



# Application of revised universal soil loss equation model for assessment of soil erosion and prioritization of ravine infested sub basins of a semi-arid river system in India

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## Abstract

Soil is an integral part of Earth's ecosystem. Topographic and climatic factors play an important role in influencing the complex process of soil erosion. Lithological formation, elevation, slope steepness, soil texture, land-use and land-cover constitute the primary topographic factors and rainfall constitutes the major climatic factor. Soil erosion in India's semiarid regions results in soil fertility loss as well as a slew of other significant environmental consequences, posing a threat to the region's long-term agricultural production and river health. Revised Universal Soil Loss Equation (RUSLE) and Geographic Information System (GIS) constitute a very successful technique to assess soil erosion. The present study assessed soil erosion, specific sediment yield and quantified the yearly rate of soil loss in the ravine infested Kunwari River basin, a part of the Yamuna-Chambal Badlands region, India. RUSLE model, integrated with geospatial techniques is useful for soil loss estimation, prioritization of sub basins and their implications on land use in this ravine infested area. Rainfall, soil, satellite imagery, and DEM data derived the model factors. The annual estimated soil loss varied from 0 to 176.942 t ha<sup>-1</sup> year<sup>-1</sup> with a total annual soil loss of 4,260,929.52 t year<sup>-1</sup> and a mean soil loss of 6.42 t ha<sup>-1</sup> year<sup>-1</sup> from the entire catchment. The result shows the annual average sediment yield is 1.22 t ha<sup>-1</sup> year<sup>-1</sup> and the total volume of the sediment yield for Kunwari basin is 8,09,576.61 t year<sup>-1</sup>. Since the bulk of the area has rugged and dissected, the topographical factors play a major role in the results which shows higher rates of soil erosion. The result of sub-basin prioritization indicates that sub-basin Sb 5, Sb 8 and Sb 9 are found to be under the high priority zone. The findings of the study based on RUSLE and GIS offer a precise appraisal of soil loss, identifying the priority areas which can be helpful in designing and executing effected policies for sustainable soil management practice to prevent soil erosion.

**Keywords** Semi-arid basin · Soil erosion · Geospatial technique · RUSLE · GIS · Soil management practice

## Introduction

Loss of soil is one of the common forms of land degradation due to the natural and anthropogenic factors. The growing tempering of anthropogenic activities with natural environment has intensified the issues related to soil erosion throughout the globe as of late. To study soil erosion and transfer of sediments, scientists over the years have continued to develop and use empirical methods which differ from each other in terms of data input and level of accuracy to predict soil erosion. It has emerged as a

worldwide problem which causes concern for deterioration of ecosystem and society (Angima et al. 2003; Haregeweyn et al. 2015; Teng et al. 2019; Rosas and Gutierrez 2020; Bogale et al. 2020). Soil erosion degrades soil quality and crop productivity, making it difficult to manage agricultural land in a sustainable manner. Furthermore, it promotes agricultural soil loss, sedimentation, which increases risk of flood and pollution, which ultimately causes turbidity and eutrophication (Bewket and Teferi 2009; Lal 2001). Deforestation, grazing, agricultural intensification and population growth also intensify the soil erosion rate (Kumar and Pani 2013; Pani 2016; Haregeweyn et al. 2017). Because of the fast-transformation of land use and land cover practices (LULC), soils are becoming increasingly susceptible to water erosion; rigorous agricultural activities and deforestation also contribute

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towards soil loss (Gomiero 2016). Soil degradation has a direct influence on massive sediment production in river basins. Human-induced soil degradation affects over 1960 million hectares globally, with 1903 M ha aggravated due to water erosion (Bhattacharya et al. 2015). Researchers have taken more interest in estimating a river basin's sediment yield and soil erosion using geospatial technology in the recent decade (Issaka and Ashraf 2017). Soil erosion is one of the most significant threats to India's rich topsoil, where about 5334 Mt of soil erosion occurs every year (Narayana and Babu 1983; Kouli et al. 2009; Prasannakumar et al. 2012; Lal 2015). The agricultural yield, land use intensity, and cropping pattern changes cost around 68 billion rupees per year (Bhattacharyya et al. 2015; Rajbanshi and Bhattacharya 2020). Soil erosion in semiarid regions of India cause soil fertility loss as well as a host of other serious environmental repercussions, and has become a danger to the region's long-term agricultural productivity and water quality. Hence, rapid soil erosion must be managed to ensure the natural resource sustainability through the analysis of location specific data set. A quantitative evaluation is usually necessary with appropriate management measures, however, due to the intricacy of the variable factors it becomes very challenging. Soil erosion-based studies on sub-watershed level helps the planners significantly for planning proper conservation and management plans (Pandey et al. 2007; Douglas 2006; Van De et al. 2008; Prasannakumar et al. 2012). Numerous approaches and equations for estimating and evaluating the soil have been proposed by researchers worldwide. The most well-known models are Universal Soil Loss Equation (USLE), followed by a modification known as Revised Universal Soil Loss Equation. Wischmeier and Smith (1965, 1978) studied and examined the primary causes of soil erosion, resulting in the development of USLE to quantify water-induced soil erosion. Taking into account data obtained from rainfall, topographic factors, soil classes, agricultural methods, and conservation techniques, USLE calculates the average annual rate of erosion. Subsequently the model was refined and enhanced to RUSLE. Recent advances in geospatial technology provide an improvement over conventional methods and give effective solutions towards monitoring, analysing and managing earth resources. The geospatial data, DEM, GIS and RUSLE together form a very effective method for soil erosion estimation and have been successfully utilized by many researchers (Srinivas et al. 2002; Baby and Nair 2016).

Kunwari basin has been selected as the study area, a part of the Chambal region of India with a well-known badland topography which is very sensitive to land degradation. The aim of this study is to determine the annual rate of soil erosion at the sub-basin level and estimate the

sediment yield to prepare a soil erosion severity map integrating geospatial technology with RUSLE.

## Study area

The Kunwari flows through the districts of Shivpuri, Sheopur, Morena and Bhind of Madhya Pradesh. It is a tributary of the Sind River, having a basin area of 6737.17 square kilometres. It runs for about 273 km until it meets River Sind southwest of village Bithauli. The river Kunwari initially flows from south to northeast towards river Chambal but instead of joining the Chambal River it takes a sharp turn near village Udaypura and flows practically parallel to river Chambal. This flow pattern continues for quite some distance before the Kunwari River turns south east at Bhonpura. The river comes so close to the Chambal River on this route that the ravines on both river banks are only 50 m apart, northwest of village Galetha. The ravines of both the rivers are separated by the Ambah canal. The Kunwari River meets the Sind River at its confluence with the Yamuna River. However, ultimately the Chambal meets the Yamuna River at a distance of roughly 3.5 kms upstream of the Yamuna-Sind confluence.

The Kunwari basin is located in between the latitudes 25° 39' 3" N to 26° 47' 45" N and longitudes 77° 10' 21" E to 79° 4' 16" E (Fig. 1). The higher elevation of the basin is towards southwest (465 m asl) while the lower elevation is towards north east side (75 m asl). June to September, the monsoon months, receive the majority of the annual precipitation, which ranges from 750 to 1400 mm. Among the land use and land cover classes, agricultural fields occupy about 48% of the area, followed by forest (28.2%) and wastelands (20.5%), built up (1.63%) and water bodies (1.53%). Wheat, soya bean, gram, mustard, rice, sunflower, and millet are the primary crops cultivated in this area. Almost all the wasteland areas are mainly dominated by gullies and ravines along the banks of Kunwari forming an inaccessible rugged terrain. Gully erosion is quite widespread and may be seen up to 1 or 2 kms away from the Kunwari's banks. The overall drainage pattern of the basin is dendritic. Lithologically, alluvium and Upper Vindhyan sandstones cover most of the basin area with some bedded limestone and compact shales at places. Alluvium occupies almost 58.72% of the areal extent of this basin whereas the Vindhyan sandstones covers 36.17% of the area. Together they cover 94.88% area.

## Data sources and methods

### Data sources

Objectives of the study were accomplished through a variety of data sources (Table 1). The surface land features of

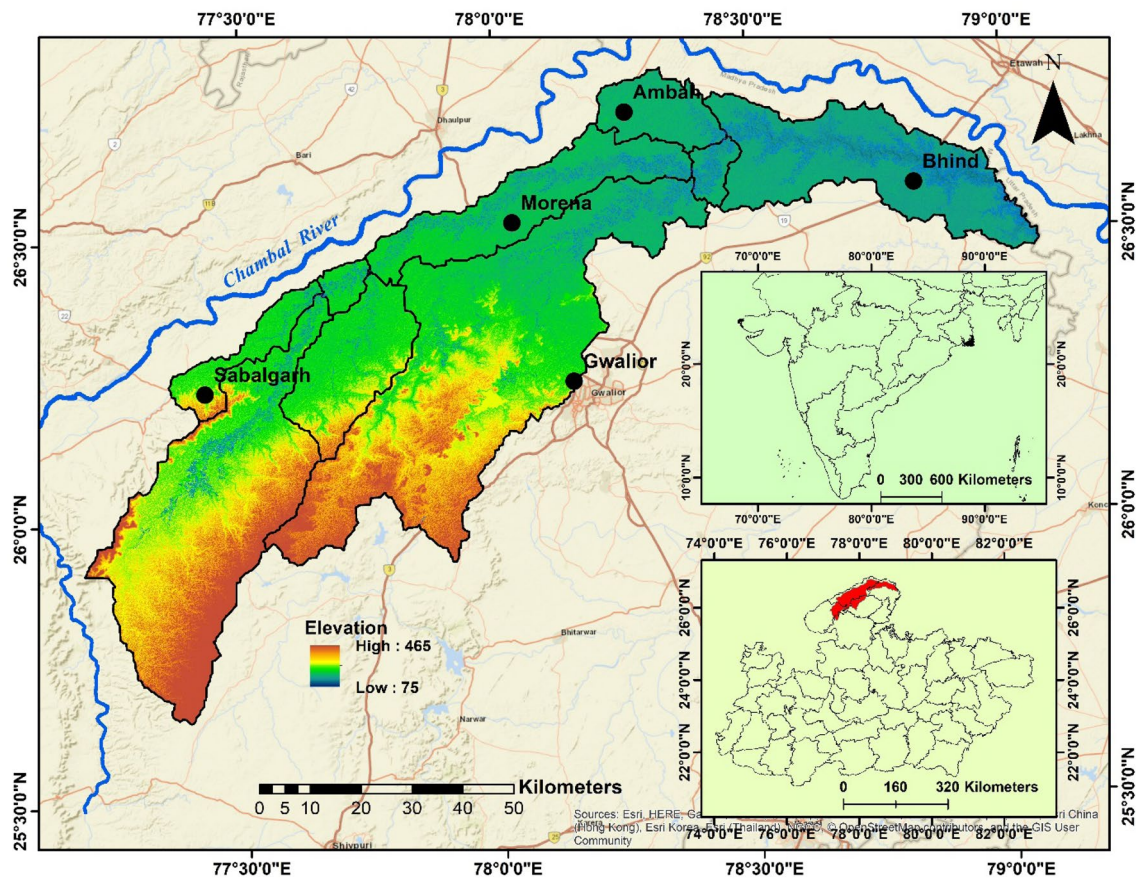


Fig. 1 Location map with elevation and sub-watersheds of the study area

Table 1 Datasets and data sources

Data sets	Data source	Details of data acquisition
Satellite data (Landsat 8)	<a href="http://earthexplorer.usgs.gov">http://earthexplorer.usgs.gov</a>	Date of data acquired 29.03.2020 4.07.2020 Date of data downloaded 31.01.2021
Aster DEM	<a href="https://search.earthdata.nasa.gov/search">https://search.earthdata.nasa.gov/search</a>	Date of data downloaded 29.01.2021
Rainfall data	<a href="https://power.larc.nasa.gov/">https://power.larc.nasa.gov/</a>	Date of data acquired 28.1.2021
Soil map	<a href="http://www.fao.org/geonetwork/">http://www.fao.org/geonetwork/</a>	Date of data acquired 28.01.2021

the basin were generated using LANDSAT-8 satellite image of March 2020 (Source: <http://earthexplorer.usgs.gov>). The river basin area, stream network, elevation, and slope steepness were extracted from ASTER DEM [(30 m spatial resolution), source: <https://search.earthdata.nasa.gov/search>]. The local monthly rainfall data over 37 years (1988–2017) of the study basin has been collected from the Prediction of Worldwide Energy Resources (POWER) Project web portal of NASA. The meteorological data sets were procured

from the POWER Project, under the Applied Earth Science Research program supported by NASA. Moreover, this website provides the single point data (latitude-longitude) to near real-time  $0.5^\circ \times 0.5^\circ$  resolution. FAO (Food and Agricultural Organization) offers worldwide soil vector databases that include information on sand, silt, clay, organic matter content along with pH and soil depth. The soil texture information for the area was extracted from FAO soil vector databases (scale 1:5,000,000; source: <http://www.fao.org/geone>

work/). Arc GIS has been extensively utilised to extract different factors related to RUSLE and also for analysis using various suitable tools.

### Methods

Each established well known model has its own specific characteristic features and provide appropriate soil erosion assessment which help the development of proper conservation plans (Morgan et al. 1984; Shrestha, 1997; Diodato and Bellocchi 2007; Tian et al. 2009; Bhattacharyya et al. 2015). The RUSLE model incorporated with GIS and remote sensing techniques were used in the study because of its global acceptance and its efficient parameter integration (Van der Knijff et al. 2000; Jain et al. 2001; Lu et al. 2004; Bonilla et al. 2010; Alonso-Sarria et al. 2011). The Specific Sediment Yield (SSY) and Soil Erosion (SE) of the sub river basins were predicted by combining the RUSLE model and Sediment Delivery Ratio (SDR).

Revised Universal Soil Loss Equation is an improvement over the Universal Soil Loss Equation with more flexibility and was developed by Renard et al. (1996).

### Database generation for RUSLE parameters

The most widely used and universally acknowledged approach is RUSLE for estimating inter-rill and rill erosion rates (Ganasri and Ramesh 2016). RUSLE was created to forecast yearly averages of long-term soil loss. RUSLE is so-far considered as the most realistic model. Moreover, DEM and remote sensing data are suitable for extracting several input parameters for the RUSLE model. The various significant factors such as topography, soil types, rainfall, crop conservation as well as management are mainly use to run the RUSLE model. However, these factors can be changed through time and place. The other input variables are also of significant influence.

RUSLE equation was implemented using GIS application along with raster analysis to calculate particular variables and compute annual soil loss. The methodology adopted to derive the various parameters and the soil loss estimation has been represented by schematic diagram as a flowchart (Fig. 2).

The equation of the RUSLE model can be expressed as:

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

where *A* represents the annual soil loss ton per hectare per year ( $t\ ha^{-1}/year$ ); *R* represents rainfall-runoff factor ( $MJ\ mm\ ha^{-1}\ h^{-1}\ yr^{-1}$ ); *K* represents soil erodibility factor (ton

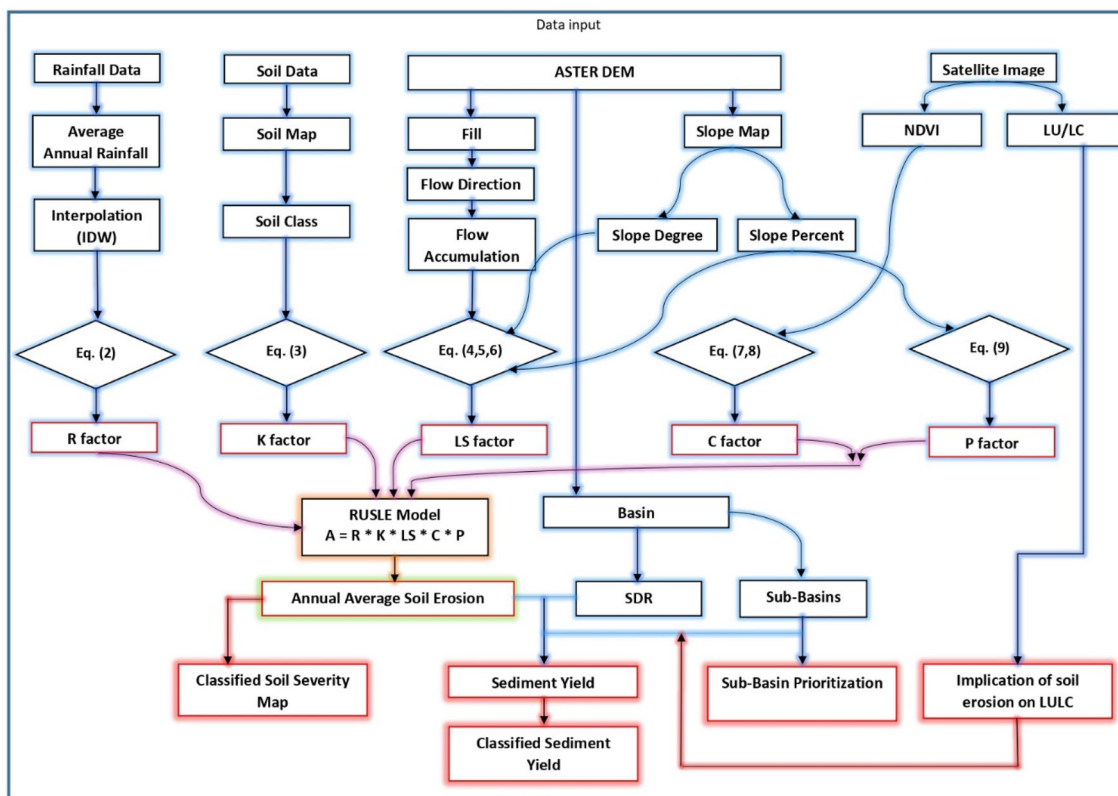


Fig. 2 Flow chart showing methodology adopted

$h \text{ MJ}^{-1} \text{ mm}^{-1}$ );  $LS$  represents the slope length and steepness factor (unit less),  $C$  represents the crop management factor (unit less), and  $P$  is the conservation and support practice factor (unit less).

Erosivity, erodibility, and management factors are thus the three primary groups of parameters in the RUSLE equation.

### Rainfall-runoff factor or rainfall erosivity ( $R$ ) factor

Rainfall's impact on erosion is estimated by computing the rainfall runoff erosivity factor ( $R$ ). It indicated the erosional force of a rainfall event and its computation needs accurate, continuous precipitation data (Wischmeier and Smith 1978). High intensity precipitation for a long period of time erodes the maximum soil amount possible through surface runoff. The  $R$  factor is computed by multiplying the rainfall intensity over 30 min ( $I_{30}$ ) by the kinetic energy of the storm ( $E$ ). However, because these data are not available for the research area an indirect method is used to generate  $R$  factor through the equation established for Indian perspective by Singh et al. (1981) and applied by Rajbanshi and Bhat-tacharya (2020).

$$R = 79 + 0.063 \times \text{AAP}. \quad (2)$$

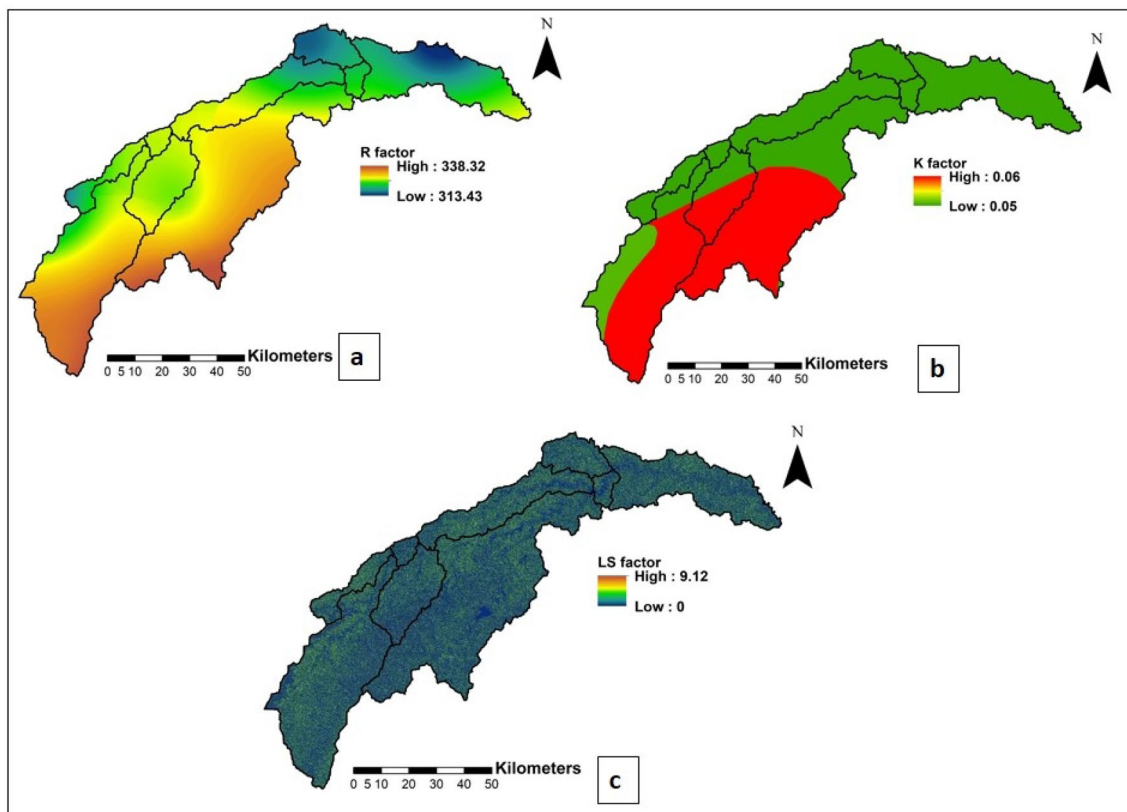
The annual average precipitation (AAP) is in mm.

The higher the  $R$ -factor value, the greater the rainfall capacity to erode away the soil from the surface. Therefore more susceptible to soil loss.

Monthly rainfall data has been gathered for 37 years (1981–2017) based on the coordinate point of basin weather stations. The  $R$  factor requires information on the average annual rainfall (Eq. 2). Hence, the annual rainfall for every year was determined by adding monthly rainfall and then the annual average rainfall for the required 37 years (1981–2017) was calculated. Subsequently the data set has been converted to shape file point data sets using Arc GIS. The spatial distribution of AAP was computed using Inverse Distance Weighted (IDW) interpolation and finally applying Eq. (2) using raster calculator, the  $R$  factor map of the study has been generated. (Fig. 3a).

### Soil erodibility factor ( $K$ )

The  $K$  factor measures how prone the top soil is to erosion along with sediment transportability. It also indicates the quantity and runoff rate for a given rainfall input (Ganasri



**Fig. 3** R K LS factor maps. **a** Rainfall erosivity factor map, **b** soil erodibility factor map, **c** slope length and steepness factor map

**Table 2** Soil structure codes

Structure code	Soil structure	Soil particle diameter (in mm)
1	Granular (very-fine)	Less than 1
2	Granular (fine)	1–2
3	Granular (moderately-coarse)	2–10
4	Platy, blocky, massive	More than 10

**Table 3** Soil permeability codes

Permeability code	Permeability condition	Rate of permeability (in mm)
1	Rapid	More than 130
2	Moderately-rapid	60–130
3	Moderate	20–60
4	Slow-moderate	5–20
5	Slow	1–5
6	Very-slow	Less than 1

and Ramesh, 2016; Baruah et al. 2019). Soil loss estimation models frequently use the term soil erodibility which is defined as the detachment of surface soil when external pressures are applied (Renard 1997). The properties of top soil are linked to the severity of soil erosion. The values can range from 0 to 1, in order of increasing susceptibility to erosion. Its calculation is essential as the higher value of soil erodibility indicates high probability of surface soil erosion. The soil erodibility factor is generally derived from Wischmeier's nomograph, alternatively it may be calculated using the empirical equation, according to the USLE equation (Tosic et al. 2012). The empirical equation which was utilised to calculate soil erodibility in the present investigation (Wischmeier and Smith 1978) can be expressed as:

$$K = [2.110^{-4}(12 - Og)M^{1.14} + 3.25(sr - 2) + 2.5(pb - 3)]/100, \quad (3)$$

where  $K$  represents the soil erodibility,  $*M$  represents soil component percentages (% sand, %silt, %clay),  $Og$  is the soil

organic matter,  $sr$  represents as structure codes of soil, which various from 1 to 4 (Table 2),  $pb$  is the soil permeability code (Table 3)  $*M$  value = (% sand + %silt) × (100 – % clay).  $K$  values expressed in SI units, of  $t\ ha\ ha^{-1}\ MJ^{-1}\ mm^{-1}$ .

The FAO soil vector datasets of the world have been used in Arc GIS to extract the soil textural information for the study. The major soil type identified are Eutric Cambisols (clay loam) Chromic Luvisols (sandy loam), Lithosols (sandy clay loam) (Table 4). Using Eq. 3 the respective soil class'  $K$  values were derived and further multiplied by 0.1317 for conversion to the International System of Units (ISU) (Chadli 2016). The  $K$  factor map is generated with IDW interpolation method in Arc GIS (Fig. 3b).

**Slope length and steepness factor (LS)** Soil erosion is also influenced by the length of the slope and steepness of the slope, therefore the LS Factor plays an important role. In the RUSLE model, both of these variables were termed LS-factors also known as topographic factor. The LS factor is the “ratio of soil loss at site-specific conditions to the soil loss at a site with standard conditions”. The standard conditions being 9% slope steepness ( $S$ ) and 22.13 m slope length ( $L$ ) (Wischmeier and Smith 1978). Hence greater topographic slope length will increase risk for soil erosion. The steep slope with little barrier enhance the velocity of surface runoff that carries maximum sediment particles. As a result, steep topographic slopes induce greater soil loss than flat surfaces.

The LS factor thus calculated using Arc GIS followed by the equation suggested by McCool et al. (1987) and later on used by Biswas and Pani (2015).

The following equation was used to compute the topographic length of slope.

$$L = \left( \frac{\text{flow accumulation} \times \text{pixel size}}{22.13} \right)^s, \quad (4)$$

where  $L$  is the topographic slope length;  $s$  denotes the percentage of slope steepness (the value of which ranges between 0.2 and 0.5) (0.2 for slopes less than 1%; 0.3 for slopes 1–3%; 0.4 for slopes 3–5%; 0.5 for slopes more than 5%) (Wischmeier and Smith 1978).

**Table 4** Component of Kunwari basin soil classes

Soil class	Domsols name	%sand	%silt	%clay	%organic matter	Soil structure code	Soil texture	Soil permeability code
BE	Eutric Cambisols	36.4	37.2	26.4	1.07	1	Clay loam	5
LC	Chromic Luvisols	64.3	12.2	23.5	0.63	2	Sandy Loam	4
I	Lithosols	58.9	16.2	24.9	0.97	2	Sandy clay loam	3

Slope steepness i.e. the slope gradient factor was calculated as follows:

$$S = 10.8 \times \sin(\text{slope in degree}) + 0.03 \text{ when, slope is } < 9\%, \quad (5)$$

$$S = 16.8 \times \sin(\text{slope in degree}) - 0.50 \text{ when, slope is } \geq 9\%. \quad (6)$$

By multiplying the values of  $L$  and  $S$  factor using raster calculation tool, the  $LS$  factor for the area has been calculated ( $LS = "L" \times "S"$ ) (Fig. 3c).

**Crop management factor (C)** The ratio of soil loss in a cropped land from site-specific parameters to soil loss from standard conditions is considered as the  $C$  factor. The standard conditions being tilled, continuous fallow land (Wischmeier and Smith 1978). Therefore, the  $C$  factor is the ratio of soil loss from land to the given vegetation. It is used to figure out how successful different soil and crop management techniques are in preventing soil loss. Use of  $C$  factor in USLE and RUSLE equation is important as it shows how land cropping and surface vegetation management influences the topsoil erosion rate (Renard et al. 1996).  $C$  factor values range between 0 and 1 in the RUSLE model, and is dependent on land surface features. A value towards 1 suggests barren land and water bodies, whereas a value around 0 denotes vegetation.

The  $C$  factor value may be calculated using either the USLE guide manual or through the field observation. An alternate method for determining the  $C$  factor of a region is to use the Normalized Difference Vegetation Index (NDVI) calculation as the vegetation cover that impacts soil erosion significantly.

Many researchers followed the method of determining NDVI and used in the following equation developed by Van der Knijff et al. (2000) which states that the crop management factor decreases exponentially with NDVI (Zhou et al. 2008; Kouli et al. 2009).

$$C = \exp \left[ -\alpha \frac{\text{NDVI}}{\beta - \text{NDVI}} \right]. \quad (7)$$

The NDVI- $C$  factor curve is determined by the unit less parameters  $\alpha$  and  $\beta$ . This scaling technique produced improved results compared to a linear relationship scaling technique (Angima et al. 2003).  $\alpha$  and  $\beta$  were assigned the values 2 and 1 respectively.

Equation 8 has been used to obtain the  $C$  factor values for various Indian terrain by the researchers (Kouli et al. 2009; Pandey et al. 2007; Prasannakumar et al. 2011; Parveen and Kumar 2012, Kartic et al. 2014; Biswas and Pani 2015; Rahaman et al. 2015; Shit et al. 2015; Agarwal et al. 2016; Bhat et al. 2017; Maury et al. 2019).

Thus, the  $C$  factor has been calculated for the study using the above equation based on NDVI values. First the Landsat 8 images of March 2020 have been used to calculate NDVI (Fig. 4a) following the equation:

$$\text{NDVI} = \frac{\text{Near Infrared Band} - \text{Red band}}{\text{Near Infrared Band} + \text{Red band}}. \quad (8)$$

Thereafter the  $C$  factor has been obtained using raster calculator in GIS, using Eq. 8. Values less than 0 were set to 0 and those higher than 1 were set to 1. (Fig. 4b).

### Conservation and support practice factor (P)

The  $P$  factor is the ratio of soil loss in topographic tillage slope and soil loss under conservation support conditions (Renard 1997). The soil erosion rates reduce because of land support practices and ultimately conserves the soil's qualitative characteristics. The  $P$  factor can take values ranging from 0, (denoting an area where conservation practises have been implemented) to 1 (denoting an area with no support practices) in the RUSLE model.

The equation derived by Wener (1981) that gives a linear relationship between the amount of conservation practice ( $P$ ) and the slope of the area ( $S$ ) is:

$$P = 0.2 + 0.03 \times S, \quad (9)$$

where  $S$  denotes slope (in percentage).

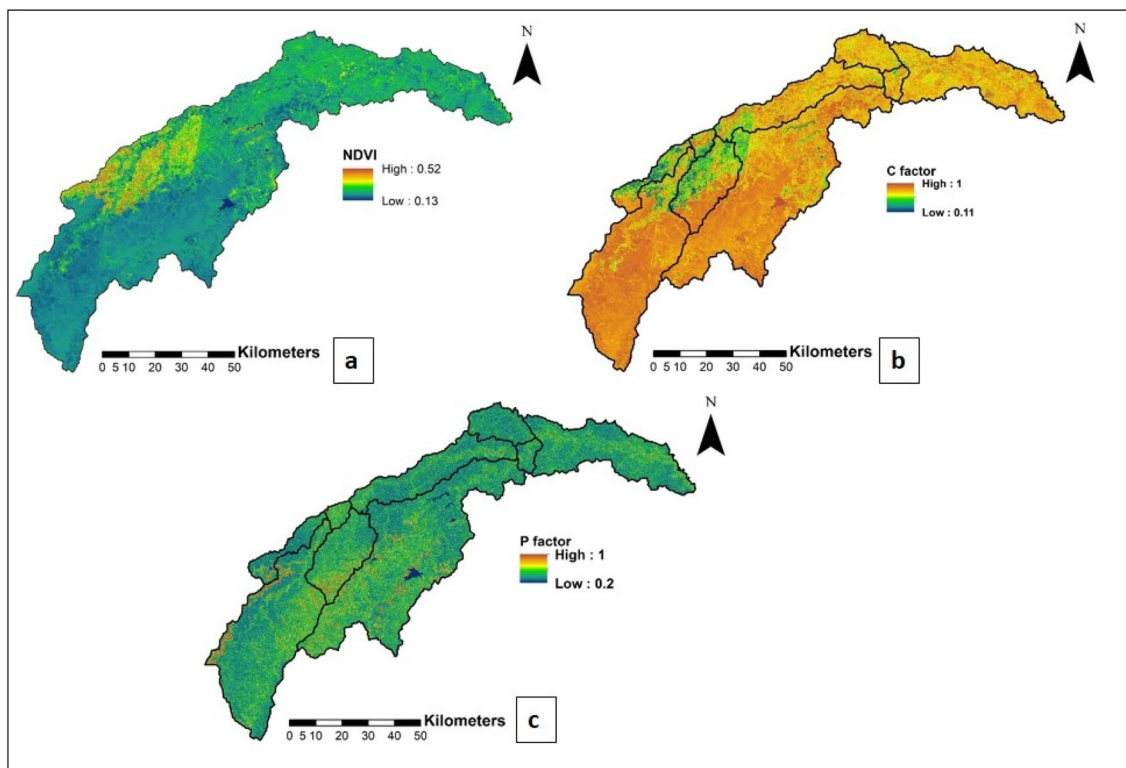
The  $P$  factor map (Fig. 4c) was prepared using this equation. The higher values for  $P$  parameters indicate the areas with no conservation practices whereas the lower values are for more effective conservation practices followed by Wener (1981).

### Potential soil erosion estimation

The soil loss was computed and after integrating all factor maps created using Eq. 1, a soil erosion map of the basin was created. Further this map was reclassified to produce the erosion severity map. The annual soil loss for various sub basins have also been estimated.

### Sediment yield (SY) estimation

It is the separated out soil materials that are carried downslope by river water flows, eventually settling on the level surface when the river's velocity is reduced (Ebrahimzadeh et al. 2018). SY is determined based on the rate of soil erosion. Higher the rate, higher the amount of sediment yield. Sediment yield estimation, as well as soil erosion estimation, have become increasingly important in recent years.



**Fig. 4** a NDVI Map, b C Factor Map 4, c P Factor Map

Usually field observation determines the amount of sediment yield, however, the rate cannot be directly computed from the RUSLE model. (Ebrahimzadeh et al. 2018). SY may be calculated based on the Sediment Delivery Ratio (SDR) method and the Revised Universal Soil Loss Equation. As per Ebrahimzadeh et al. (2018), SDR is the ratio between annual erosion and the net erosion.

The equation for the estimation of SY using SDR can be expressed as:

$$SY = SDR \times M, \quad (10)$$

where SY = sediment yield; SDR = Sediment Delivery Ratio;  $M$  = mean raster value of annual soil erosion

As it is necessary to determine the basin's net erosion, the annual soil erosion has been calculated using RUSLE model. We need the value of the SDR of the area to apply Eq. 11 to compute net erosion or sediment yield of the basin.

The SDR value is influenced by several factors in the basin, such as the watershed's overall area, the soil particle size, and the gradient and relief length ratio. To determine SDR based on these factors, several formulae have been developed. According to earlier research (Maner 1962; Renfro 1975; Vanoni 1975; USDA 2002), there is a strong link between watershed area and SDR with  $R^2 = 0.92$  (Ouyang and Bartholic 1997).

The six alternative formulae previously used by researchers have been considered to determine the basin's SDR (Maner 1962; Renfro 1975; Vanoni 1975; USDA 1972, 1979, 2002). The SDR for individual sub-watersheds was estimated based on the equation proposed by Renfro (1975). The sediment yield for the basin, annual sediment erosion, and annual sediment yield are computed using the equation (Eq. 11) and finally calculated the average SDR of the basin (Table 5).

$$\text{Log (SDR)} = 1.7935 - 0.14191 \log(\text{Ar}), \quad (11)$$

where Ar represents the watershed area in  $\text{km}^2$ .

## Results and discussion

### R factor

The  $R$  factor was determined to be between 313.43 and 338.32  $\text{MJ mm ha}^{-1} \text{h}^{-1} \text{year}^{-1}$  with 326.65  $\text{MJ mm ha}^{-1} \text{h}^{-1} \text{year}^{-1}$  as average  $R$  factor. The maximum value ( $> 330 \text{ MJ mm ha}^{-1} \text{h}^{-1} \text{year}^{-1}$ ) was concentrated mostly in the basin's southern section. The



**Table 5** Calculation of SDR from different methods

Methods	Formula	Basin area (Ar <sup>a</sup> )	SDR value
Maner (1962)	$\text{Log}(\text{SDR}_1) = 1.8768 - 0.14191 \log(10\text{Ar})$	2558.56 mi <sup>2</sup>	0.18
USDA (1972)	$\text{SDR}_2 = 0.5656\text{Ar}^{-0.11}$	6626.64 km <sup>2</sup>	0.21
Vanoni (1975)	$\text{SDR}_3 = 0.472\text{Ar}^{-0.125}$	6626.64 km <sup>2</sup>	0.16
Renfro (1975)	$\text{Log}(\text{SDR}_4) = 1.7935 - 0.14191 \log(\text{Ar})$	6626.64 km <sup>2</sup>	0.18
USDA SCS (1979)	$\text{SDR}_5 = 0.51\text{Ar}^{-0.1}$	2558.56 mi <sup>2</sup>	0.22
USDA (2002)	$\text{SDR}_6 = 0.51\text{Ar} - 0.11$	6626.64 km <sup>2</sup>	0.19
Average SDR	$\text{DR} = \frac{\sum_{i=1}^r \text{SDR}_i}{6}$		<b>0.19</b>

<sup>a</sup>Since A is denoted for total Soil loss hence Ar is denoted as basin area instead of A

**Table 6** Derived K factor value of the river basin

Soil class	Soil name	Soil texture	K value	Area km <sup>2</sup>
BE	Eutric cambisols	Clay loam	0.057	3424.81
LC	Chromic Luvisols	Sandy loam	0.065	2845.17
I	Lithosols	Sandy clay loam	0.058	356.64

basin’s north-eastern sections had relatively less yearly average erosivity than the south-western section (Fig. 3a).

**K factor**

The majority of the basin area is made up of sandy loam, clay loam and followed by sandy clay loam texture. The K factor value ranges from 0.0569 to 0.0653 t ha h ha<sup>-1</sup> MJ<sup>-1</sup> mm<sup>-1</sup>. The mean value of the K factor is 0.061 and the southern half of the basin had relatively higher values (Fig. 3b). The clay loam occupies 3428.82 square kilometres area, whereas the sandy loam occupies 2845.18 square kilometres and that of sandy clay loam occupies 356.65 square kilometres. Sandy-loam has the highest rate of soil erodibility with a K factor of 0.065 t ha h ha<sup>-1</sup> MJ<sup>-1</sup> mm<sup>-1</sup> (Table 6). Sandy loam soil has low levels of organic matter and clay minerals along with a large number of sand components due to which it has poor water retention capacity.

Soils with low antecedent moisture content and poor permeability capacity are indicated by their low K factor value. Clay loams are detachment resistant and hence have low K values. Sandy loams, while having comparatively higher K values are also on the lower end of the spectrum due to their high infiltration rates and limited runoff.

**LS factor**

The LS factor has significant impact on soil erosion processes. The Kunwari basin’s LS factor ranges between 0 and 9.126, with the average raster value of the LS factor being 1.17 (Fig. 3c). The maximum area of the basin exhibits the low value of the LS factor (0–2). A flat surface covers approximately 76.28% of the land, medium slope factors

covers 21.98% of the area, and comparatively more steep topographic slope factors covers just 1.74% of the basin and implies that erosion is more severe in steep slopes.

**C factor**

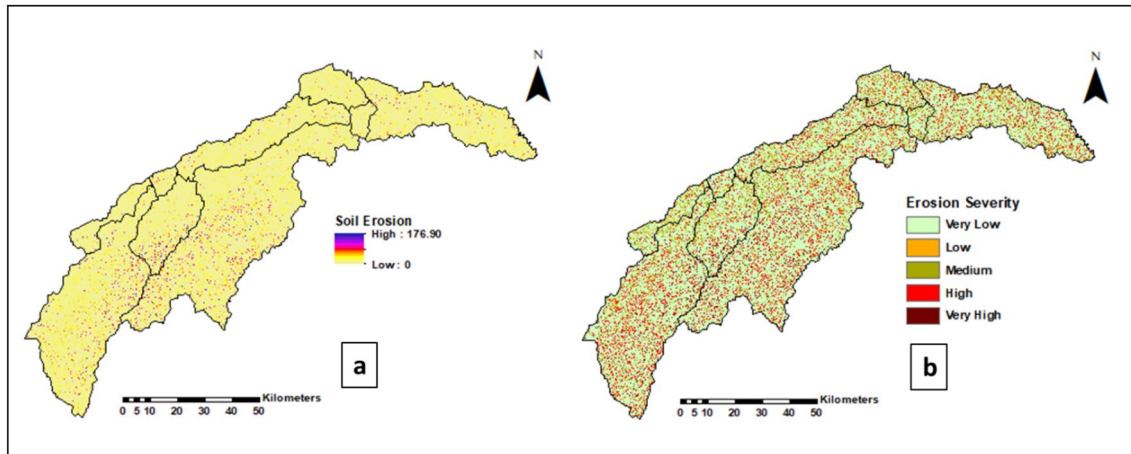
As mentioned in the methodology the Landsat 8 image of March 2020 based on NDVI was used to compute the surface cover management factor (C). According to the equation NDVI and C factor value are inversely related which means the high NDVI areas will show low C factor value because of the presence of healthy vegetation. The NDVI value ranges between – 0.137 and 0.521 (Fig. 4a). In the study, C factor of the basin ranged from 0.113 to 1, this resulted in a mean value of 0.71. The higher values are typically found on the basin’s southern part, where it is mainly dominated by the wastelands. The low values are primarily concentrated in the northwest part of the basin, comprising mainly by agricultural areas (Fig. 4b). Erosion is more frequent in areas where the C-factor is high (poor in vegetation).

**P factor**

In the study area this value ranges between 0.2 and 1 with a mean of value 0.41 (Fig. 4c). The values are based on the conservation practice used on the ground to prevent soil loss and overland flow. Lower values are mostly indicative of agricultural areas and higher values indicate areas where little to no conservation practices have been implemented.

**Annual soil erosion rate**

RUSLE equation and GIS analysis were applied on the study area on a pixel by pixel basis to get an estimate of the yearly soil loss. The spatial distribution of the area in terms of soil erosion was also generated. The result estimates that the basin’s soil loss annually varies from 0 to 176.94 t ha<sup>-1</sup> year<sup>-1</sup> (Fig. 5a). The soil erosion map is reclassified into 5 main classes based on their severity—very high, high, medium, low and very low (Fig. 5b). It is calculated that 73.2% falls under the class very low



**Fig. 5** Figure showing soil erosion (a) and soil erosion severity (b) maps

**Table 7** Soil loss severity

Severity class	A ( $\text{t ha}^{-1} \text{ year}^{-1}$ )	Area ( $\text{km}^2$ )	Area percentage
Very low	$\leq 5$	4850.75	73.2
Low	5.1–10.0	220.92	3.33
Medium	10.1–20.0	609.37	9.2
High	20.1–40	722.46	10.9
Very high	40.1–80	174.38	2.63

rate of soil erosion ( $\leq 5 \text{ t ha}^{-1} \text{ year}^{-1}$ ), whereas 3.33% ( $5.1\text{--}10.0 \text{ t ha}^{-1} \text{ year}^{-1}$ ), 9.2% ( $10.1\text{--}20.0 \text{ t ha}^{-1} \text{ year}^{-1}$ ), 10.9% ( $20.1\text{--}40.0 \text{ t ha}^{-1} \text{ year}^{-1}$ ), and 2.63% ( $40.1\text{--}80 \text{ t ha}^{-1} \text{ year}^{-1}$ ). This has been represented in Table 7. The high soil erosion areas account for  $896.84 \text{ km}^2$  or 13.53% of the area. These areas account for those with steep slopes, high to moderate rainfall and high soil erodibility, which causes the area to have high rates of soil erosion. The soil loss annually of the study area was calculated as  $4,260,929.52 \text{ t year}^{-1}$ . The average soil erosion rate was

taken out as  $6.42 \text{ t ha}^{-1} \text{ year}^{-1}$ . The annual soil loss of the sub basins of the Kunwari basin have also been estimated and tabulated (Table 8).

### Sediment delivery ratio (SDR)

The average SDR value for the Kunwari basin is calculated as 0.19 (Table 5). SDR and watershed size have an inverse relationship. The value of SDR increases as the watershed area decreases, and it will decrease as the watershed sizes increases. The mean SDR values for the individual sub watersheds of the basin have also been estimated (Table 9). The smallest basin SB-1 has a mean SDR of 0.34 whereas in the largest sub-watershed SB-9 the value of SDR is 0.21. A lower SDR value indicates the presence of flat topography, or topography with moderate slopes, which promotes decreasing sediment movement and depositing eroded sediments (Roy 2019).

**Table 8** Average annual soil loss of sub basins

Sub-basins	Mean					A (average annual soil loss) ( $\text{t ha}^{-1} \text{ year}^{-1}$ )	SY (sediment yield) ( $\text{t ha}^{-1} \text{ year}^{-1}$ )
	R	K	LS	C	P		
SB-1	326.23	0.057	1.06	0.60	0.45	5.13	1.74
SB-2	322.33	0.057	1.06	0.68	0.39	4.88	1.61
SB-3	323.21	0.057	1.33	0.56	0.38	4.91	1.43
SB-4	317.98	0.057	1.15	0.68	0.37	4.97	1.40
SB-5	326.00	0.062	1.14	0.62	0.45	6.40	1.65
SB-6	324.01	0.057	1.20	0.68	0.38	5.45	1.4
SB-7	320.52	0.057	1.18	0.70	0.39	5.54	1.3
SB-8	329.66	0.063	1.21	0.74	0.42	7.31	1.6
SB-9	329.47	0.062	1.13	0.73	0.43	6.85	1.4

**Table 9** SDR of Sub-basins

Sub-basins	Area km <sup>2</sup>	Area hectare	SDR
SB-1	71.23	7123.07	0.34
SB-2	85.70	8569.27	0.33
SB-3	207.70	20,770.12	0.29
SB-4	264.93	26,493.11	0.28
SB-5	501.08	50,108.50	0.26
SB-6	630.61	63,060.53	0.25
SB-7	961.61	96,160.97	0.23
SB-8	1617.92	161,791.87	0.22
SB-9	2285.87	228,586.67	0.21

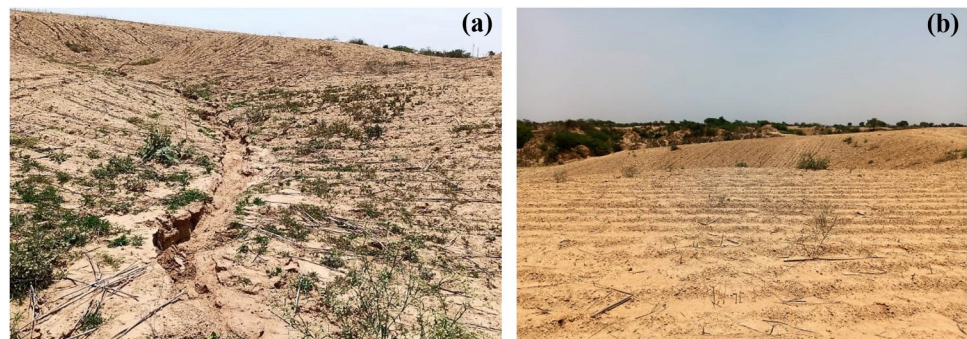
### Specific sediment yield

The Kunwari basin's average SDR value is calculated to be 0.19. Hence, using the Eq. 11, the annual average sediment yield is calculated as 1.22 t ha<sup>-1</sup> year<sup>-1</sup>. Subsequently the total volume of the sediment yield for Kunwari basin is calculated as 809,576.61 t year<sup>-1</sup>. The Kunwari river basin is in the Chambal region, which has been badly affected by gully erosion. Rather than soil erosion, gully and stream erosion is the primary source of sediments (Fig. 6a, b). This is the most likely explanation as to why soil erosion was surpassed by sediment yield. The soil yield map of the area is again reclassified to 5 different class based on the soil yield (t ha<sup>-1</sup> year<sup>-1</sup>) and their areal distribution within the basin has been estimated (Table 10). Most of the study area (about 73.32%) has the soil yield of ≤ 1 t ha<sup>-1</sup> year<sup>-1</sup> and 18.31% area the soil yield is in between 1.1 and 5 t ha<sup>-1</sup> year<sup>-1</sup>. Thus, for the 91.63% of the area together the soil yield is ≤ 5 t ha<sup>-1</sup> year<sup>-1</sup>. The sub-basin wise soil yield has also been estimated. The smallest basin Sb1 yields the highest rate as 1.74 t ha<sup>-1</sup> year<sup>-1</sup> while Sb7 has the lowest rate 1.30 t ha<sup>-1</sup> year<sup>-1</sup> (Table 7).

### Implications of soil erosion on land use

The impact of different types of LULC (Fig. 7a) on the spatial distribution of soil erosion and sediment yield were

**Figure.6** Field Photographs showing the Gully erosion. **a** Effects of stream erosion and ravines. **b** Both the photographs are near village Bagulari of Bhind District (about 1 km from river Kunwari)

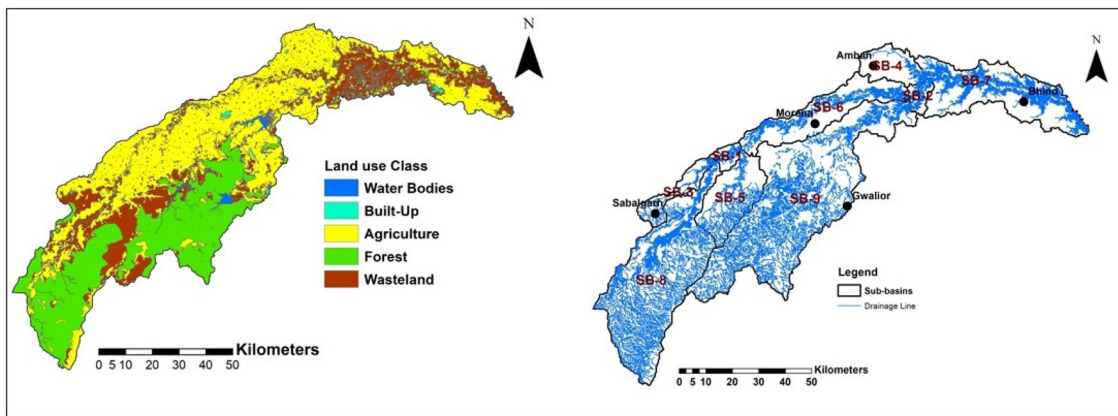
**Table 10** Sediment yield in Kunwari Basin

SY (t ha <sup>-1</sup> year <sup>-1</sup> )	Area (km <sup>2</sup> )	Percentage
≤ 1	4858.51	73.32
1.1–5.0	1213.62	18.31
5.1–10.0	401.25	6.06
10.1–15	62.73	0.95
15.1 to > 25	43.51	0.65

studied (Table 11). The results imply that forests have relatively higher soil loss (7.78 t ha<sup>-1</sup> year<sup>-1</sup>) as well as wastelands (6.84 t ha<sup>-1</sup> year<sup>-1</sup>) in comparison to built-up lands (6.2 t ha<sup>-1</sup> year<sup>-1</sup>) and agriculture lands (5.56 t ha<sup>-1</sup> year<sup>-1</sup>). Similar trend is also observed for the soil yield as forest and wastelands have relatively higher soil yield than built-up and agriculture. Although vegetative areas are supposed to have low soil erosion rates, the bulk of the area is within the rugged and dissected land, hence the topographical factors play a major role in determining the results which show higher rates of soil erosion. There are substantial variations in the SDR values among the land use and land cover types which ranges between 0.20 and 0.32 (Table 12). The SDR value of built-up (0.32) category is quite high in comparison to the forest (0.21) and wasteland (0.22) category. The high SDR in built-up areas suggest the importance of anthropogenic activity in acceleration of soil erosion.

### Prioritization of sub-basin

Sub-basin prioritisation entails ranking distinct sub-watersheds by the order in which they should be treated with preservation technologies, keeping in mind the soil loss quantity (Khadse et al. 2015). The mean soil loss for the nine different sub-basins (Fig. 7b) have been calculated (Table 7) and the highest annual soil erosion rate 7.31 t ha<sup>-1</sup> year<sup>-1</sup> is observed for SB-8. The lowest annual soil erosion 4.88 t ha<sup>-1</sup> year<sup>-1</sup> is observed for SB-2 sub-basin. Nine sub-watersheds have been categorised into three groups based on mean soil loss as low (≤ 5 t ha<sup>-1</sup> year<sup>-1</sup>) moderate (5–6 t ha<sup>-1</sup> year<sup>-1</sup>) and high (> 6 t ha<sup>-1</sup> year<sup>-1</sup>).



**Figure. 7** Land use land cover map of the area (a) and sub-basins with drainage (b)

**Table 11** Implication of soil erosion on LULC

LU/LC class	Mean				
	LS	C	P	A (t ha <sup>-1</sup> year <sup>-1</sup> )	SY (t ha <sup>-1</sup> year <sup>-1</sup> )
Agriculture	1.24	0.67	0.38	5.56	1.06
Built-up	1.20	0.69	0.42	6.20	1.18
Forest	1.12	0.75	0.46	7.78	1.48
Wastelands	1.11	0.73	0.45	6.84	1.30
Water bodies	0.60	0.74	0.40	3.41	0.65

**Table 12** Variation of SDR as per LULC

Land use class	Area (Km <sup>2</sup> )	Percentage area	SDR
Agriculture	3176.41	48.05	0.20
Built-up	108.06	1.63	0.32
Forest	1866.82	28.24	0.21
Wastelands	1356.58	20.52	0.22
Water bodies	102.89	1.56	0.32

The sub-basins with most soil loss are given high priority for soil conservation measures, and priority is provided accordingly. The sub-basins SB-5, SB-9 and SB-8 are found to be under the high priority zone. All these basins are towards the southern part of the main basin.

### Conclusion

The use of remote sensing techniques and GIS in simulating soil erosion using RUSLE-SDR model have been demonstrated in the study. The implication of soil erosion on land use have also been studied. The sub-basins wise SDR derivations have also been attempted to verify the

relationships of SDR value with the size of the basins. The study estimated soil loss and sediment yield in the dissected ravenous Kunwari basin of Madhya Pradesh, India with the RUSLE-SDR model. As per the severity, soil erosion zones have also been delineated. The soil erosion rate ranges between 0 and 176 t ha<sup>-1</sup> year<sup>-1</sup> with a mean rate of 6.43 t ha<sup>-1</sup> year<sup>-1</sup> and the soil loss annually for the basin area was computed as 4,260,929.52 t year<sup>-1</sup>. The sediment yield varies from 1 to 25 t ha<sup>-1</sup> year<sup>-1</sup> with a mean of 1.22 t ha<sup>-1</sup> year<sup>-1</sup> and that of total sediment yield computed is 8,09,576.61 t year<sup>-1</sup>. Very low severity soil erosion areas accounted for the 73.2% of the basin where as that of high severity and very high severity zones accounted for 10.9% and 2.63% area. As far as sediment yield is concerned, the 7.32% area experiences ≤ 1 t ha<sup>-1</sup> year<sup>-1</sup> soil yield and 18.31% area has the soil yield in between 1.1 and 5 t ha<sup>-1</sup> year<sup>-1</sup>. The higher value of soil yield is suggestive of more gully erosion in comparison to soil erosion. Soil erodibility rate is highest in sandy-loam soil which occupies 2845.18 square kilometers area as sandy loams are easily separated and induce high-to-severe soil erosion loss when slope gradients are high. In comparison to built-up lands and agricultural lands, forest (7.78 t ha<sup>-1</sup> year<sup>-1</sup>) and wastelands (6.84 t ha<sup>-1</sup> year<sup>-1</sup>) show greater soil loss because of the rugged topography and dissected badlands in the area. The soil yield follows a similar trend, with relatively high soil yields in the forest and wasteland area. Anthropogenic activity accelerating soil erosion accounted for the high SDR values in built-up areas. The quantitative findings of the work will certainly be beneficial for the development and improvement of management practices in this ravenous terrain part of Chambal basin. In such areas, appropriate soil conservation techniques must be implemented. The implementation of appropriate erosion control measures can be made in the highly affected areas based on the study. Based on the results of severity, proper

management may be designed phase-by-phase/sub-basin wise for controlling soil erosion.

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## Declarations

**Conflict of interest** We have no conflict of interest to declare.

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