soil susceptibility to erosion identified by the soil texture class and organic matter content by Schwab *et al.* (1981), as shown in Fig. 7. The standard condition is the unit plot, 22.6 m long with a 9% gradient, maintained in continuous fallow, tilled up and down the hill slope (Kim, 2006).

K values reflect the rate of soil loss per rainfall-runoff erosivity (R) index.

Slope Length and Steepness (LS-factor)

Slope length (L) factor: According to Soo (2011), the slope and slope-length influences (S and L) (Fig. 8) account for the effect of topography on soil erosion. The element is a ratio of soil depletion under defined conditions. The chances are flooding is more on the steeper slope and longer cliff. According to Renard and Ferreira (1993), the factor can be measured using field measurements or a digital elevation model (DEM). Wischmeier and Smith (1978) describe L-factor as the distance between the source of runoff and the point at which the slope decreases enough to allow the deposition to begin.

Slope (S) factor: The hill slope-gradient component, S, accounts for the effect of the hill slope-profile gradient on soil loss. It is calculated as a percentage or in degrees as the difference in elevation per change in horizontal space (Zhang *et al.,* 2008). If the gradient rises, it does soil loses. Since the relationship of angle and length of the slope affects the degree of erosion, the two are often viewed together (Morgan and Davidson, 1991). The slope gradient (S) and slope length (L) can be precisely measured and combined to form a single factor known as the topographic factor LS with DEM integration into GIS. The slope length (L) and the slope(S) are, respectively defined by eq's 2 and 3.

$$L = 1.4(A_s / 222.13)^{0.4} \quad ...(2)$$

$$S = \left(\frac{\sin\alpha}{0.0896}\right)^{1.3} \quad ...(3)$$

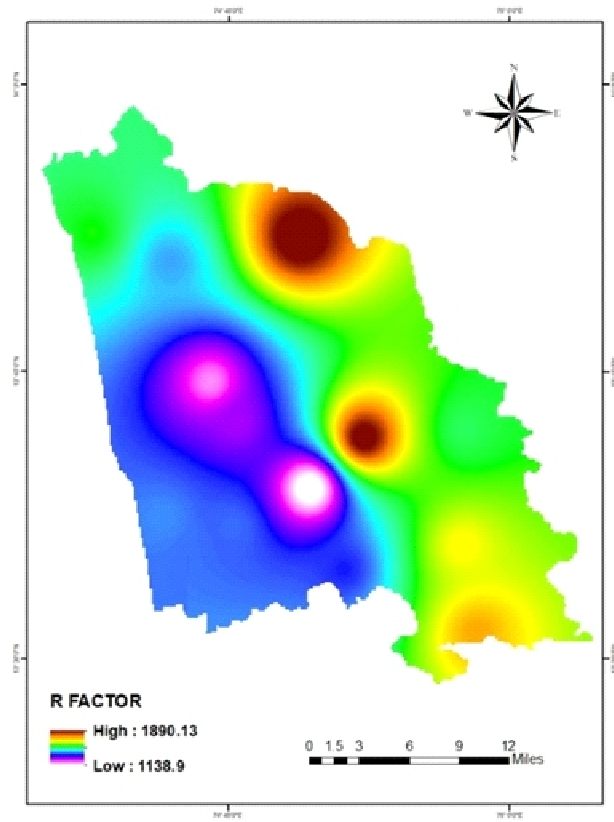

Fig. 6. R-factor map for Kundapura taluk

Table: 3
Rainfall erosivity factor values

Station name	Latitude	Longitude	Average annual rainfall (2010-2018)	
			Rainfall (mm)	R-factor
Albadi (Ardi)	13.52262	74.97159	4529.889	1709.76
Amasebail	13.59819	74.958252	4361.889	1649.28
Ampar	13.64811	74.82247	2943.889	1138.8
Baindur (Yedthere)	13.87054	74.6279	4102	1555.72
Kundapura	13.6231	74.6919	3720.889	1418.52
Hosangadi (Siddapur)	13.6998	74.96055	4023.667	1527.52
Halady	13.57796	74.85267	3597.333	1374.04
Kollur	13.8665	74.813	5031.111	1890.2
Ull00r Ii	13.614991	74.753917	3684.222	1405.32
Yelajith	13.84578	74.69765	3746.667	1427.8
Vandse	13.70524	74.75719	3440.889	1317.72
Aluru	13.74084	74.73355	3211.556	1235.16
Ajri	13.69248	74.87056	4965.333	1866.52

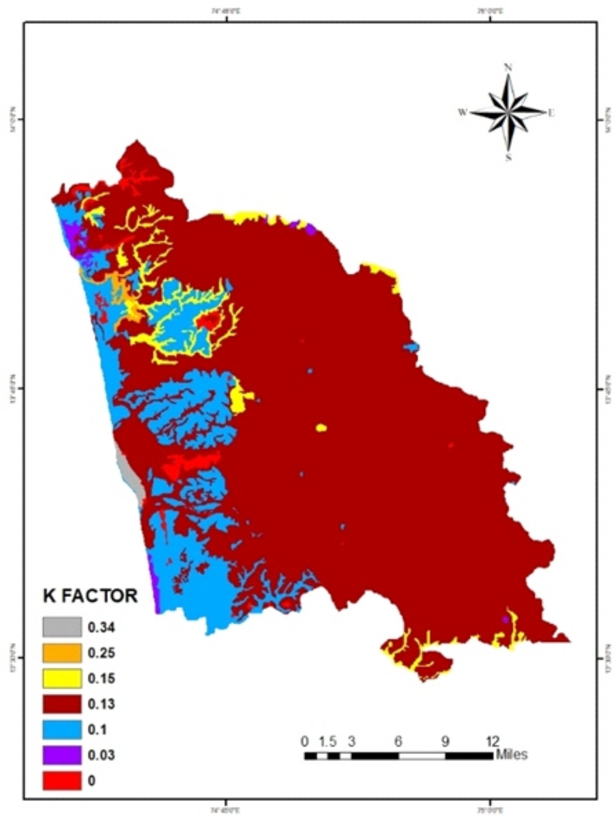

Fig. 7. K-factor map of Kundapura taluk

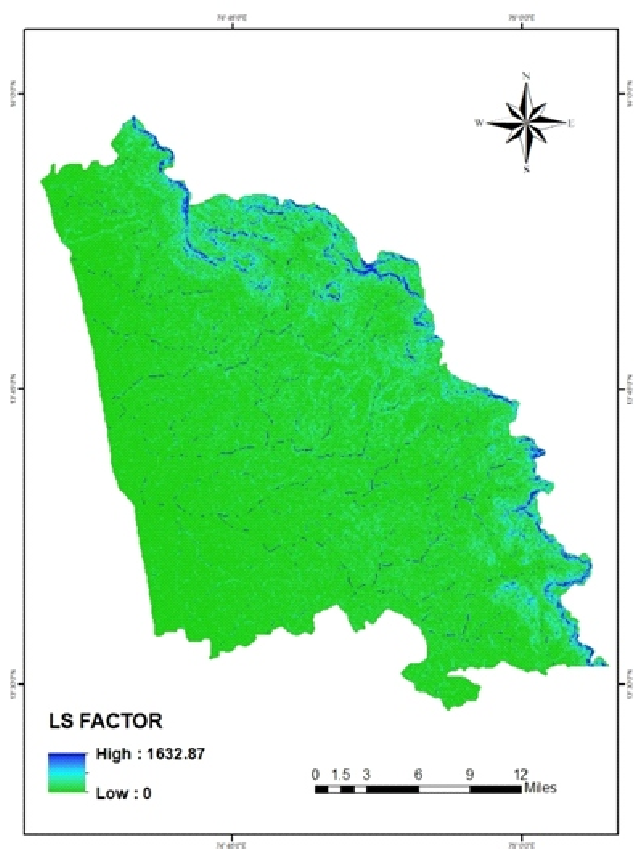

Fig. 8. LS factor map of Kundapura taluk

Where, A_s - Specific contributing area (m^2), α - Slope angle (degrees), estimated using a DEM, eq's 1 and 2 can be combined (Morgan and Davidson, 1991) by use of eq. 4, which is defined as:

$$LS = \sqrt{\frac{1}{22}}(0.065 + 0.045 * s + 0.0065 * s^2 \qquad ...(4)$$

Where, L - Slope length (m), S - Percent slope

Crop management factor (C)

Since C-factors values are low for most Indian crops, Karaburun's (2010) C-factors were used to show the impact of cropping and management activities on soil erosion rates in agricultural lands. The effect of plant canopy and land covers on soil erosion in forested areas differ according to season and crop production method (Renard *et al.,* 1997). The seasonal variation of the C-factor is determined by a number of factors such as rainfall, agricultural practice, crop type, etc. The relative effect of management choices can be easily compared to adjusting the C-factor, which ranges from near zero for well-protected land cover to one for barren fields. As a result, the effect of the C-factor on soil erosion is marginal when the study area's LU/LC is dominated by woodland and plantation crops. The crop management factor map was developed based on the study area's land use and cover map. LU/LC were categorized into six classes based on ground details. The LC classes are water body, forest area, built-up land, and wasteland and agriculture land.

NDVI map was also generated based on NIR and red bands of LANDSAT 8 OLI (Fig. 9). These are the main land use-land cover characteristics observed in Kundapura taluk. The supervised classification method was used to extract these six-land use-land cover groups from a LANDSAT image. The supervised classification process includes ground truth knowledge for LU/LC category, which was obtained using a global positioning system (GPS) and used to train the algorithm to extract these six LU/LC categories. The controlled classification system has an average precision of around 82%.

Each LU/LC class area has been estimated, and C-factors have been allocated (Table 4). In the current research suggested by Kim *et al.,* 2005, C-values were used. For the generation of the C-factor map, the land use-land cover map was reclassified based on C-factor (Fig. 10). This factor is specifically influenced by land use and is the soil loss ratio of planted soil. C-factor was calculated using the method suggested by De Jong *et al.,* 1998.

C = 0.431 - 0.805 NDVI

Conservation support practice factor (P)

The conservation practice factor (P) reflects the ratio of soil depletion incurred by a support practice to that caused

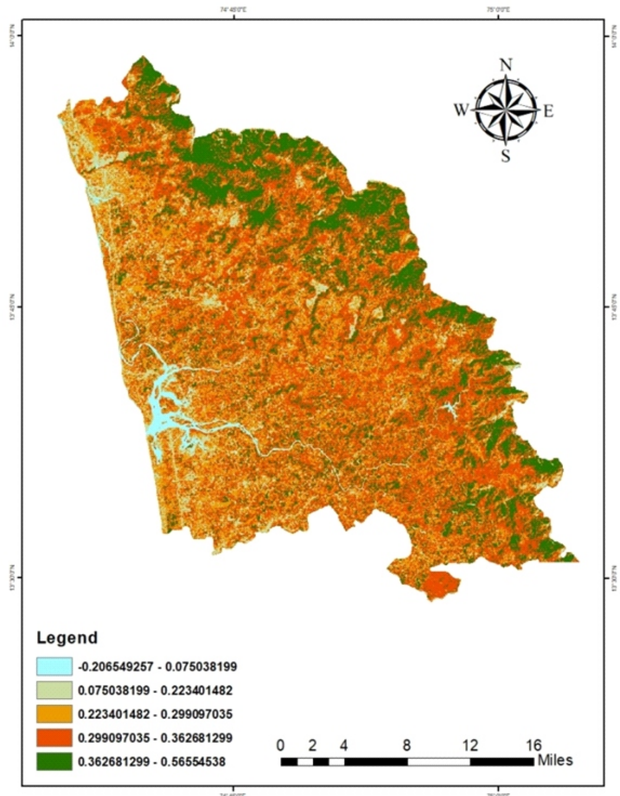

Fig. 9. Shows NDVI map of Kundapura taluk

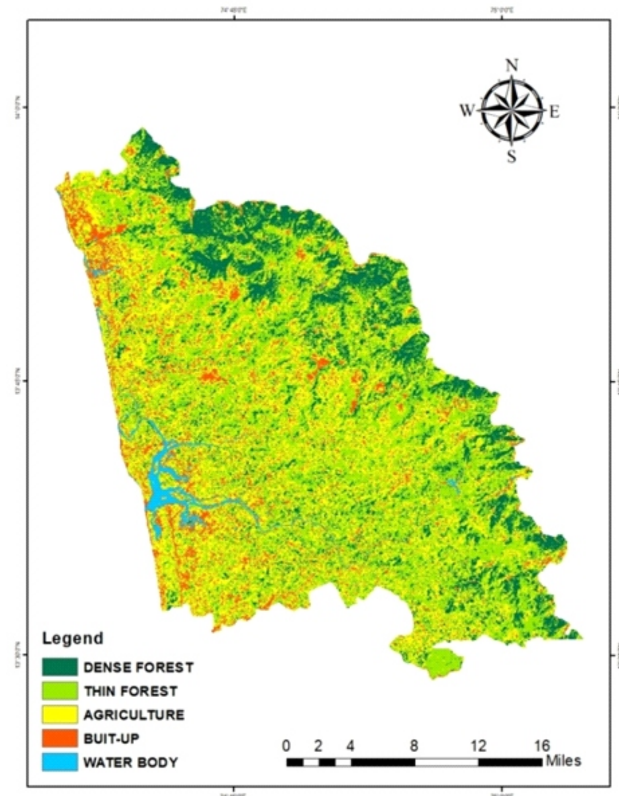

Fig. 10. C-factor for Kundapura taluk

Table: 4
Land use / land cover classes and respective C-factor value

S.No.	Class name	C-factor
1	Dense forest	0.13
2	Thin forest	0.18
3	Agriculture	0.24
4	Built-up	0.36
5	Water body	0.59

by straight-row cultivation up and down the slope, and it is used to account for the beneficial results of such support practices (Ganasri *et al.,* 2016). The P-factor takes into account management activities that reduce runoff' erosion capacity by influencing drainage patterns, runoff concentration, runoff velocity, and hydraulic forces exerted by runoff on the soil. The P-factor value varies from 0 to 1, with a value close to 0 indicating a good P-factor value was set to 1 since most of the study area is covered by Urban area, Bare land, Dense forest, Sparse forest, and Paddy field.

Sediment Yield Estimation

The sediment yield is the ratio of sediment delivered at a given area in the stream system to the gross erosion is the sediment delivery ratio for that drainage area (Sreenivasulu *et al.,* 2012). Thus, the annual sediment yield of a watershed is defined as follows:

$$SY = (A)\,(SDR)$$

Where, A = total gross erosion computed from USLE, SDR = sediment delivery ratio. Unfortunately, a general equation for computing watershed delivery ratios is not yet available since they depend on several watershed properties like infiltration, roughness, vegetation cover, hydrograph or runoff drainage, etc. Since much of the above data are not available for the study area to derive *SDR*, some of the simple models provided by various researchers have been attempted to estimate sediment production at the basin's outlet. However, the one provided below by Jimmy *et al.,* 1972 is finally chosen because it gives fair results despite the use of few catchment characteristics.

$$SDR = 0.627\,SLP^{0.403}$$

Where, SLP = % slope of the mainstream channel. The computed sediment yield (2010-2018) values range from 137.29-17, 504.65 t yr^{-1}.

3. RESULTS AND DISCUSSION

Rainfall erosivity factor (R)

According to Ganasri *et al.* (2016), the catchment's soil erosion rate is more susceptible to rainfall. Therefore, to describe the seasonal distribution of sediment yield, daily rainfall is a stronger measure of variance in the rate of soil erosion. The benefits of using annual rainfall include its simplicity of calculation and greater geographical accuracy of the exponent. As a result, the current analysis used average annual rainfall (obtained by dividing gross rainfall by total number of rainy days) to measure the R component. The average R-factor varies between 1138.8-1890.2 Mt ha-cm^{-1}. According to the findings, rainfall is abundant in Brahmvara area, Kundapura taluk.

Soil erodibility factor (K)

To produce the soil erodibility chart, K factor values were assigned to respective soil types in the soil chart. The K-factor values are observed to be between 0 - 0.34 (t ha MJ^{-1} mm^{-1}). A lower K-factor value is correlated with soils with low permeability, low antecedent moisture content, and so on.

Topographic factor (LS)

The topographic component expresses the effect of slope length and slope steepness on the erosion process. The flow accumulation and slope in percentage were used as inputs to measure the LS component. According to the results of the study, the value of the topographic component increases in a range of 0-1632.87 as the flow accumulation and slope rise.

Crop management factor (c)

Land use data allows for a clearer understanding of the land utilization dimensions of cropping practices, fallow land, woodland, wasteland, and surface water sources, which are important for development planning / erosion studies. In addition, RS and GIS techniques have the potential to generate a thematic layer of a region's LU/LC. The research area has been divided into six land use classes. The C-factor map was prepared using the land use-land cover map and C-factor value.

Average annual soil loss (A factor)

The average annual soil erosion potential (A) was calculated by multiplying the produced raster data from each factor of the USLE study ($A = R\,K\,L\,S\,C\,P$). Fig. 11 depicts the final 'A' factor diagram, which shows the estimated annual soil loss potential of Kundapura taluk. The findings indicate that the sample region has a gentle slope, so the erosion loss is minimal and within reasonable limits. The predicted average annual soil loss of Kundapura taluk has been classified into six erosion intensity classes to assess potential erosion severity. (Table 5). The average annual predicted soil loss ranges between 292.16 to and 41044.92 t yr^{-1}.

The loss of soil near coastal areas is <292.16 t yr^{-1} have been recorded, and 1741.86 t yr^{-1} was found intensely plantation (mainly areca nut plantation and paddy field) area and degraded forest area. Soil erosion rate was predicted moderately high (4802.34 t yr^{-1}) for agriculture and the slopy regions, which needs proper soil conservation measures to reduce erosion. The high, very high, and extreme rate (10601.16 - 41044.92 t yr^{-1}) of soil erosion was found in the dense forest because of moderate slope value and the high slope length and steepness factor. The computed sediment yield (2010-2018) values range from 137.29-504.65 t yr^{-1}. Despite the fact that extreme and extremely severe erosion regions have decreased significantly, there has been a significant rise in areas of mild erosion. In addition, there is evidence of increased soil degradation in areas of minor

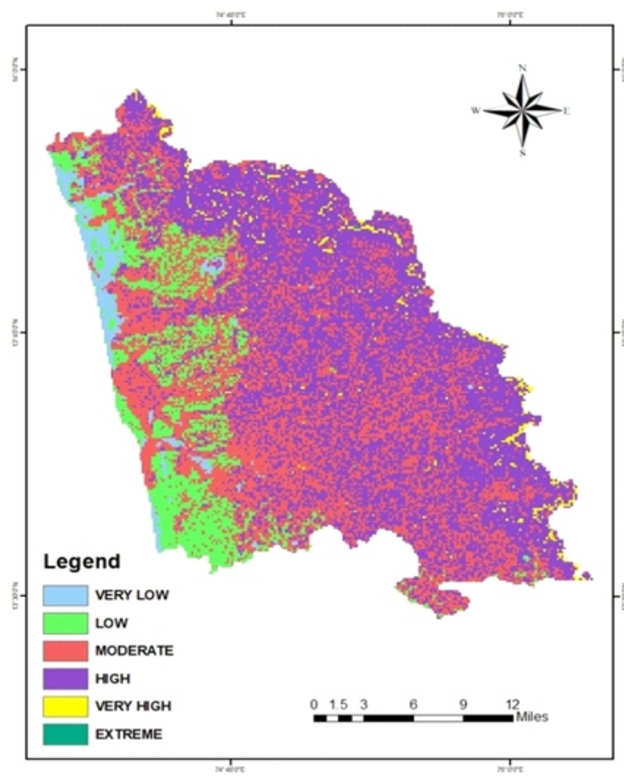

Fig. 11. Average annual soil loss of Kundapura taluk

Table: 5
Erosion characteristics of the Kundapura taluk

Erosion categories	Soil loss classes (t yr^{-1})	Area (ha)	Area (%)	Soil loss (t yr^{-1})
Very low	0-500	20.84207	2.903828	292.156
Low	500-1000	85.09612	11.85604	1741.859
Moderate	1000-2500	272.0268	37.90022	4802.344
High	2500-7000	326.8641	45.54045	10601.156
Very high	7000-10000	12.85081	1.790443	23326.328
Extreme	>10000	0.064794	0.009027	41044.921
Total		717.7447	100	81808.76

erosion, as areas of minor erosion have declined dramatically. Soil erosion-resistant areas were defined by qualitative evaluation by analyzing soil erosion variables using combined weightages. The approach can be used with a more detailed study over a longer time frame to obtain a detailed image of the region's past soil erosion pattern. The report also analyzes the region's land-use trend over time and the amount of plant cover destruction that occurred during that period. Even though only a few of the sample areas have exceptionally high erosion, the numbers may grow in the future due to an increase in construction activities and deforestation in the region.

4. CONCLUSIONS

Soil erosion includes dynamic, hydrological processes, and models can only simulate these processes. Erosion losses have been assessed for Kundapura taluk quantitatively and qualitatively. The study also throws light on the land use pattern of the region in the time scale and the amount of vegetation cover damage that happened in the period. Even though only a few of the study areas had very high erosion, this may rise in the future owing to the rise in construction activities and deforestation in the region. The results did not prove a drastic increase in soil erosion in the Kundapura region. However, huge man-made interventions in the Western ghats region can significantly increase soil erosion in the coming years. Also, most changes in soil erosion happen at the micro-level and need much-localized study for specific regions. This study effectively proves the importance and the role of RS and GIS in geological processes and that the RULSE method can effectively use for erosion mapping. The work has been carried out using available data, which expands the usability and accessibility of the work produced, ensuring the continuity for further comparative studies. Similar studies are also essential for the adjacent areas in the Konkan belt to compare and improvise better planning measures by town planning departments.

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