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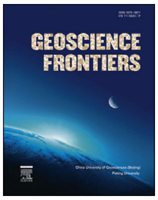

Research paper

Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin

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ABSTRACT

Soil erosion is a serious problem arising from agricultural intensification, land degradation and other anthropogenic activities. Assessment of soil erosion is useful in planning and conservation works in a watershed or basin. Modelling can provide a quantitative and consistent approach to estimate soil erosion and sediment yield under a wide range of conditions. In the present study, the soil loss model, Revised Universal Soil Loss Equation (RUSLE) integrated with GIS has been used to estimate soil loss in the Nethravathi Basin located in the southwestern part of India. The Nethravathi Basin is a tropical coastal humid area having a drainage area of 3128 km^2 up to the gauging station. The parameters of RUSLE model were estimated using remote sensing data and the erosion probability zones were determined using GIS. The estimated rainfall erosivity, soil erodibility, topographic and crop management factors range from 2948.16 to 4711.4 $MJ/mm \cdot ha^{-1} hr^{-1}/year$, 0.10 to 0.44 $t\ ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$, 0 to 92,774 and 0 to 0.63 respectively. The results indicate that the estimated total annual potential soil loss of about 473,339 t/yr is comparable with the measured sediment of 441,870 t/yr during the water year 2002–2003. The predicted soil erosion rate due to increase in agricultural area is about 14,673.5 t/yr. The probability zone map has been derived by the weighted overlay index method indicate that the major portion of the study area comes under low probability zone and only a small portion comes under high and very high probability zone. The results can certainly aid in implementation of soil management and conservation practices to reduce the soil erosion in the Nethravathi Basin.

1. Introduction

Degradation of agricultural land by soil erosion is a worldwide phenomenon leading to loss of nutrient rich surface soil, increased runoff from more impermeable subsoil and decreased water availability to plants. Thus, estimation of soil loss and identification of critical area for implementation of best management practice is central to success of a soil conservation program. The total land area subjected to human-induced soil degradation is estimated at about 2 billion hectares. By this, the land area affected by soil degradation due to erosion is estimated at 1100 Mha by water erosion and 550 Mha by wind erosion (Saha, 2003). Soil erosion in India has a major effect on the agricultural sector, siltation of reservoirs, degradation of soils, etc. in the nation. Many actions have been taken by the government for rectification of the problem and preventing further destruction of the soil layer. In India, almost 130 million hectares of land (Kothyari, 1996), i.e., 45% of the total geographical surface area, is affected by serious soil erosion through the gorge and gully, shifting cultivation, cultivated wastelands, sandy areas, deserts and water logging. Excessive soil erosion with a resultant high rate of sedimentation in the reservoirs and decreased fertility has become solemn environmental problems for the country with disastrous economic consequences.

The soil erosion process is modified by biophysical environment comprising soil, climate, terrain, ground cover and interactions between them. Important terrain characteristics influencing the mechanism of soil erosion are slope, length, aspect and shape. Impact of slope and aspect would play a major role in runoff mechanism. More the slope, more the runoff and thus infiltration reduces. The runoff generated from slope will find a path nearby and this would lead to erosion of soil as the velocity of the runoff increases. Erosion is a natural geological phenomenon resulting from the removal of soil particles by water or wind, transporting

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them elsewhere, while some human activities such as agricultural practice, conversion of forest to agriculture etc. would increase erosion rates. Erosion is triggered by a combination of factors such as steep slopes, climate (e.g., long dry periods followed by heavy rainfall), inappropriate land use, and land cover patterns (Renschler et al., 1999). Moreover, some intrinsic features of a soil can make it more prone to erosion. Effective modelling can provide information about current erosion, its trends and allow scenario analysis.

Substantial efforts have been spent on the development of soil erosion models (Nearing et al., 2005). Soil erosion and degradation of land resources are significant problems in a large number of countries (Lu et al., 2003; Kim et al., 2005). Often, a quantitative assessment (Kothyari et al., 1994) is needed to infer on the extent and magnitude of soil erosion problems so that sound management strategies can be developed on a regional basis with the help of field measurements. In addition, simulation models for soil erosion can be used to evaluate alternative land management scenarios in both gauged and un-gauged basins. As in the case of water management, decision making for the management of land resources can be realized by developing a number of alternative land use scenarios and by assessing their results through the use of soil erosion models (Fistikoglu and Harmancioglu, 2002). The main problem in relation to the erosion risk models is the validation, because of scarcely available data for comparing the estimates of the models with actual soil losses (Gitas et al., 2009; Lazzari et al., 2015). Several soil erosion models exist with varying degrees of complexity. One of the most widely applied empirical models for assessing the sheet and rill erosion is the Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith in 1965. Agriculture Handbook 703 (Renard et al., 1997) is a guide to conservation planning with the RUSLE. Originally, USLE was developed mainly for soil erosion estimation in croplands or gently sloping topography. With its revised (RUSLE) and modified (MUSLE) versions (Wischmeier and Smith, 1978; Remortel Van et al., 2001; Lee G.H and Lee K.H, 2006), USLE is still being used in a large number of studies on soil loss estimation. Other soil erosion models range in various degrees of complexity. EUROSEM (European Soil Erosion Model)/MIKE SHE (Systeme Hydrologique Europeen or European Hydrological System) has been a recently developed comprehensive soil erosion model with a distributed and physically-based character. Soil erosion models are classified (Jha and Paudel, 2010) into three groups viz. Empirical, Conceptual (partly empirical/mixed) and Physically-based. Examples for first two groups comprise the empirical USLE and its modifications, and few comprehensive models like ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation), CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems), and MODANSW (MODified ANSWers). ANSWERS and CREAMS are basically conceptual and event based models.

Using conventional methods to assess soil erosion risk is expensive and time consuming. The integration of existing soil erosion models, field data and data provided by remote sensing technologies through the use of geographic information systems (GIS) appears to be an asset for further studies (Fernandez et al., 2003; Gitas et al., 2009; Xu et al., 2009). DEM (Digital Elevation Model) is one of the essential inputs required for soil erosion modelling, which can be created by analysis of stereoscopic optical and microwave (SAR) remote sensing data (Kim, 2006). The RUSLE model can predict erosion potential on a cell-by-cell basis (Shinde et al., 2010), which is effective when attempting to identify the spatial pattern of the soil loss present within a large region. GIS can then be used to isolate and query these locations to identify the role of individual variables contributing to the observed erosion potential value. Keeping in view of the above aspects, the objectives of the present study are made: (1) to develop a methodology that combines remote sensing data and GIS with Revised Universal Soil Loss Equation (RUSLE) to estimate spatial distribution of soil erosion at a catchment scale; (2) to analyze the impact of land use/land cover changes on erosion using remote sensing and GIS and (3) to delineate soil erosion probability zones using overlay method.

2. Description of study area and data

The Nethravathi Basin shown in Fig. 1 on digital elevation model (DEM) drains 3128.72 km^2 area and located in the middle region of Western Ghats, western India. The river originates at Bellaraya Durga in the Dakshina Kannada district at an altitude of 1125 m above mean sea level and flows westward down to its confluence with the Arabian Sea. The rainfall from three seasons respectively contributes about 4, 90 and 6% of the total annual rainfall. Streams expand their channels during rains and occupy the whole valley floors. The satellite images, soil, DEM, and rainfall were used in the

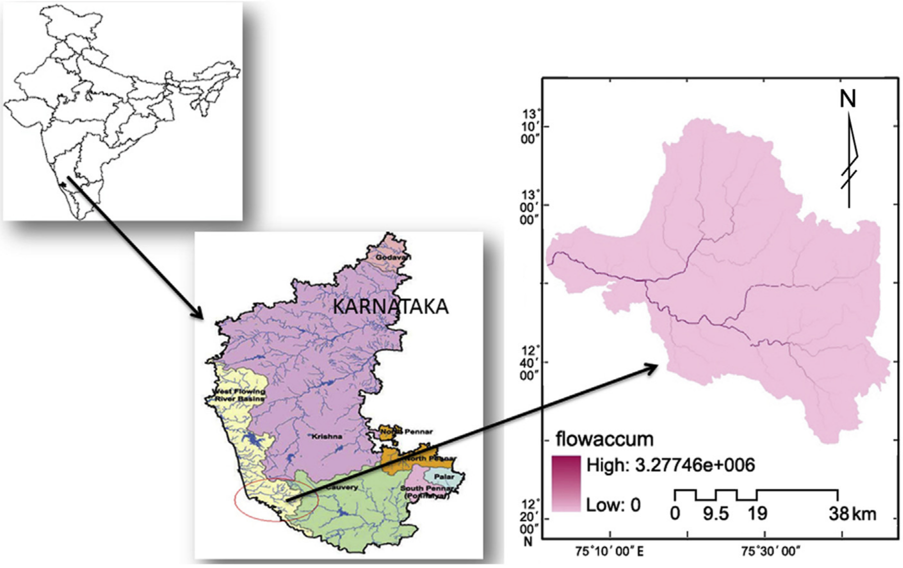

Figure 1. Location map of Nethravathi Basin.

present study (Table 1) to estimate soil loss in the basin. The sediment load was measured up to the year 2003 in the Nethravathi river at Bantwala station, which is located nearly 20 km upstream of the river mouth. The basin characteristics and the measured sediment load at gauging location are presented in Table 2. Presently, the sediment load is not being measured after 2003. Hence the latest data is not available.

2.1. Geology and soils

The basement rocks in the basin are of Archean age, one of the oldest rocks of peninsular India. Genesis is the preliminary rock formations of the basin. They are overlaid by laterite. Due to heavy leaching during rainy season, a thin layer of clay is formed at the base of laterite. Highly porous sandy soils, coastal alluvial and red loam are the three types of soils found in the basin (Putty and Prasad, 2000; Avinash kumar et al., 2010; Putty Yadhupathi et al., 2014).

2.2. Meteorological conditions

The southwest monsoon period (June–September) is the coolest part of the year with the mean daily temperature below 25 °C. The mean daily temperature during March to May is about 35 °C and the weather is highly humid all through the year and particularly, during south-west monsoon when mean humidity exceeds 85% (Babar Santosh and Ramesh, 2013).

Table 1
Description of the data.

Sl. No.	Data type	Source	Description
1	Digital elevation model	www.bhuvan.nrsc.gov.in	CARTO DEM (30 m Resolution)
2	Satellite image	www.bhuvan.nrsc.gov.in	LISS-3 Image (year-2009 with resolution 23.5 m)
3	Soil data	The National Bureau of Soil Survey and Land Use Planning, India	Soil map for the year 2003. 17 categories of soil based on the soil texture
4	Rainfall data	Indian Meteorological Department, India	Rainfall data for a period of 10 years (2000–2009) with 12 rainguage stations

Table 2
Annual sediment load and basin characteristics of Nethravati rivers (after Rahiman et al., 2009).

Year	Sediment load of Nethravati (t)
1992–1993	1,051,120
1993–1994	703,621
1994–1995	1,540,399
1995–1996	1,334,979
1996–1997	1,252,848
1997–1998	2,808,892
1998–1999	2,036,893
1999–2000	1,349,496
2000–2001	321,547
2001–2002	359,859
2002–2003	441,870
Total	**13,201,524**
Catchment area and length:	3128 km^2, 103 km
Mean annual rainfall:	4160 mm
Number of dams on upstream side of CWC gauging station:	No large dams (18 vented dams).
Topography and geology:	More gentle slope region and steep slope region is only 8 km. Mainly lateritic soil.

2.3. Vegetation

Heavy rainfall in the study area favours luxurious growth of vegetation due to porous laterite soil. The upper portion of the basin lies in the western Ghats region (western ghat mean thick forest with mountains) covered with dense forests. Forest of different types, in varying stages from evergreen scrub to fully grown forest can be seen in the basin (Mohan Kumar, 2011).

3. Methodology and parameter estimation

Problems associated with soil erosion, movement and deposition of sediment in rivers, lakes and estuaries persist through the geologic ages in almost all parts of the earth. Nevertheless, the situation is aggravated in recent times with man's increasing interventions with the environment. Thus, a feasible course of action is to develop and use empirical models. The lack of availability of data such as sediment deposition data, rainfall intensity at shorter intervals (less than 30 min) in the study area, has limited the options for selection of data intensive models such as USPED, WEPP, soil erosion module in SWAT (soil and water assessment tool) model. Therefore, RUSLE model was selected and applied in study area as it requires land use land cover map that can be generated by remote sensing images, management practices, soil types and properties. The other advantage of a selection of RUSLE is that the parameters of this model can be easily integrated with GIS for better analysis. The main aim of present study is to integrate RUSLE model with remote sensing and GIS techniques for assessing the erosion risk in Nethravathi river basin. The methodology describes the basic concepts, the procedure of the RUSLE model to estimate parameters and parameter prediction of RUSLE model. The parameters of RUSLE model have been estimated based on the rainfall events, DEM, soil type, and land cover. The overall methodology used in the present study is schematically represented in Fig. 2.

3.1. RUSLE parameter estimation

RUSLE is the method, most widely used around the world to predict long-term rates of inter-rill and rill erosion from field or farm size units subject to different management practices. The present study was started with delineation of Nethravathi river basin from Survey of India (SoI) toposheet of 1:50,000 scale using ArcGIS 9.3 software. Influencing rain gauge stations located in and around the basin are identified and marked on the map. The prepared base map was then used for the extraction of study area from satellite image (Indian Remote Sensing satellite, linear image self scanning sensor-3 IRS LISS-3) and Carto DEM (digital elevation model obtained by cartographic satellite).

The underlying assumption in RUSLE is that the detachment and deposition are controlled by sediment content of the flow. The eroded material is not source limited, but the erosion is limited by the carrying capacity of the flow. When the sediment load reaches the carrying capacity of the flow, detachment can no longer occur. Sedimentation must also occur during the receding portion of the hydrograph as the flow rate decreases (Kim, 2006). The basic form of RUSLE equation has remained the same, but modifications in several of the factors have changed.

In this study, RUSLE was used for the assessment of annual soil loss. RUSLE was designed to predict long-term annual averages of soil loss. A modern computer interface makes RUSLE easily used and uses physically meaningful input values that are widely available in existing databases or can be easily obtained from DEM and

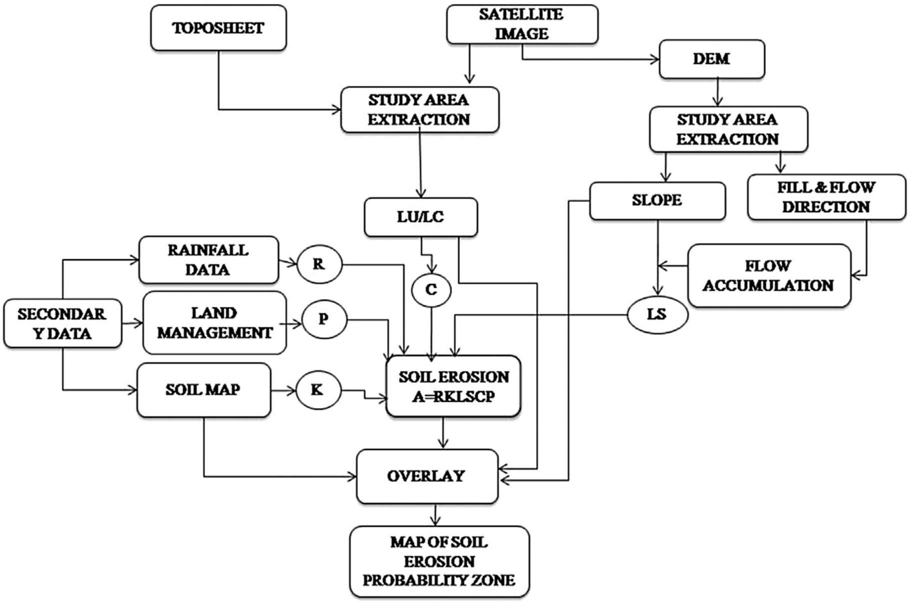

Figure 2. Flow chart of methodology.

satellite images. RUSLE is the best available practical erosion prediction model that can be easily applied at the local or regional level. In addition to this, many parameters such as slope, aspect, etc. derived from DEM and LULC (land use land cover) from satellite images can be easily integrated with RUSLE. The disadvantage of RUSLE is that it does not have the capability for routing sediment through channels, hence its application is limited to small areas. Therefore, the model is not applied to the very large watershed (Nearing et al., 2005). The RUSLE is applied to the Nethravathi Basin by representing the basin as a grid of square cells and calculating soil erosion for each cell. RUSLE (Wischmeier and Smith, 1978) compute the average annual erosion expected on field slopes using in Eq. (1).

$$A = R \times K \times LS \times C \times P \tag{1}$$

where A = computed spatial average soil loss and temporal average soil loss per unit of area, expressed in the units selected for K and for the period selected for R. In practice, these are usually selected so that A is expressed in ton per hectare per year (t ha^{-1}/yr), (but other units can be selected (i.e., t acre^{-1}/yr)); R = rainfall-runoff erosivity factor—the rainfall erosion index plus a factor for any significant runoff from snow melt expressed in MJ mm ha^{-1} h^{-1} per year; K = soil erodibility factor – the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot, which is defined as a 72.6-ft (22.1-m) length of uniform 9% slope in continuous clean-tilled fallow expressed in t ha^{-1} MJ mm^{-1}; L = slope length factor – the ratio of soil loss from the field slope length to soil loss from a 72.6-ft length under identical conditions; S = slope steepness factor – the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions; C = cover management factor – the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow; P = support practice factor – the ratio of soil loss with a support practice like contouring, strip cropping, or terracing to soil loss with straight-row farming up and down the slope; L and S factors stand for the dimensionless impact of slope length and steepness, and C and P represent the dimensionless impacts of cropping and management systems and of erosion control practices.

All dimensionless parameters are normalized relative to the unit plot conditions, as described in widespread use (Jain et al., 2001; Dabral et al., 2008) has substantiated the usefulness and validity of RUSLE for this purpose. Broadly, the parameters of RUSLE equation were grouped into three classes, namely erosivity, erodibility and management factors. All these parameters were determined from geomorphological and rainfall characteristics.

3.2. Rainfall erosivity factor (R)

The rainfall erosivity factor (R) reflects the effect of rainfall intensity on soil erosion, and requires detailed, continuous precipitation data for its calculation (Wischmeier and Smith, 1978). R is an indication of the two most important characteristics of a storm determining its erosivity viz amount of rainfall and peak intensity sustained over an extended period. Previous studies indicate that soil loss from cultivated fields is directly related to the energy and intensity of each rainfall. The value of rainfall erosivity factor used in RUSLE must quantify the effect of raindrop impact and must also reflect the amount and rate of runoff likely to be associated with the rainfall. The rainfall erosivity factor is often determined from rainfall intensity if such data are available. In the present study, monthly rainfall data of 10 years (2000–2009) were used to calculate the R factor from the following Eq. (2) developed by Wischmeier and Smith (1978):

$$R = \sum_{1}^{12} 1.735 \times 10^{(1.5 \log_{10}(P_i/P) - 0.08188)} \tag{2}$$

where R is a rainfall erositivity factor (MJ mm ha^{-1} h^{-1} per year); P_i is monthly rainfall (mm); P is an annual rainfall (mm).

Spatial distribution of average annual precipitation (P) in the study area is estimated using 'Kriging' method of interpolation. In the process of interpolation, 10 years rainfall data for 13 rainguage stations (Fig. 3) in and around the study area were considered. It is observed that the highest rainfall occurred in Subramanya region and the lowest rainfall occurred in Sakaleshpura region. Fig. 3 shows the rainfall erosivity map prepared by rainfall data of the study area.

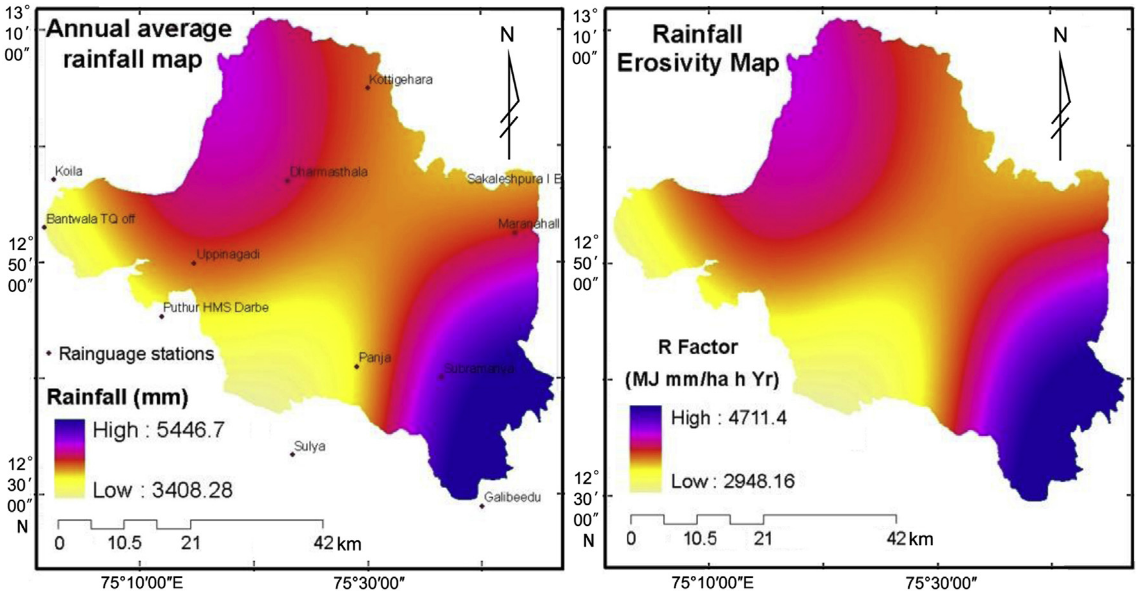

Figure 3. Rainfall and rainfall erosivity map (R).

3.3. Soil erodibility factor (K)

Soil Erodibility factor (K) represents the susceptibility of soil or surface material to erosion, transportability of the sediment, and the amount and rate of runoff given a particular rainfall input as measured under a standard condition. 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). The soil erodibility factor K was estimated on the basis of soil textures. K values reflect the rate of soil loss per rainfall-runoff erosivity (R) index. Soil erodibility factors (K) shown in Eq. (3) are best obtained from direct measurements on natural runoff plots. Normally nomograph is used to determine K factor for a soil, based on its texture; % silt plus very fine sand, % sand, % organic matter, soil structure, and permeability (Wischmeier and Smith, 1978).

$$K = 27.66 \times m^{1.14} \times 10^{-8} \times (12 - a) + 0.0043 \times (b - 2) + 0.0033 \times (c - 3) \tag{3}$$

where,

m = silt (in %) + very fine sand (in %) × (100−clay (in %))
a = organic matter (%)
b = structure code in which (1) is very structured or particulate, (2) is fairly structured, (3) is slightly structured, and (4) is solid
c = profile permeability code in which (1) is rapid, (2) is moderate to rapid, (3) is moderate, (4) is moderate to slow, (5) is slow, and (6) very slow

In general, clay soils have low K value because these soils are resistant to detachment. Sandy soils are also have low K values due to high infiltration rates and reduced runoff, and because sediment eroded from these soils is not easily transported. Silt loam soils have moderate to high K values as the soil particles are moderately to easily detachable, infiltration is moderate to low producing moderate to high runoff, and the sediment is moderately to easily transport. Silt soils have the highest K values as these soils crust readily, producing high runoff rates and quantities.

The Nethravathi river basin consists of 14 different soil types as presented in Fig. 4 with varying soil characteristics. Soil erodibility value was assigned to different soil types based on soil texture, permeability and antecedent moisture content of the soil. The soil map was reclassified with assigned K-factor value (Fig. 4). The K factor is a numerical value varies from 0 to 1 in which soil erodibility values closer to 0 are less prone to soil erosion.

3.4. Topographic factor (LS)

The Topographic factor represents a ratio of soil loss under given condition to that at a site with the “standard” slope steepness of 9% and slope length of 22.6 m. Topographical factor constitutes two factors which are slope length (L) and slope steepness (S).

Slope length (L) is the effect of slope length on erosion. The slope length is defined as the distance from the point of origin of overland flow to the point where either the slope decreases to the extent that deposition begins, or runoff water enters a well-defined channel. Thus, the soil loss per unit area increases as the slope length increases.

Slope steepness (S) represents the effect of slope steepness on erosion. The effects of slope steepness have a greater impact on soil loss than slope length. Steeper the slope, the greater is the erosion. The worst erosion occurring between 10 and 25% slope. Therefore, the topographic factor is calculated using Eq. (4).

$$LS = \left[\frac{Q_a M}{22.13}\right]^y \times \left(0.065 + 0.045 \times S_g + 0.0065 \times S_g^2\right) \tag{4}$$

where LS = Topographical factor; Q_a = Flow Accumulation grid; S_g = Grid slope in percentage; M = Grid size (x × y), y = dimensionless exponent that assumes the value of 0.2–0.5.

Wischmeier and Smith (1978) came out with varying values of exponent m for different slopes depends on slope steepness, being 0.5 for slopes exceeding 4.5%, 0.4 for 3–4.5% slopes, 0.3 for 1–3%, and 0.2 for slopes less than 1%. The slope map in percentage is prepared from the DEM for the Nethravathi Basin as shown in Fig. 5.

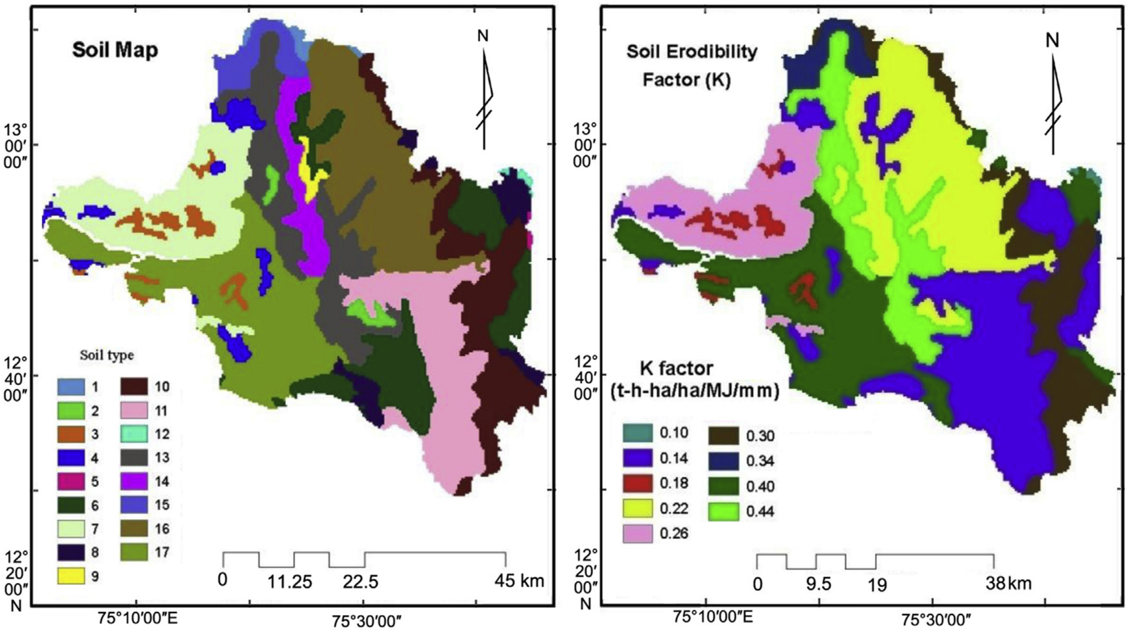

Figure 4. Soil and soil erodibility map (*K*).

3.5. *Crop management factor (C)*

The *C*-factors are the most important values for crop management. Since *C*-factors are not available for most of Indian crops. Therefore, the *C*-factors found by Karaburun (2010) were used to indicate the effect of cropping and management practices on soil erosion rates in agricultural lands. The effects of vegetation canopy and ground covers on reducing soil erosion in forested regions (Renard et al., 1997) varies with season and crop production system. The seasonal variation of *C*-factor depends on many factors such as rainfall, agricultural practice, type of crops etc. However, the present study considered an annual variation as there is no cultivation in rabi season (November–April) in the study area and also, there is no rainfall after October month. The relative impact of management options can easily be compared with making changes in the *C*-factor which varies from near zero for a well-protected land cover to 1 for barren areas. Hence, the impact of *C*-factor on soil erosion is not much significant when the land use-land cover of the study area comprises highest percentage of forest and plantation crops.

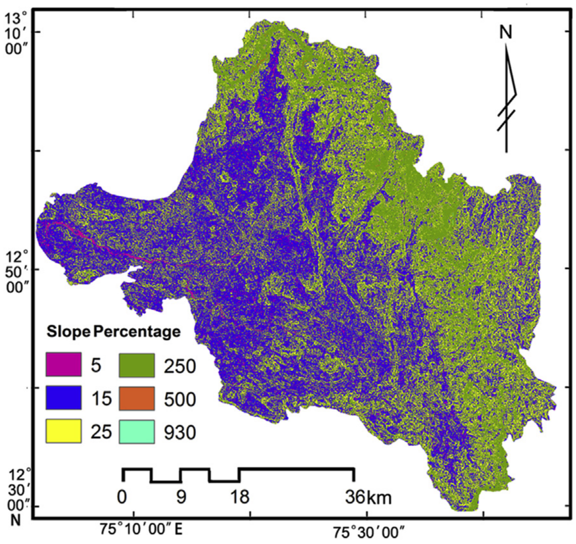

Figure 5. Slope map in percentage.

The crop management factor map (Fig. 6) was prepared on the basis of land use-land cover map of the study area. The land use-land cover of the Nethravathi Basin was classified with six land use-land cover classes, namely, water body, forest area, built-up land, wasteland, agriculture land, other category (Fig. 6) based on the ground information. These are the major land use-land cover features found in Nethravathi Basin. Indian remote sensing (IRS) satellite 1D-LISS-3 image was processed for extracting these six land use-land cover classes using supervised classification method. The supervised classification method is the method which requires ground truth information for each land use-land cover category was collected using global position system (GPS) and trained the algorithm to extract these six land use-land cover. The overall accuracy of the supervised classification method was about 82%. The area associated with each land use-land cover classes have been calculated and *C*-factors were assigned (Table 3). The *C*-values were used in the present study proposed by Kim et al. (2005). The land use-land cover map was reclassified based on *C*-factor value for the generation of the *C*-factor map.

3.6. *Conservation support practice factor (P)*

The conservation practice factor (*P*) represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope and is used to account for the positive impacts of those support practices. The *P* factor accounts for control practices that reduce the erosion potential of the runoff by their influence on drainage patterns, runoff concentration, runoff velocity, and hydraulic forces exerted by runoff on soil. The value of *P* factor ranges from 0 to 1, the value approaching to 0 indicates good conservation practice and the value approaching to 1 indicates poor conservation practice. Since there is a lack of field data regarding the conservation practices that have been taken place in the Nethravathi Basin.

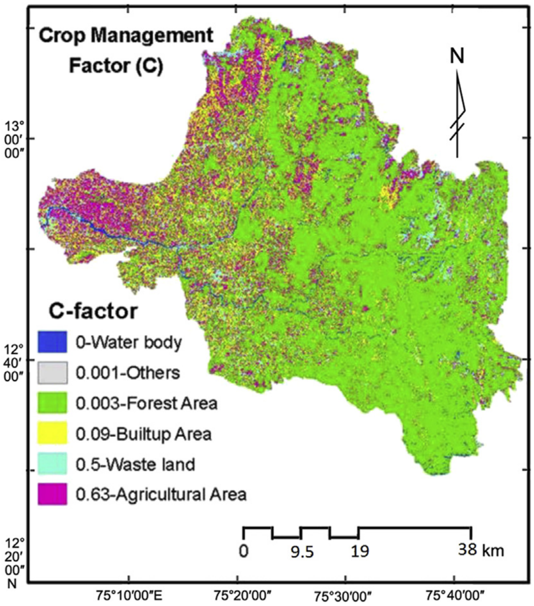

Figure 6. Crop management factor (*C*) with LULC.

Table 3
Land use/land cover classes and respective *C*-factor value.

Sl. no	Class name	Area (ha)	Area (%)	*C*-factor
1	Agricultural area	553.903	17.7	0.63
2	Built-up land	385.944	12.38	0.09
3	Forest area	1909.7	61.1	0.003
4	Others	0.688	0.02	0.001
5	Waste land	204.11	6.5	0.5
6	Water body	71.749	2.3	0

Thus, *P* factor value was taken as 1 because the majority of the study area is covered by forest.

4. Assessing the impact of increase in agricultural area on soil erosion rate

For assessing the impact of increase in an agricultural area, a part of forest area which is adjacent to agricultural area was hypothetically misinterpreted as an agricultural area. With this hypothetically misinterpreted signature file, the satellite image was again classified using supervised classification method. The classified image with increased agricultural area was assigned with a *C*-factor (Table 4) to generate *C*-factor map. Then, the soil erosion was estimated by considering the *C*-factor map for hypothetically increased agricultural area.

5. Estimation of potential soil erosion

Within RUSLE modelling frame work, the rain erosivity, soil erodibility and topographic factor can be considered as naturally occurring factors determining the erosion processes. Together, they can be considered as the erosion susceptibility or potential soil erosion loss for the area.

6. Delineation of soil erosion probability zones

In order to identify and map the areas vulnerable to soil erosion, various thematic maps prepared were integrated in GIS. Major factors that are considered to be influencing soil erosion include land use-land cover, soil properties, rainfall intensity, and slope. The weightages for individual themes were assigned by considering its role in the soil erosion. The process involved raster overlay analysis and is known as Weighted Index Overlay (WIO). The maximum value is given to the feature with highest susceptibility and the minimum being to the lowest susceptible feature.

Table 4
Categories of soil erosion, area and the amount of soil loss.

Erosion categories	Numeric range (t/ha/year)	Area (ha)	Area (%)	Soil loss (t/year)
Low erosion	0–100	177,805.5	56.8	1747.6
Moderate erosion	101–1000	78,964.8	25.2	33,437.1
High erosion	1001–5000	42,479.6	13.6	88,491.2
Very high erosion	5001–1,907,287	13,644.1	4.4	349,663.2
Total	–	312,894.0	100	473,339.1

7. Results and discussions

7.1. Rainfall erosivity factor (R)

Many studies (Jain et al., 2001; Dabral et al., 2008) revealed that the soil erosion rate in the catchment is more sensitive to rainfall. The daily rainfall is a better indicator of variation in the rate of soil erosion to characterize the seasonal distribution of sediment yield. While the advantages of using annual rainfall include its ready availability, ease of computation and greater regional consistency of the exponent (Shinde et al., 2010). Therefore, in the present analysis, average annual (obtained by total rainfall divided by the total number of rainy days) rainfall was used for *R* factor calculation (Eq. (2)). The estimated *R* factor value ranges from 2948.16 to 4711.4 MJ/mm·ha^{-1}hr^{-1}/year. It is observed that rainfall is high in Subramanya region as indicated from the results.

7.2. Soil erodibility factor (K)

K factor values were assigned to respective soil types in soil map to generate the soil erodibility map. The values of *K* factor are found to be ranging between 0.10 and 0.44. The lower value of *K* factor is associated with the soils having low permeability, low antecedent moisture content, etc.

7.3. Topographic factor (LS)

Topographic factor represents the influence of slope length and slope steepness on erosion process. *LS* factor was calculated by considering the flow accumulation and slope in percentage as an input. From the analysis, it is observed that the value of topographic factor increases in a range of 0–1240 as the flow accumulation and slope increases.

7.4. Crop management factor (C)

Information on land use permits a better understanding of the land utilization aspects of cropping pattern, fallow land, forest, wasteland and surface water bodies, which are vital for developmental planning/erosion studies. Remote sensing and GIS technique has a potential to generate a thematic layer of land use-land cover of a region. The study area has been classified into six land use classes. Crop management factor was assigned to different land use patterns using the values given in Table 3. Using land use-land cover map and *C* factor value, the *C* factor map was prepared.

7.5. *Potential annual soil erosion estimation*

The GIS analysis has been carried out for RUSLE to estimate annual soil loss on a pixel-by-pixel basis and the spatial distribution of the soil erosion in the study area. The gross amount of soil loss accounts for 473,339 t/yr by RUSLE model against measured annual sediment load of 441,870 t during the water year 2003–2003 as shown in Table 4. However, the measured sediment load from the water year 1992–1993 to 1999–2000 was very high and found in the order of million tons. This was mainly due to less number of check dams (locally called "vented dam") constructed across Nethravathi river and its tributaries. After the year 2000, more number of vented dams (about 18 numbers) were constructed across the river Nethravathi and its tributaries. The sediment from the river has been stored at the upstream side of these vented dams and the sediment is being removed every year. The sediment is in the form of a good sand and it is been used as construction material. This has an implication of reduction in sediment load at measuring location. However, the soil loss estimated in the present study is compared with the measured sediments. It is found that the soil loss of 473,339 t per year estimated by RUSLE model using land use-land cover of 2003 is almost matching with the measured sediment load of 441,870 t during year 2002–2003. The potential soil loss in the study area has been categorized into four types viz., low, moderate, high and very high erosion based on the rate of erosion (t/ha/year), i.e., More erosion corresponds to very high erosion and least rate of erosion correspond to low erosion (Table 4). The rest two categories fall in between moderate and high erosion. It is observed that few parts of the study area have higher values of soil loss, which may be due to the steep slope. The erosion severity map was prepared by considering four ordinal categories of soil erosion. It is observed that most part of the study area comes under lower erosion category, which could be found in almost all areas, very high erosion occurs only in a few regions where the steep slope with barren land exists. Moderate erosion occurs in the foothills of western Ghats of the study area where agricultural area with mild slope exists.

7.6. *Impact of increase in agricultural area on soil erosion rate*

Soil loss has a close relationship with land use-land cover. An attempt was made to analyze the impact of land use-land cover change on erosion rate. The satellite image was reclassified by increasing agricultural and decreasing forest category. The change in agricultural area was obtained by comparing with initial land use-land cover map. The crop management factors *C* for the increased agricultural area (Table 5) were derived from remote sensing image. The gross amount of erosion has been increased due to increase in agricultural area is 488,012.6 t/yr against 473,339 t/yr. The difference of about 14,673.5 t/yr has been generated due to small increases in agricultural area and small decrease in forest area. Hence, there is an increase of 3.1% of soil loss when compared with the actual soil loss. The increase in soil loss was found mainly due to the agricultural activities like ploughing, tillage, land preparation, etc.

7.7. *Soil erosion probability zones*

The soil erosion probability zone was generated by overlaying different layers such as land use-land cover, soil, slope and a rainfall maps using weighted index overlay method. The soil erosion probability zones in the study area has been categorized into four types viz., low, moderate, high and very high erosion. In Fig. 7, it is observed that nearly 56.8% of the basin area produces low erosion of 1747.6 t annually, whereas very high probability zone covers about 4.4% of the basin area and produces soil erosion of 349,663 t annually.

Table 5
LU/LC classes and respective *C*-factor for increased agricultural area.

Sl. no	Class name	Area (ha)	Area (%)	*C*-factor
1	Agricultural area	570.90	18.26	0.63
2	Built-up land	401.21	12.83	0.09
3	Forest area	1862.27	59.56	0.003
4	Others	0.688	0.02	0.001
5	Waste land	217.17	6.96	0.5
6	Water body	74.00	2.37	0

8. Conclusions

Empirical soil erosion models, though relatively simple, are easy to interpret physically, require minimal resources and can be worked out with readily available inputs to precisely the areas exposed to high erosion risk. This paper demonstrates the application of empirical soil erosion model such as RUSLE integrated with GIS to estimate soil erosion potential and the potential zones in Nethravathi Basin. Also, an attempt has been made to study the impact of change in land use-land cover on erosion rate. The analysis and results conclude that the annual average soil loss estimated using RUSLE model is about 473,339 t/yr in the Nethravathi Basin. It is also observed that the quantity of erosion varies mainly on topography and land use-land cover. The erosion severity map revealed that about 18% of the area comes under high and very high erosion category. It is necessary to implement suitable soil conservation practices in such areas. By analyzing the impact of increase in agricultural area on soil erosion, it can be concluded that as the agricultural area increases, erosion risk also increases due the agricultural practices. The comparison of potential soil loss with actual soil loss helps in assessing the erosion impact of various cropping system and conservation support practices. The implementation of Weighted Index Overlay (WIO) method, enable to classify the area into different zones on the basis of probability of soil erosion which ultimately helpful to derive suitable protection measures. This study demonstrates that GIS is a valuable tool in

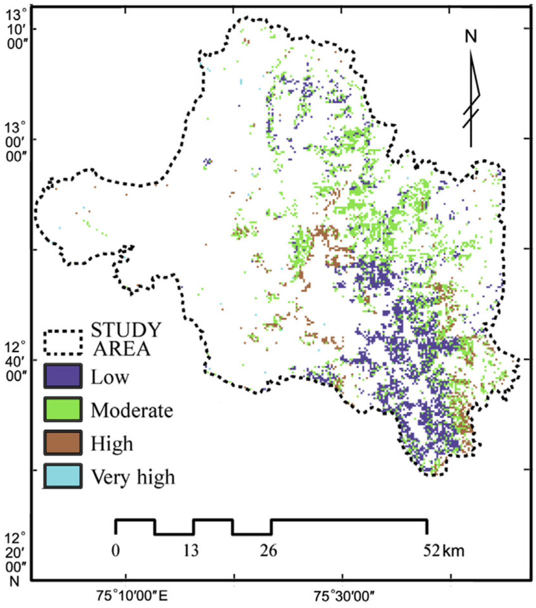

Figure 7. Soil erosion probability map.

assessing soil erosion and assisting the estimation of erosion loss. The potential soil loss of 473,339 t estimated by RUSLE was compared with measured annual sediment of 441,870 t during the water year 2002–2003 in Nethravathi river. The model result reasonably matches with the observed data. The study also concludes that RUSLE is sensitive to land use-land cover (particularly, agricultural activities) and thus, the gross amount of erosion has been increased to 488,012.6 t/yr against 473,339 t/yr due to increase in agricultural areas. The difference of about 14,673.5 t/yr has been generated due to small increases in agricultural area with small decrease in forest area.

GIS-based RUSLE methodology was used to identify the spatial distribution of different erosion prone areas in the Nethravathi Basin. The outcome would help to take suitable erosion control measures in the severely affected areas. The results obtained from the study can assist in developing management scenarios and provide options to policy makers for managing soil erosion hazards in the most efficient manner for prioritization of different regions of the basin for treatment.

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