

# A RS and GIS Approaches for the Estimation of Runoff and Soil Erosion in SA-13 Watershed

H. N. Bhange and V. V. Deshmukh

**Abstract** The research work was conducted for the estimation of runoff and soil loss from SA-13 watershed. SA-13 watershed has area of 213 km<sup>2</sup> in Ashti tahsil, Beed. The SCS curve number method and Revised USLE using RS and GIS techniques were used to find out runoff volume and soil erosion. The results show that the average rainfall for the year 2005 in the SA-13 watershed was 406.50 mm and average annual runoff was 93.52 mm, amounting 23.01% of the total rainfall received. The average annual soil loss of the SA-13 watershed is 8.2 tons/ha/year. Soil erosion is in moderate erosion risk class. The results obtained using remote sensing techniques can help decision makers to prepare resource map accurately in less time and cost.

## Introduction

A watershed is a natural ecological unit composed of interrelated parts and contributes runoff water to a single point. Rainstorms generate runoff, and its occurrence and quantity are dependent on the intensity, duration, and distribution of the rainfall event. There are a number of catchment-specific factors, which have a direct effect on the occurrence and volume of runoff which includes soil type, vegetation cover, slope, and catchment's type. Runoff is one of the most important hydrologic variables used in most of the resource applications. Reliable prediction of quantity and rate of runoff from land surface into stream and river is difficult and time-consuming to obtain for ungauged watershed. However, this information is

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needed in dealing with many watershed development and management problems. Conventional methods for prediction of river discharge require considerable hydrological and meteorological data. Collection of these data is expensive, time-consuming, and a difficult process.

In India, the availability of accurate information on runoff is scarcely available and that too in a few selected sites where recording and automatic hydrologic gauging stations are installed. Thus, there is an urgent need to generate information on basin runoff and silt yield for the acceleration of the watershed development and management programs (Zade et al. 2005). Most of the agricultural watersheds in India are ungauged, having no past record whatsoever of rainfall–runoff processes (Sarangi et al. 2005a, b). Non-availability of continuous rainfall and runoff records in majority of Indian watersheds has led to the development of techniques for the estimation of surface runoff from ungauged basins (Chattopadhyay and Choudhury 2006).

However, speeding up of the watershed management program for conservation and development of natural resource management has necessitated the runoff information. Remote Sensing data was provided a quick result for decision-makers before any quantification of Runoff. These tools provide significant reduction in the cost and time over the conventional methods with reliability and accuracy. So the RS and GIS techniques provide valuable modern tools in evaluation, management, and system performance of the water resources (Ingle et al. 2008). Advances in computational power and the growing availability of spatial data have made it possible to accurately predict the runoff. The possibility of rapidly combining data of different types in a geographic information system (GIS) has led to significant increase in its use in hydrological applications. The runoff depth computed for ungauged watershed using SCS-CN method in the GIS environment is used for management and conservation purposes (Ebrahimian et al. 2009). Out of several methods for runoff estimation from ungauged watershed, the curve number (CN) is an index developed by the Natural Resource Conservation Service (NRCS), to represent the potential for storm water runoff within a drainage area. The curve number method, also known as the hydrologic soil cover complex method, is a versatile and widely used procedure for runoff estimation. The CN for a drainage basin is estimated using a combination of land use, soil's permeability, and antecedent soil moisture condition (AMC).

Soil erosion is one of the most critical environmental hazards of modern times. Assessing the severity of soil erosion is difficult due to the fact that land often erodes at an imperceptible rate. In addition, some areas may be more susceptible to soil erosion than others and the rate of erosion is not the same everywhere. Vast areas of land now being cultivated may be rendered economically unproductive if the erosion of soil continues unabated.

Soil erosion is a complex phenomenon as it is governed by various natural processes, and it, in turn, results in decrease of soil fertility and reduction of crop yields. Globally, 1964.4 M ha of land is affected by human-induced degradation (UNEP 1997). Of this, 1,903 M ha is subject to soil erosion by water and

548.3 M ha by wind erosion. Each year, 75 billion tons of soil is removed due to erosion largely from agricultural land. The process of soil erosion involves detachment, transport, and subsequent deposition (Meyer and Wischmeier 1969). The consequence of soil erosion occurs both on-site and off-site (Morgan 1986). On-site effects are particularly, where the redistribution of soil within a field, the loss of soil from a field, the breakdown of soil structure, and the decline in organic matter and nutrient result in a reduction of cultivable soil depth and decline in soil fertility. Erosion also reduces available soil moisture, resulting in more drought-prone conditions. The net effect is a loss of productivity which, at first, restricts what can be grown and results in increased expenditure on fertilizers to maintain yields but later, ultimately leads to land abandonment. Off-site problems result from sedimentation downstream, which reduces the capacity of the rivers, enhances the risk of flooding, blocks irrigation canals, and reduces the design life of reservoirs.

The prevention of soil erosion, which means reducing the rate of soil loss to approximately that which would occur under natural conditions, relies on selecting appropriate strategies for soil conservation, and this, in turn, requires a thorough understanding of the processes of erosion. The factors, which influence the rate of soil erosion, are rainfall, runoff, soil, slope, plant cover, and the presence or absence of conservation measures (Morgan 1986).

Several parametric models have been developed by various scientists to predict soil erosion from drainage basins, hillslopes, and field levels. With a few exceptions, these models are based on soil type, land use, climatic and topographic information. Remote sensing technique makes it possible to measure hydrologic parameters on spatial scales. Scientific management of soil, water, and vegetation resources on watershed basis is very important to arrest erosion and rapid siltation in rivers, lakes, and estuaries.

It is, however, realized that due to financial and organizational constraints, it is not feasible to treat the entire watershed within a short time. Prioritization of watersheds on the basis of those sub-watersheds within a watershed which contribute maximum sediment yield obviously should determine our priority to evolve appropriate conservation management strategy so that maximum benefit can be derived out of any such money-time-effort making scheme. Within any particular area, there will be a considerable variation in erosion rates, but if the rates are grouped into those related to natural vegetation, cultivated land, and bare soil, each group follows a broadly similar pattern of similar variation.

Erosion is not only a function of climate alone but also depends on the frequency at which potentially erosive events coincide with ground conditions that accelerate the erosion. The most vulnerable time for erosion is the early part of the wet season when the rainfall is high, but the vegetation has not grown sufficiently to protect the soil. Generally, the period between plowing and the growth of the crop beyond the seedling stage contains an erosion risk if it coincides with heavy rainfall (Morgan 1986).

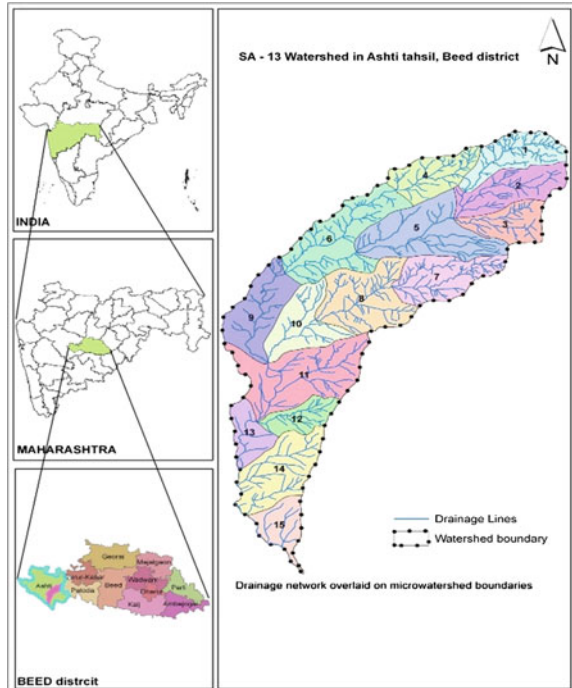
Erosion and land use change are very closely related. Rates of soil loss accelerate quickly unacceptably high levels whenever land is misused. Erosion is a natural

process but that its rate and spatial and temporal distribution depends on the interaction of physical and human circumstances.

Simple methods such as the Universal Soil Loss Equation (USLE) (Musgrave 1947), the Modified Universal Soil Loss Equation (MUSLE) (Williams 1975), or the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1991) are frequently used for the estimation of surface erosion from catchment areas (Ferro and Minacapilli 1995; Ferro 1997; Kothiyari and Jain 1997; Ferro et al. 1998). Both of these quantities are found to have large variability due to the spatial variation of rainfall and catchment heterogeneity. The use of geographical information system (GIS) methodology is well suited for the quantification of heterogeneity in the topographic and drainage features of a catchment (Shamsi 1996; Rodda et al. 1999). With this view in mind, the study was carried out with the objectives, estimation of runoff using SCS-CN and estimation of soil erosion using RUSLE, by RS and GIS from watershed. SA-13 watershed is located in Ashti tahsil, district Beed of Maharashtra. Area represents typical semiarid region of Maharashtra state and associated agroecological setup.

Watershed SA-13 lies between longitude 75° 04' 55" to 75° 16' 25"E and latitude 18° 40' 11" to 18° 56' 20"N. SA-13 occupies an area of about 21,300 ha (Fig. 1). The elevation of the watershed ranges from 730 m above mean sea level at northeast border and gradually decreases down to 575 m at the confluence of Sina and Talwar rivers

**Fig. 1** Location map of study area



## **Materials and Methods**

### ***Watershed Delineation***

Survey of India toposheets 47°N/1, 47°N/2, and 47°N/5 (1:50,000 scale) in combination with satellite image was used for watershed delineation. Contours, spot heights, and elevation along with drainage pattern exhibited on the toposheets were the guiding features for micro-watershed delineation. 15 micro-watersheds were delineated for the project area.

### ***Land Use/Land Cover***

Land use/land cover was one of the most important thematic inputs in any study as it provides the present status of land utilization and its pattern. The change in the land use/land cover is very dynamic that is why satellite remote sensing is widely used for its mapping. The multiseasonal satellite data are used to know the status of different crops in different seasons. Classification system suggested by NRSA (1989) was adopted. The preprocessing techniques need to be employed on the satellite data before it can be used for actual interpretation. Geometric correction of satellite images and enhancement used as a preprocessing step is required for further processing. ERDAS Imagine 9.1 image processing software is used for preprocessing of satellite data (ERDAS Imagine Field Guide 1998), whereas Arc GIS 9.2 suite was used for performing integration of various thematic layers which includes spatial and non-spatial analysis (ESRI User Manual 1994).

In this study, hybrid classification approach (supervised, unsupervised, and NDVI threshold) was adopted to classify the area into different land use classes. The soil map of the study area has been prepared by MRSAC under the project IMSD (Integrated Mission for Sustainable Development) as per the guidelines of NBSS and LUP (1995), AIS and LUS, and Ministry of Agriculture was used for this purpose.

### ***Slope Extraction from SRTM DEM***

The NASA Shuttle Radar Topographic Mission (SRTM) has provided digital elevation model (DEMs) for over 80% of the globe. These data are currently distributed free of charge by USGS and are available for download from the National Map Seamless Data Distribution System, or the USGS ftp site. The SRTM data are available as 3-arc second (approx. 90-m resolution) DEMs. A 1-arc second data product was also produced, but is not available for all countries. The vertical error of the DEMs is reported to be less than 16 m. The data come in two formats:

arc-formatted ASCII and GeoTIFF. (<http://glcf.umiacs.umd.edu/index.shtml>) SRTM DEM is used to understand the drainage networks, elevation, and generation of the slope.

### ***Runoff Estimation by SCS Curve Number Method***

The requirements for the soil conservation service (SCS) curve number (CN) method are rainfall amount and curve number. The curve number is based on the hydrologic soil group, land use treatment, and hydrologic condition. As defined by SCS soil scientists, soil was classified into four hydrologic groups (A, B, C, and D) (USDA 1985), depending on infiltration and soil classification. Land use and treatment classes were used in the preparation of hydrologic soil cover complex method.

Antecedent soil moisture condition (AMC) is an indicator of watershed wetness and availability of soil moisture storage prior to a storm and has a significant effect on runoff volume. Recognizing its significance, SCS developed a guide for adjusting CN according to AMC based on the total rainfall in the 5-day period preceding a storm. Three levels of AMC are used in the CN method: AMC-I for dry, AMC-II for normal, and AMC-III for wet conditions. Table 1 gives seasonal rainfall limits for these three antecedent soil moisture conditions.

The CN method is based on the recharge capacity of the watershed. The recharge capacity is determined by antecedent soil moisture conditions and physical characteristics of the watershed. The storage capacity (*S*) can be obtained from CN by using the following relationship

$$S = \frac{24,500}{CN} - 245 \tag{1}$$

where

- S* Maximum recharge capacity of watershed after 5-day rainfall antecedent, mm
- CN Curve number.

In the past 30 years, the SCS method has been used by a few researchers because it gives consistently usable results (Rao et al. 1996; Sharma et al. 2001;

**Table 1** Classification of antecedent soil moisture condition

AMC	5-days Antecedent rainfall (mm)	
	Active growing season	Dormant season
I	Dry (<35)	Dry (<12.5)
II	Medium (35–52.5)	Medium (12.5–27.5)
III	Wet (>52.5)	Wet (>27.5)

Chandramohan and Durbude 2001; Sharma and Kumar 2002) for runoff estimation. Putting the value of curve number in above, the recharge capacity ‘S’ was calculated. The direct runoff of the watershed was calculated using following equation.

$$\begin{aligned} Q &= 0, & \text{If } P \leq 0.2S \\ Q &= \left( \frac{P-0.2S}{P+0.8S} \right)^2 & \text{If } P \geq 0.2S \end{aligned} \quad (2)$$

where

$Q$  Runoff depth (mm)

$P$  Rainfall (mm)

$S$  Maximum recharge capacity of watershed after 5-day rainfall antecedent (mm).

### ***Generating CN Map***

To generate the CN map, the hydrologic soil group and land use maps were integrated into GIS environment. An integrated, hydrologic soil cover complex method map with new polygons representing the merged soil hydrologic group and land use was generated. Weighted CN map was generated using following equation:

$$CN = \frac{\sum CN_i \times A_i}{A} \quad (3)$$

where

CN weighted curve number.

$CN_i$  curve number from 1, 2, 3, ...  $i$ .

$A_i$  area with curve number  $CN_i$

$A$  total area of the watershed.

### ***Antecedent Soil Moisture Condition (AMC)***

The CN values for each polygon were calculated for average conditions (i.e., antecedent soil moisture condition Class II). To determine which AMC class was the most appropriately related to study area, the use of rainfall data is necessary. The CN values are documented for the case of AMC-II (USDA 1985). To calculate CN values for AMC-I and AMC-III conditions, the following equations are used (Chow et al. 2002):

$$\text{CN for AMC-I, } \text{CN}_{(I)} = \frac{4.2 * \text{CN}_{(II)}}{10 - (0.058 * \text{CN}_{(II)})} \tag{4}$$

$$\text{CN for AMC-III, } \text{CN}_{(III)} = \frac{23 * \text{CN}_{(II)}}{10 + (0.13 + \text{CN}_{(II)})} \tag{5}$$

where

$\text{CN}_{(II)}$  curve number for normal condition,  
 $\text{CN}_{(I)}$  curve number for dry condition, and  
 $\text{CN}_{(III)}$  curve number for wet condition.

### ***Slope-Adjusted CN***

Slope has profound impact on the determination of CN values; therefore, incorporating slope values in CN and adjusting CN values accordingly are essential from hydrology study point of view. To achieve this, slope and CN maps were intersected to get slopes of each polygon. Since each polygon has different slopes, calculating weighted slope is needed for each polygon. Weighted slope of a polygon was computed using formula (6).

$$\text{Weighted slope} = \frac{\sum_{i=1}^n a_i \times s_i}{A} \tag{6}$$

where

$a_i$  area of slope (ha)  
 $s_i$  slope in percent  
 $A$  polygon area (ha)

Weighted slope of polygon was applied in Eq. (8) to compute slope-adjusted CN values. Huang et al.'s (2006) approach was used to make the improvement and incorporate the slope factor into the analysis. The CN values for AMC-II condition are calculated by formula (8) considering the slope correction, and then,  $\text{CN}_{(II)}$  modified is converted into CN values for AMC-I and AMC-III condition by using following Eqs. (7) and (9)

$$\text{CN}_{(I)} = \text{CN}_{(II)} - \left( \frac{20(100 - \text{CN}_{(II)})}{(100 - \text{CN}_{(II)} + \exp[2.533 - 0.0636(100 - \text{CN}_{(II)})])} \right) \tag{7}$$

$$\text{CN}_{(II)\text{Mod-II}} = \text{CN}_{(II)} \left( \frac{322.79 + 15.63\alpha}{\alpha + 323.52} \right) \tag{8}$$



$$CN_{(III)} = CN_{(II)} \times \exp[0.00673(100 - CN_{(II)})] \tag{9}$$

The daily rainfall data for the year 2005 for the study area and the values of maximum potential retention, *S*, obtained from the CN for the watershed area were used for the estimation of runoff from SCS (model).

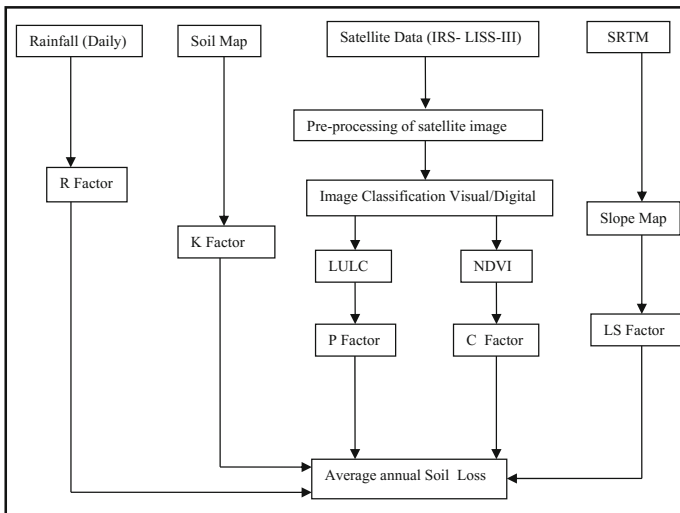
**Soil Erosion by Revised Universal Soil Loss Equation (RUSLE)**

In this study, RUSLE an empirical equation is a used and estimated annual soil loss in croplands (tons/ha/year) resulting from sheet and rill erosion. The RUSLE is based on the series of factors, each quantifying one or more processes and their interactions, are combined to estimate overall soil loss. The overall schemas of estimating annual soil loss using remote sensing and GIS techniques are given in Fig. 2. Annual soil loss potential from different categories of land uses has been calculated using RUSLE equation, as under:

$$A = R * K * L * S * C * P \tag{10}$$

where

- A Gross amount of soil erosion (t/ha/year);
- R Rainfall erosivity factor (MJ mm ha<sup>-1</sup> h<sup>-1</sup>);



**Fig. 2** Flowchart for the estimation of annual soil loss

- K* Soil erodibility factor ( $t\ ha\ h\ ha^{-1}\ MJ^{-1}\ mm^{-1}$ );  
*L* Slope length factor (dimensionless);  
*S* Slope steepness/gradient factor  
*C* Cover management factor (dimensionless) and  
*P* Support practice factor (dimensionless)

### ***R-Factor (Rainfall Erosivity Factor)***

Rainfall data from nine rainfall stations surrounding the SA-13 watershed were used to calculate rainfall erosivity factor (*R*-value). Monthly precipitation for these stations was collected for the year 2005. The monthly precipitation surface was interpolated to determine the value of each cell. Inverse distance weighted (IDW) technique was adopted to generate interpolated rain image (rain.img) to find the *R*-factor.

$$R\text{-Factor} = 81.5 + [0.380^*(rain.img)] \quad (11)$$

### ***K-Factor (Soil Erodibility Factor)***

*K* values had been estimated for all the vertical layers of the soil series by using the analytical relationship for the nomograph by Atawoo and Heerasing (1997) given as below

$$100K = (2.1 \times 10^4 \times (2 - OM) \times m^{1.14} + 3.25 \times (St - 2) + 2.5 \times (Pt - 3)) \quad (12)$$

where

- K* Soil erodibility (tons-year/MJ-mm),  
 OM % Organic matter,  
 Pt Permeability code,  
 St Soil structure code,  
 M A function of the primary particle size function given by  
 M (% silt + % sand content)

### ***LS-Factor (Slope Length and Steepness Factor)***

Slope gradient ( $S$ ) and slope length ( $L$ ) were determined and combined to form a single factor known as the topographic factor  $LS$ . The accuracy of estimation depends on the resolution of DEM. The  $LS$ -factor in the present study was therefore computed by using the equation stated by Moore and Wilson (1992):

$$LS = (A_s/22.13)^n \times (\sin \beta/0.0896)^m \quad (13)$$

where

$A_s$  the specific area (=Alb), defined as the upslope contributing area for an overland cell (A) per unit width normal to the flow direction (b);

$\beta$  the slope gradient in degrees;

$n$  0.4; for 3–4% slope

$m$  1.3

The slope steepness factor  $S$  is evaluated by the relationship developed by McCool et al. (1987)

$$S = 10.8 \sin \theta + 0.03S < 9\% \quad (\text{i.e. } \tan \theta \leq 0.09) \quad (14a)$$

$$S = (\sin \theta / \sin 5.143)^{0.6} S \leq 9\% \quad (\text{i.e. } \tan \theta \geq 0.09) \quad (14b)$$

$\beta$  is calculated as

$$\beta = (\sin \theta / 0.0896) / [3.0(\sin \theta)^{0.8} + 0.56] \quad (15)$$

where

$\theta$  slope angle.

The combined topographic ( $LS$ ) factor was computed rather than the individual slope length and slope angle factors. The inputs for the computation include the slope in percent and the slope length as a flow length.

### ***C-Factor (Cover Management Factor)***

The Normalized Difference Vegetation Index (NDVI), an indicator of the vegetation vigor and health, is used along with the following formula to generate the  $C$ -factor image for the study area (Zhou et al. 2008; Kouli et al. 2009).

$$\text{NDVI} = \frac{\text{NIR} - R}{\text{NIR} + R} \quad (16)$$

where

NDVI Normalized Difference Vegetation Index (ratio varying from  $-1$  to  $+1$ ).

NIR Near-infrared band.

R Red band

The NDVI map was generated for the watershed to formulate the linear equation between NDVI and  $C$ -factor. The NDVI values less than zero indicate water and other non-vegetated features, so the negative values are not considered in preparing the  $C$ -factor equation. With these boundary conditions, the regression equation for  $C$ -factor was developed.

$$C = 0 \quad \text{NDVI} \leq 0 \quad (17a)$$

$$C = -0.50 \text{NDVI} + 1 \quad 0 < \text{NDVI} \leq 0.68 \quad (17b)$$

$$C = 0 \quad \text{NDVI} \geq 0.68. \quad (18c)$$

### ***P-Factor (Support Practice Factor)***

In this study, the watershed was broadly divided into three zones by considering the present land use/land cover practices and support factors (rabi season image reflects the management practices undertaken in the watershed in terms of soil moisture and vegetation cover). The values of conservation practice factor for different management practices were adopted for the SA-13 watershed as suggested by Haan et al. (1994). The  $P$ -factor was assumed by using the conservation practice of the study area, and the value of  $P$ -factor for strip cropping was taken as 0.37 (Stone and Hilborn 2000).

## **Result**

### ***Runoff Estimation***

In this study, modified soil conservation system (SCS) CN model was used for rainfall–runoff estimation that considers parameter such as soil type, vegetation cover, slope, and watershed characteristics. SCS-CN provides an empirical relationship for estimating initial abstraction and runoff as a function of soil type and land use. Rainfall runoff relationship can be visualized by the factors such as initial abstraction, runoff, and actual retention. The curve number (CN) is an index

developed by the Natural Resource Conservation Service (NRCS), to represent the potential for storm water runoff within a drainage area. The CN for a drainage basin was estimated using a combination of land use, soil, and antecedent soil moisture condition (AMC).

### ***Land Use/Land Cover***

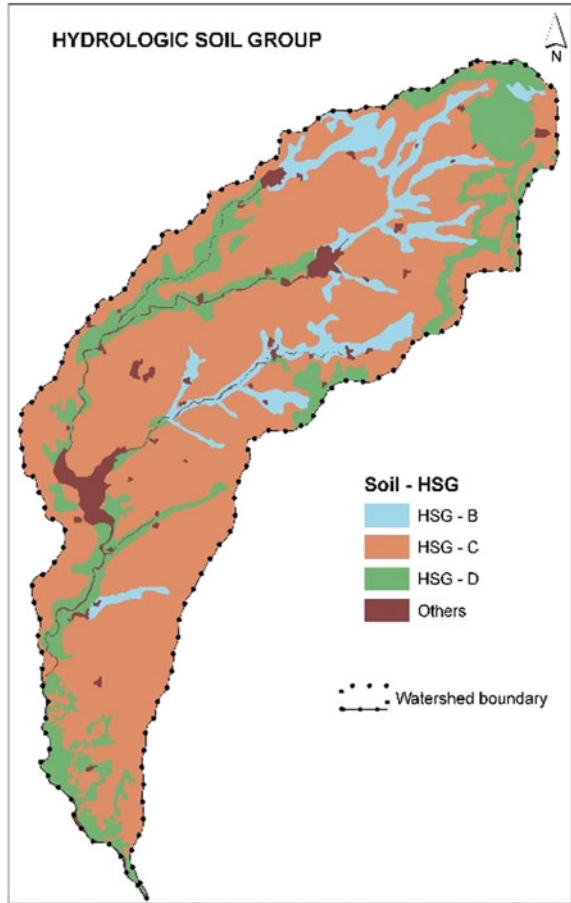
There were eight land use/land cover categories, viz. kharif, rabi, seasonal fallow, double crop, forest, wasteland, water bodies, and settlement in the study area. Watershed was dominantly agrarian in nature with other categories such as forest, wasteland, settlement, and water bodies. Agriculture categories observed in the watershed were kharif season crops, rabi season crops, seasonal fallows, and area cropped twice in a year called as double crop area. In total, 17,847.56 ha of area was demarcated as agriculture land which was 83.79% of the total area of the watershed. Seasonal cropping such as kharif, rabi, and fallows occupies about 13.04, 8.63, and 41.20%, respectively. Watershed was dominated by dry deciduous type of forest, occupying the undulating areas and hills in northern part. Based on the canopy coverage, the forest area was categorized as dense, open, and degraded forest (reported as total forest area). The total area under forest was 1127.10 ha, which was 5.29% of the total watershed area.

Wastelands were mainly the non-arable areas occupying undulating landforms and the hillslopes. The total 2039.26 has area under this category, which was 9.57% of the total watershed area. Other classes, such as settlement and water bodies, occupy about 29.60 and 256.47 ha, respectively.

### ***Hydrologic Soil Groups***

Soils of the watershed were classified into hydrologic soil groups B, C, and D based on infiltration and runoff generating potentials. Hydrologic group A was absent in the study area. Hydrologic soil groups occurring in the area are depicted in Fig. 3. HSG-C occupies highest aerial extent of about 14,820.99 ha which was 69.58% of the total geographical area of the watershed. Dominance of HSG-C indicates that the soils in the watershed have moderately fine-to-fine structure with slow rate of water transmission and with slow rate of infiltration when thoroughly wetted. HSG-C soils are spread all over the watershed in interdrainage areas where ridge line exist with moderate elevation. These areas are conspicuously cultivated for rainfed crops.

**Fig. 3** Hydrological soil grouping (HSG) map of SA-13 watershed

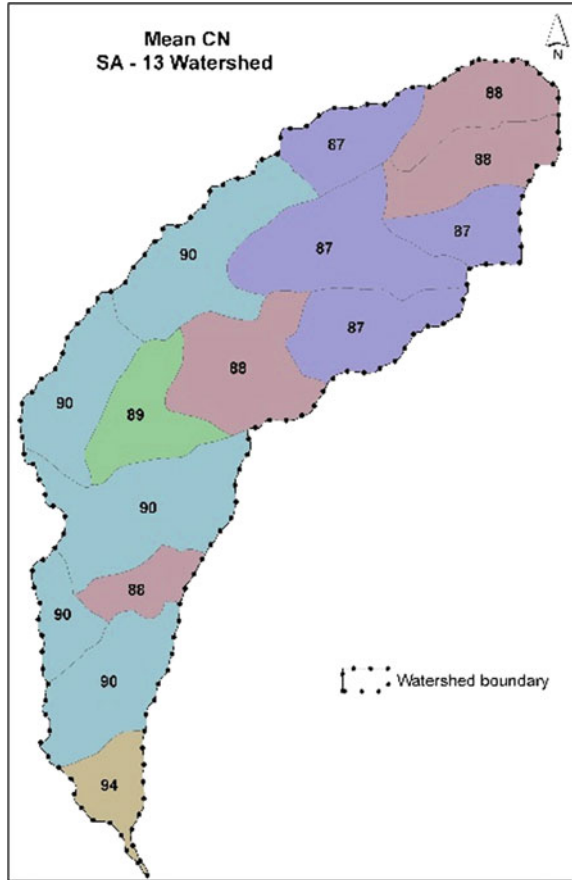


HSG-D covers 17.65% area of watershed. Area occupied by HSG-B was very less, i.e., 1885.50 ha which was mere 8.85% of watershed. They were forming catchment zones for smaller water bodies located in the watershed.

### ***CN Values***

Composite curve number for each micro-watershed was calculated by multiplying weights according to the area occupied by each land use class and the corresponding curve numbers. The weighted CN values were further corrected using slope in m/m (initially estimated in degrees and then converted to radians). Mean slope of each micro-watershed was multiplied with weighted CN to derive

**Fig. 4** Mean CN map of SA-13 watershed



slope-corrected or slope-adjusted CN values for each micro-watershed. Final CN values in each micro-watershed for AMC-II are estimated and depicted in Fig. 4.

Hydrological soil groups C and D lead to higher CN values, whereas hydrologic soil group B leads to relatively low CN values. The lowest CN was found 88, whereas highest CN was 94. This indicates that SA-13 watershed generates higher runoff for these considerable high CN values, as CN values increasing runoff would also increase. Any change in land use can alter CN values of the watershed, and accordingly, the runoff response is also favorable to generate more runoff volume. (Mellesse and Shih 2002).

## Runoff Depth

The rainfall data of SA-13 watershed were obtained for the year 2005, and runoff estimation based on SCS-CN method had been carried out for 15 micro-watershed areas. Daily estimations of runoff were aggregated on monthly basis, and further cumulative scenario on rainfall, runoff, and percent runoff depth is given in Table 2.

It was observed from Table 2 that average annual rainfall in the watershed for the year 2005 was 406.50 mm, whereas average annual runoff depth was 93.52 mm for the year 2005, amounting 23.01% of the total rainfall. Micro-watershed No. 3 generates minimum runoff (i.e., 19.59%) as against micro-watershed No. 15, which has generated maximum runoff of 33.11%. Micro-watershed numbering 3, 5, 4, 2, 1, and 8 generates lower values of runoff, whereas micro-watershed, viz 15, 9, 6, 14, and 11, generated higher values of runoff.

## Soil Loss Estimation

Soil loss is defined as the amount of soil lost in a specified time period over an area of land. It is expressed in units of mass per unit area (t/ha/year). This study uses the RUSLE (Revised Universal Soil Loss Equation) to estimate annual soil loss from agricultural watershed. Soil loss values estimated using RUSLE are dependent upon six major parameters, i.e. *R*-factor (rainfall and runoff), *K*-factor (soil erodibility), *L*-factor (slope length factor), *S*-factor (slope steepness), *C*-factor (cover and

**Table 2** Rainfall and runoff depth for the year 2005

Micro-watershed	Rainfall (mm)	Runoff (mm)	% Runoff
1	406.5	84.19	20.71
2	406.5	85.70	21.08
3	406.5	79.63	19.59
4	406.5	80.06	19.69
5	406.5	79.99	19.68
6	406.5	102.71	25.27
7	406.5	81.36	20.01
8	406.5	87.96	21.64
9	406.5	102.84	25.30
10	406.5	96.46	23.73
11	406.5	98.97	24.35
12	406.5	89.93	22.12
13	406.5	97.16	23.90
14	406.5	101.27	24.91
15	406.5	134.58	33.11
Average	406.5	93.52	23.01



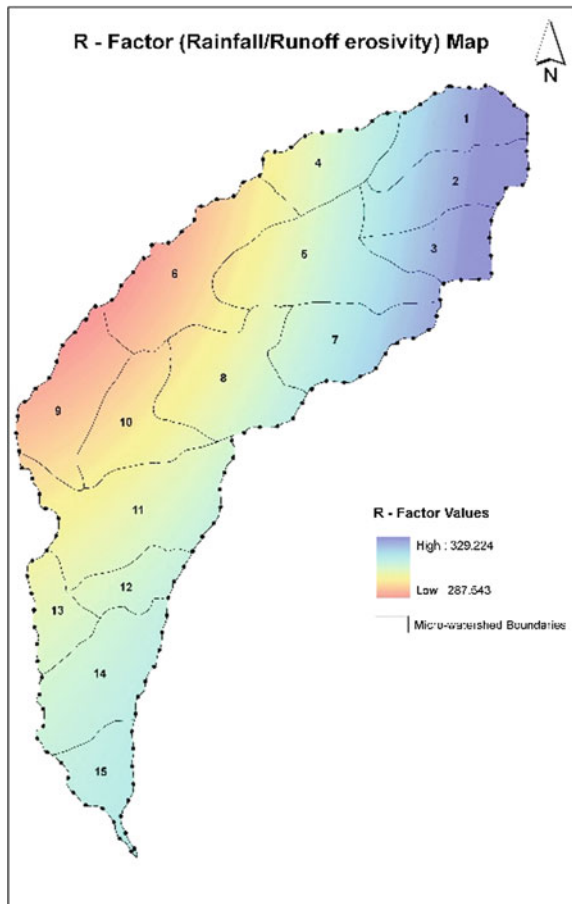
management), and *P*-factor (support practice factors). The result of individual RUSLE parameters and average annual soil loss estimated is as follows.

### ***R*-Factor (Rainfall Erosivity Factor)**

The rainfall distribution was not homogeneous all over the study area; for this reason, an interpolation of annual precipitation data was applied (using IDW interpolation technique) to have a more representative rainfall distribution. The rainfall data from 9 surrounding meteorological stations were used for estimating the average annual precipitation.

*R*-factor map of the SA-13 watershed is depicted in Fig. 5. *R*-factor values for SA-13 watershed vary from 287 to 329, tending higher values at the northeast

**Fig. 5** *R*-factor map of SA-13 watershed

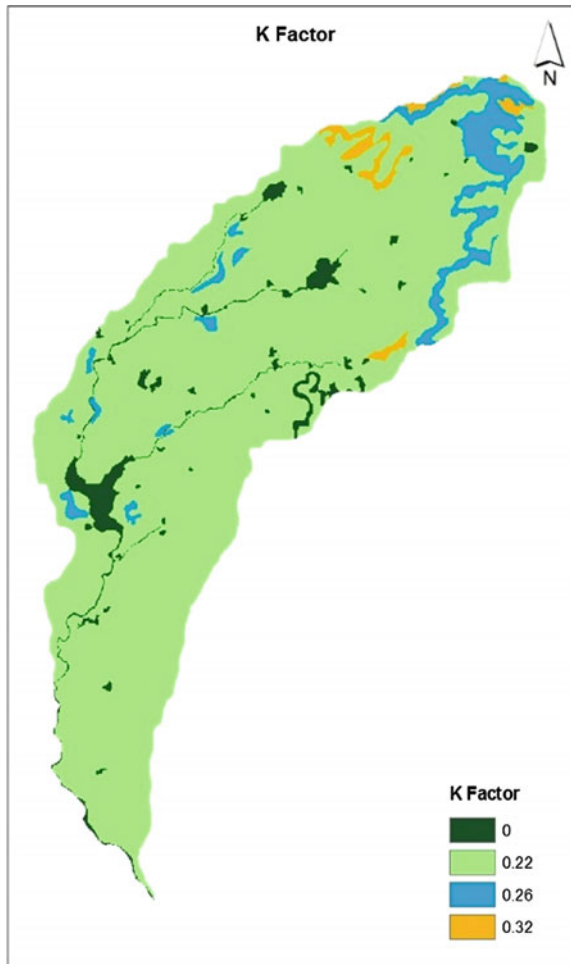


corner and gradually decreasing down to central-west part of the study area. This shows that the value of *R*-factor varies according to rainfall distribution.

***K*-Factor (Soil Erodability Factor)**

The *K*-factor reflects the fact that different soils erode at different rates when the other factors affecting erosion remain the same. Soil texture was the principal cause affecting the *K*-factor along with soil structure, organic matter content, and permeability. A map for the *K*-factor was generated based on above soil parameters and presented in Fig. 6.

**Fig. 6** *K*-factor map of SA-13 watershed



**Table 3** Area statistics of *K*-factor in SA-13 watershed

S. No.	<i>K</i> -factor	Area (ha)	% Total geographical area
1	0.00	936.88	4.40
2	0.22	18707.12	87.83
3	0.26	1288.92	6.05
4	0.32	367.10	1.72
Total		21,300	100

For SA-13 watershed, *K*-factors were varying between 0.00 and 0.32, which depict soil susceptibility to erosion, the sediment transportability, and runoff rate. One assumption was made that only the topsoil layer is the most susceptible to erosion. Therefore, only the *K*-factor values for the top portion of each soil type were used. Area occupied by *K*-factors in SA-13 watershed is given in Table 3.

### ***L*-Factor (Slope Length) and *S*-Factor (Slope Gradient/Steepness)**

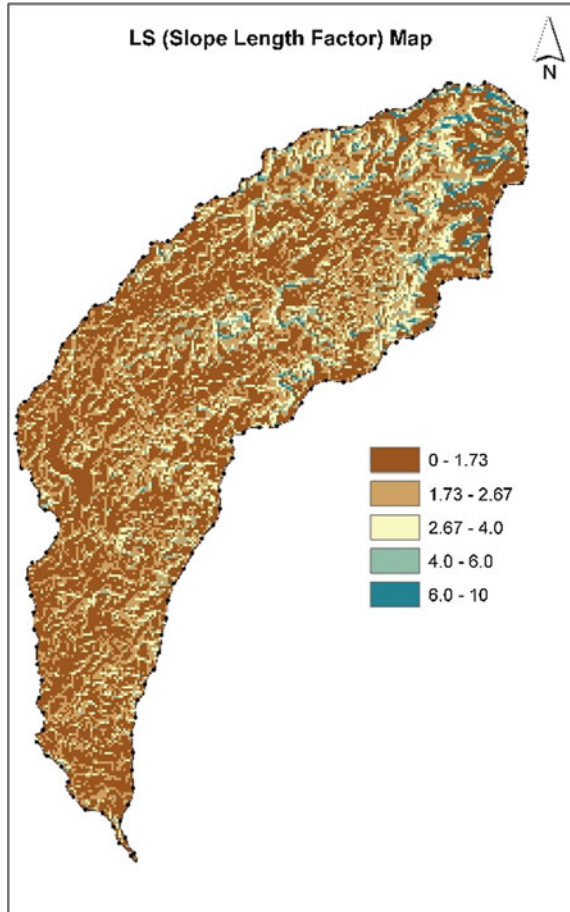
*L*- and *S*-factors in combination are called as topographic factor, both of which are determined using DEM. Slope is varying from 0° to 79.45°. Higher slopes are concentrated on northeastern part of the watershed, whereas it is gradually decreasing toward south. The *L*- and *S*-factors in RUSLE reflect the topography of watershed. The *LS*-factor in the present study was computed for overland cells by using the equation stated by Moore and Wilson (1992). The value of *LS*-factor varies from 0 to 10. The *LS*-factor map of SA-13 watershed is depicted in Fig. 7.

### ***C*-Factor (Cover Management Factor)**

The *C*-factor is the cover management factor. The cover management factor is the ratio of soil loss from an area with specified cover and management to that of an area in tilled continuous fallow. The values of *C* depend on vegetation type, stage of growth, and cover percentage and vary between 0 and 1 (Gitas et al. 2009). The value of *C*-factor varies from 0.44 to 1 depending on the NDVI.

In this study, the cover management factor *C* reflects the effect of cropping and management practices on the soil erosion rate. *C*-factor map of the watershed is presented in Fig. 8.

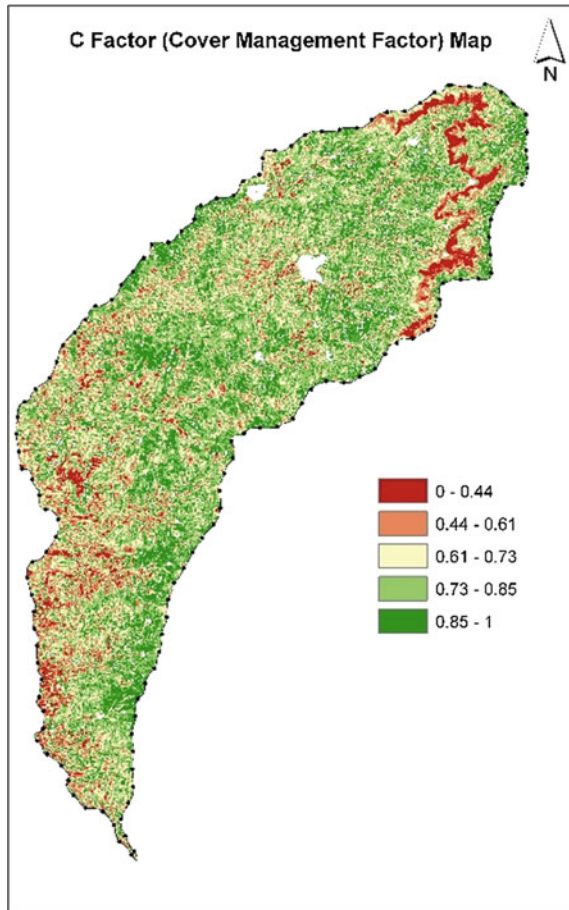
**Fig. 7** Slope length factor map of SA-13 watershed



### ***P-Factor (Support Practice Factor)***

Supporting practices typically affect erosion by redirecting runoff around the slope so that it has less erosivity or by slowing down the runoff to cause deposition. The lower the *P*-factor value, the more effective the conservation practice was deemed to be at reducing soil erosion. If there are no support practices, the *P*-factor is 1.0. In this study area, most of the agricultural area was occupied by rainfed crops such as jowar, soybean, wheat, and gram fields on strip farming method. In forest areas, the *P* value 1 was assigned because there was no support practice. The *P*-factor for strip cropping of the study area was taken 0.37 (Stone and Hilborn 2000).

**Fig. 8** C-factor map of SA-13 watershed

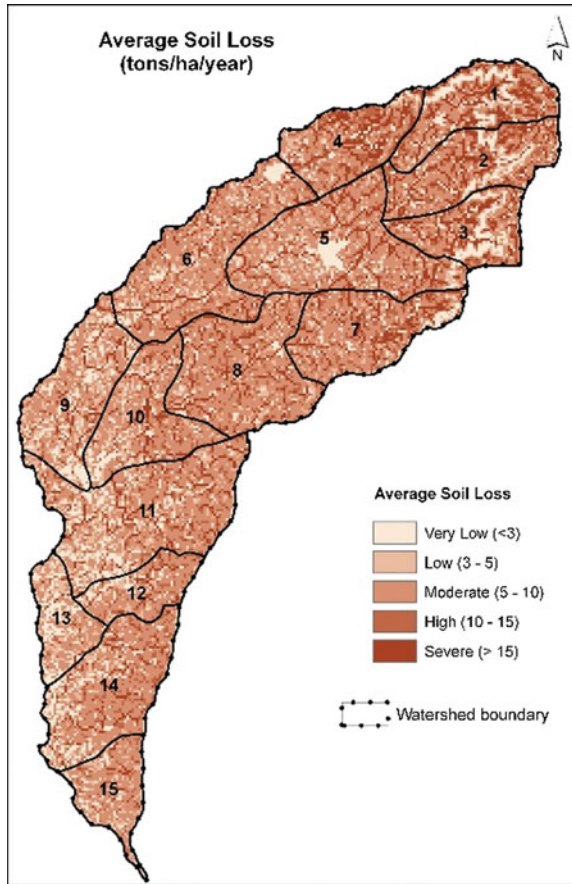


***Estimation of Soil Loss***

The composite term RKLSCP represents the soil erosion potential of different grid cells in the unit t/ha/year. The GIS database generated for the estimation of soil erosion such as *R*-factor, *LS*-factor, *C*-factor, and *P*-factor has been multiplied using ‘Raster Calculator’ in spatial analyst of ArcGIS. The final soil loss map of the watershed is given in Fig. 9. The average soil loss of the entire watershed was 8.2 t/ha/year, highest soil erosion potential of 9.97 t/ha/year was observed in micro-watershed number 4, whereas lowest potential of 5.59 t/ha/year was observed in micro-watershed number 13. Generally, the highest erosion was in areas of bare soils with upland topography where slope exceeds approximately 30°.

Soil erosion is a natural process, and the goal of any mitigation action should be for reducing erosion rates down to reasonable limits. Generally, watershed areas

**Fig. 9** Average soil loss in SA-13 watershed



which have a soil erosion potential under 3 t/ha/year are within the expected tolerable soil loss level and should be excluded from any mitigation actions. Soil erosion in present study is in moderate erosion risk class.

### Conclusions

The conclusions that may be drawn are as follows:

1. Geographical information system arises as an efficient tool for the preparation of most of the input data required by the SCS curve number model;
2. The runoff estimated using SCS curve number model is comparable with the runoff measured by the conventional method for the SA-13 watershed.

3. Generally, the highest estimates of soil erosion are in areas of bare soils with upland topography where slope exceeds approximately 30°.
4. Generally, watershed areas which have soil erosion potential of less than 3 tons/ha/year are within the expected tolerable soil loss level and should be excluded from any mitigation actions.
5. Soil erosion for SA-13 watershed is in moderate erosion risk class.
6. This approach could be applied in other ungauged Indian watersheds for planning of various conservation measures.
7. This methodology can be applied to small basins. The application of remote sensing images and GIS tools is useful to approximate the land cover and potential soil erosion of the basin.

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