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Evaluation of Soil Loss and Identification of Dominant Factors in the Semi-Arid Region Using GIS: A Case of Bhavnagar District, Gujarat, India

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Abstract: The loss of valuable topsoil worldwide has led to agricultural land degradation and a reduction in crop yields. Soil erosion is mainly caused by both natural phenomena and human interference with the ecosystem. The efficiency of spatial information systems like GIS and RS has been effectively developed. From 2015 to 2021, soil loss estimation was conducted using the Revised Universal Soil Loss Equation (RUSLE) model, with remote sensing and geographic information systems (GIS) assistance. We have produced the RUSLE model's five essential potential parameters (R*K*LS*C*P) pixel-by-pixel. We generated the R factor map through the Indian Meteorological Department's (IMD) daily rainfall data, and the K factor map using the FAO's digital soil series global map. For the LS-factor map, we used the digital elevation model data (DEM) of SRTM. Landsat 8 dataset was used to generate LULC, and NDVI maps to derive C and P factors. The highest mean annual soil loss in 2021 was estimated to be 209.16 tons per hectare per year. The riverbank area of the Shetruji River near Palitana Taluka in this district had an extremely high risk of soil loss. The coastal area from Bhavnagar to Dholera was classified as a high and very high-risk area for soil loss, which contained barren land. The results revealed that barren land is the most susceptible to soil erosion. As per statistical analysis, the C factor is the dominant factor in this region which is most influential in soil erosion. The soil erosion maps from this study will provide policymakers with the necessary information to implement suitable conservation measures in this region.
Keywords: RUSLE Model, Soil erosion, Semi-Arid region, Bhavnagar District, RS & GIS

I. INTRODUCTION

Soil erosion is one type of land degradation in which soil particles separate from their parent materials through erosive agents like water and wind, and overland flow occurs. In this phenomenon, soil nutrients lose their fundamental originality to maintain agricultural productivity due to the loss of top cover of soil. Land degradation is one of the global issues nowadays. Water is the prime erosion-causing factor. In India, the soil erosion problem is multiplied day by day due to water. An increase in population is also one of the dominant reasons for soil erosion because of the increase in demand for agricultural products to feed the huge population, so haphazard use of land increase soil loss. In addition to overlooking the fact that land degradation is fundamentally a physical process, popular theories of human-induced soil erosion and land degradation also do a disservice to adaptive ecosystem management by the local population[1]. Basically, this study includes types of erosion sheet erosion because of straightforward estimation methods available in the numerous kinds of literature. Physical models, physical-experimental models, and empirical models are used for the assessment of soil erosion. Conventional methods used for the assessment of soil erosion in semi-arid regions are complex and time-consuming exercises while the study area is about like a district. The universal soil loss equation is a widely accepted phenomenon under the empirical models' category which is suggested by [2]. A lot of innovation and revision is done under this USLE equation as per local meteorological conditions and parameters. The USLE equation is popular worldwide for estimating soil loss from croplands [3]. Improved estimates of global soil erosion and soil organic carbon pools, including the effects of land-use changes and conservation agriculture in past, present, and future scenarios, can be made possible by a USLE-based model that is applicable globally [4]. The MUSLE equation was developed in this family but, this equation is not used to predict the spatial distribution of the study area for the soil loss [5]. A revised universal soil loss equation was suggested by [6] for the soil loss assessment in small/large areas. This revised USLE model is very helpful to predict soil loss on the verge of fewer data and is highly compatible with Remote sensing (RS) and geographical information systems (GIS) [7], [8]. To get the best results from the RUSLE model used with a GIS application [9]–[11].

The digital maps and data which were prepared using GIS and RS to get accurate and significant results from the RUSLE model are more useful in planning, management of natural resources, and deciding policy about conservation measures [12], [13].

In this study, the RUSLE model integrated with the GIS platform is used for the determination of annual soil loss with an estimation of its factors using rainfall data, FAO soil map, SRTM DEM, and LULC map after studying numerous kinds of literature.

II. STUDY AREA

The study area is a Bhavnagar district located in the Saurashtra Region of Gujarat. The total geographic area of Bhavnagar district is 7034 km2. The latitude and longitude of this area are situated at 21.7645° N, and 72.1519° E, and having average elevation is 24 m from the Mean Sea level. Fig.1 shows the location of the study area.

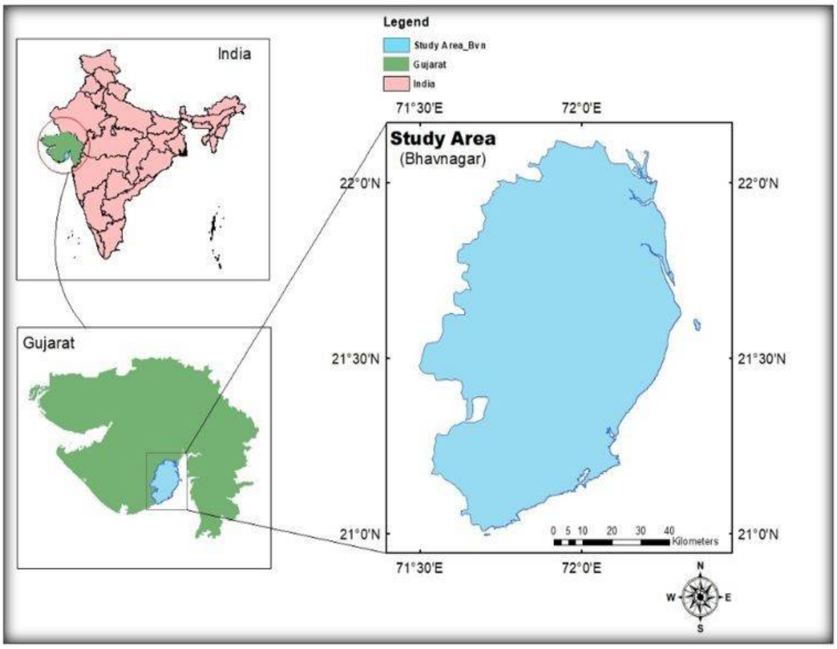

Fig.1 Location Map of the Study Area

Bhavnagar district is one of the most developed districts of the Saurashtra region of Gujarat State. Its district headquarter is located in Bhavnagar City. Bhavnagar was founded by Bhavsinhji Gohil (1703-64 AD) in 1723 AD near the Gulf of Khambhat, in a carefully chosen strategic location having the potential for maritime trade. Bhavnagar is bordered by Ahmedabad, Surendranagar, and Botad districts in the North, the Gulf of Cambay in the East and South, and Amreli and Rajkot districts in the West. Bhavnagar District has 9 talukas like Gariyadhar, Ghogha, Jesar, Mahuva, Palitana, Sihor, Talaja, Umrala, and Vallabhipur. Among these talukas, Palitana and Talaja territories have mountainous regions, and Ghogha and Mahuva territories have coastal regions. Most of the area is underlain by the Deccan Trap and alluvium. The district is characterized by a tropical climate with general dryness, except in the coastal areas, and falls under the semi-arid region category. Shetruji River is the prime source of water for the territory of the study area which is situated in Palitana Talukas of the Bhavnagar District.

There are four seasons in a year, viz., the hot season from March to May, the monsoon season from June to September, the post-monsoon season from October to November, and the cold season from December to February. The average annual rainfall of this region is 519 mm as revealed by rainfall data collected from the Indian Meteorological Department (IMD), Pune. Soil Characteristics of this area are Shallow medium black soil and coastal alluvial soil.

III. DATA USED

For Bhavnagar District Rainfall data of 0.250 x 0.250 resolution were used from the Indian meteorological department (IMD), Pune. For the present study Soil data were obtained from the FAO global soil map of 1:5000000 resolution. SRTM DEM 30 m resolution is used in this study. For Land Use and Land cover features MODIS Land cover images were used. NDVI Map obtained from the LANDSAT-8 images from USGS earth explorer. Table.1 depicts data collection and its source used in this study.

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Table 1. Data Used for the study area

Sr.	Types of Data	Details	Source of Data
1	Daily and Annual Rainfall data	NetCDF format and Gridded data format 0.25^0 x 0.25^0 Resolution	Indian Meteorological Department (IMD) Pune
2	Soil Data	FAO Global Soil map 1:5000000 resolution	https://data.apps.fao.org/map/catalog
3	Digital Elevation model	SRTM DEM 30m resolution, 1 Arc Second	https://www.earthexporer.nasa.gov/ USGS Earth explorer
4	LANDSAT Image	LANDSAT 8 *30-meter multi-spectral spatial resolutions* (From the year 2015 – 2021)	https://www.earthexporer.nasa.gov/ USGS Earth explorer
5	Land use & Land cover map	USGS MODIS Land cover data Version 6	https://urs.earthdata.nasa.gov/home (NASA Earthdata)

IV. METHODOLOGY

An updated version of USLE is RUSLE which was published in 1991 by [6]. RUSLE modified how the impact of topography is incorporated into the model, adding changes to soil erodibility owing to freeze-thaw and soil moisture, a technique for estimating cover and management parameters, and updated values to represent soil conservation methods. The RUSLE model is a variant of the USLE presented by Wischmeier and Smith 1978, by combining RUSLE, GIS, and RS methods, it is possible and cost-effective to estimate soil erosion and its spatial distributions on a larger scale [14], [15]. The simplicity of the RUSLE has been integrated into more complex soil erosion models to help with the management and decision-making of policymakers. ArcGIS 10.4 software is used for the creation, data incorporation, editing, and analysis of the processing of row data. The principal equation for the USLE model family is below:

$$A - R \times K \times L \times S \times C \times P \quad (1)$$

where A is the mean annual soil loss (tonnes ha-1 year-1), R is the rainfall and runoff factor or rainfall erosivity factor (MJ mm-1 ha-1 h-1 yr-1), K is the soil erodibility factor (tonnes ha h MJ-1 mm-1), L is the slope length factor (unitless), S is the slope steepness factor (unitless), C is the cover and management factor (unitless), and P is the support practice factor (unitless).

A. Rainfall erosivity Factor (R)

Rain gauge stations are not present everywhere in India due to the high cost of installation. Yet, because rainfall is the key contributor to soil erosion and is uneven in both time and area, it is essential to study the variation in rainfall [16]. Rainfall is unequal with time and space, to vanquish this issue the following formula was used in this study to estimate the R factor which is given by [17] as per Indian meteorological conditions.

$$R = 839.15 \times e^{0.0008P} \quad (2)$$

Where P = Annual Average Precipitation in mm and Unit of R is MJ mm ha-1 h-1 yr-1

Daily Precipitation data downloaded from Indian Meteorological Department, Pune official website in NetCDF format which is available as open source in 0.25 x 0.25-degree high resolution for 2015 to 2021 [18]. This daily data is converted into annual average rainfall data using a model builder in GIS. This NetCDF file of Precipitation is processed in ArcGIS 10.4 to take as an input for (Eq.2). Due to its acceptance and accuracy in producing spatially interpolated data of rainfall, the Kriging method of interpolation was employed, and extracted for a required region of the study area. Using the procedure sequence Arc Toolbox > Map Algebra > Raster Calculator and (Eq.2), R factor maps were produced in the ArcGIS Platform.Fig.2 shows the R factor map for the study area.

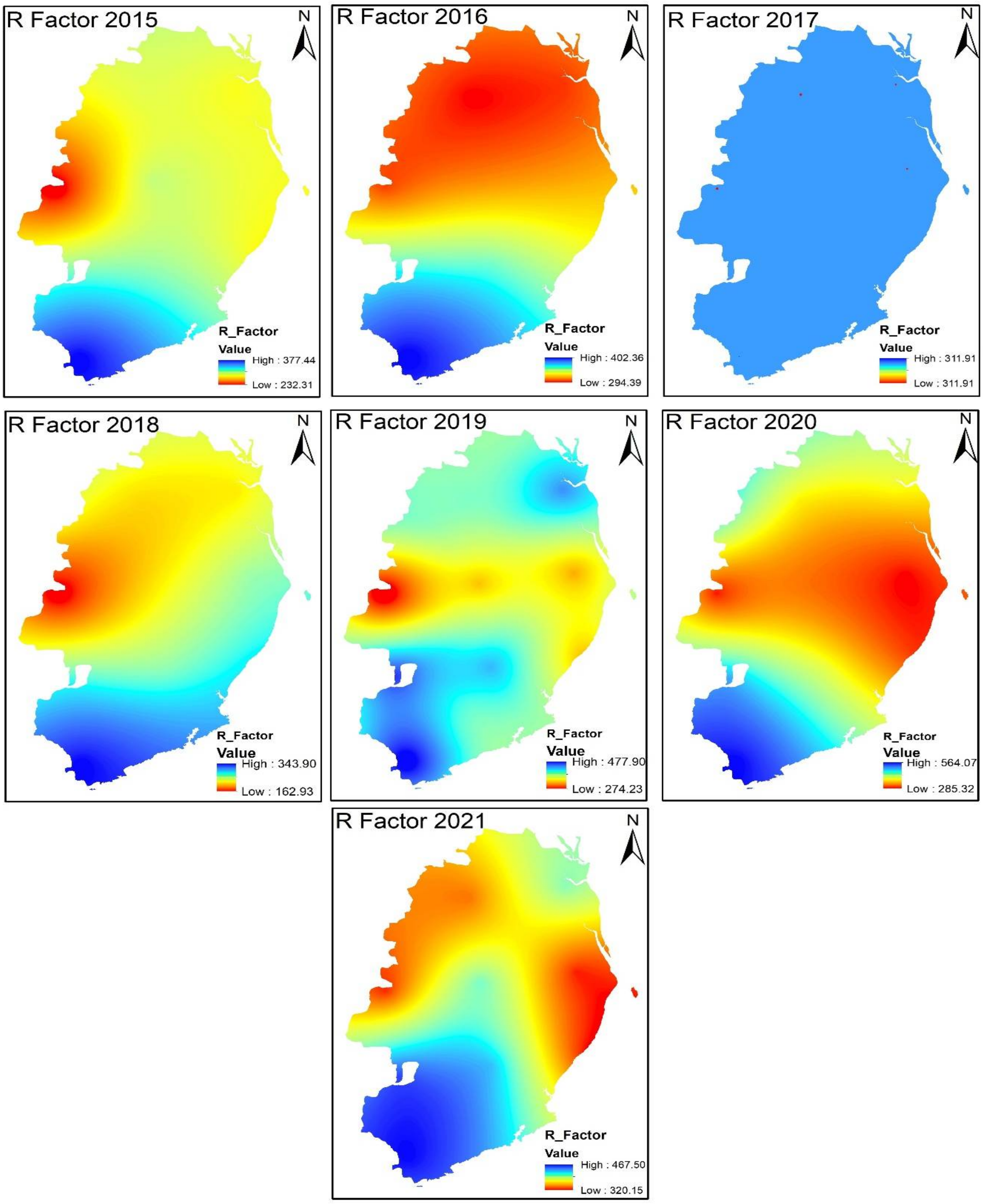


Fig. 2 R Factor map of the Bhavnagar District from the year 2015 to 2021

B. Soil Erodibility Factor (K)

The physicochemical characteristics of soil are used to determine soil erodibility (K), which is an evaluation of the susceptibility of soil particles to be removed from soil aggregates by any erosive agent [3], [19]. It runs from 0 to 0.7, where 0 represents the least vulnerable soil and 0.7 represents the most vulnerable soil to water erosion. The global Soil map and soil content data available from the Food and Agricultural Organization (FAO) of the United Nations have been used. The distribution of the soil series was located for the study area and the processed data were then extracted using the ArcGIS "Extract by Mask" tool. The following formula was used for the calculation of the K factor which was suggested by William and used by *[20]*.

$$K = f_{csand} \times f_{cl-si} \times f_{orgC} \times f_{hisand} \quad (3)$$

Where fcsand: soils with high coarse-sand content; fcl-si: low and high clay-silt ratios; f orgC: low and high organic carbon content; while f hisand for soils with extremely high sand content.

$$f_{csand} = \left(0.2 + 0.3 \times e^{\left[-0.256 \times ms \times \left(1 - \frac{msilt}{100}\right)\right]}\right) \quad (4)$$

$$f_{cl-si} = \left[\frac{msilt}{(mc + msilt)}\right] \quad (5)$$

$$f_{orgC} = \left[\frac{(1 - 0.25 \times OrgC)}{OrgC} + 0.3 \times e^{(3.72 - 2.95 \times OrgC)}\right] \quad (6)$$

$$f_{hisand} = \left(1 - 0.7 \times \frac{(1 - msilt/100)}{(1 - msilt \times 100)} + e^{\left[-5.51 + 22.9 \times \left(1 - \frac{ms}{100}\right)\right]}\right) \quad (7)$$

Where ms – the sand fraction content (0.05-2.00 mm diameter) in %, msilt – the silt fraction content (0.002-0.05 mm diameter) in %, mc – the clay fraction content (<0.002mm diameter) in %, OrgC – the organic carbon content in %.
Soil content like sand fraction, silt fraction, clay fraction, and organic matter for the study area is available as open source with Global Soil Map (FAO) as an Excel spreadsheet. We extracted our data for the study area and use that to calculate the above formula and finally, we get the K factor in an Excel spreadsheet. Extracted Soil map of the study area taken as input for the generation of the K factor maps in the ArcGIS platform. Values of K factor for different soil groups are used from an Excel spreadsheet which is shown in Table.2, and processed with "ArcGIS Interface > Select Soil Map layer > open attribute table > click Editor "ON" on interface > Enter K-factor value manually in attribute table > save edits > Classify K factor maps > K factor map" this sequence. The K factor map and Soil series map of the study area generated from GIS platform is shown in Fig.3(a) and (b).

Table.2 Data Derived for K-factor Formula of Study Area

Soil unit symbol	sand % topsoil	silt % topsoil	clay % topsoil	OC % topsoil	Fcsand	Fcl-silt	Forg	Fhisand	K-Factor
VC	22.4	24.5	53	0.69	0.20	0.71	0.97	1.00	0.146
JC	39.6	39.9	20.6	0.65	0.20	0.88	0.98	1.00	0.170
I	58.9	16.2	24.9	0.97	0.20	0.76	0.93	0.99	0.141

FAO Soil Classification: VC – Clayey Soils, JC – Alluvial Soils, I – Soils contain Rock

C. Slope length and Steepness Factor (LS)

In the RUSLE model, the slope length (L) and steepness (S) were jointly estimated. Because the L and S of the slope directly affect the erosive force of water, soil erosion will be high if they are high and vice versa [19]. Slope length and steepness for the study area derived from SRTM DEM downloaded from USGS Earth Explorer (https://earthexplorer.usgs.gov/) [21]. Shuttle Radar Topography Mission (SRTM) DEM with the resolution of 30 m, 1 arc second was used. The slope length and steepness were estimated through the following formula which was recommended by [22].

$$LS = \left[flow\ accumulation \times \frac{DEM\ Resolution}{22.1}\right]^{0.6} \times \left[Sin\ (slope) \times \frac{0.01745}{0.09}\right]^{1.3} \quad (8)$$

The spatial analyst tools in ArcGIS are used for creating a Slope map, after fill and flow direction following flow accumulation operation to the DEM and extracted for the study area. All the maps which are generated on GIS platform after applying such operation. Extracted flow accumulation and slope map were used as input for the generation of LS factor map using "Arc Toolbox > Map Algebra > Raster Calculator and (Eq. 8)" this sequence. The final generated LS factor map shown in fig.3(c).

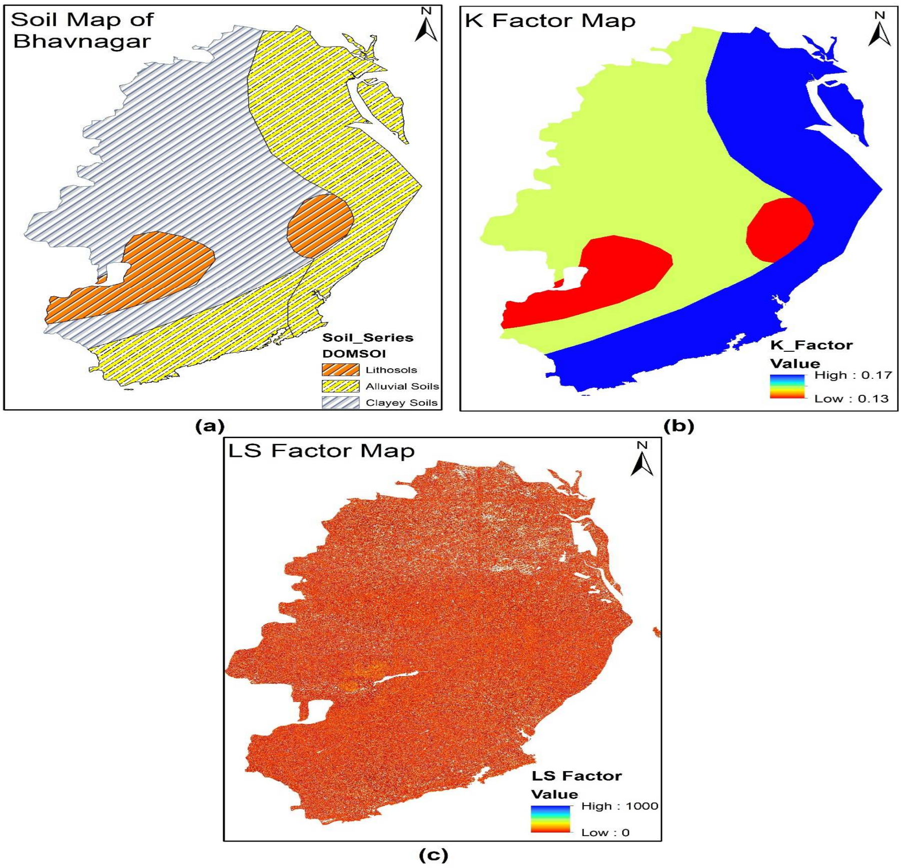


Fig.3 (a) Soil Series map of the Study area (b) K Factor map of the Bhavnagar District
(c) LS Factor map of the Bhavnagar District

D. Cover Management Factor (LS)

The ratio of soil losses from cropped land to the corresponding loss is known as the cover management factor, or C factor. It displays the ground's vegetation index, which regulates soil erosion. The loss of soil declines as the vegetation cover rises [11], [15], [23]. The C factor can be estimated using the Normalized Difference Vegetation Index (NDVI) which was derived from LANDSAT 8 data from USGS Earth Explorer. Fig.4 shows C factor map for the study area.

$$NDVI - \frac{NIR - RED}{NIR + RED} \tag{9}$$

Where NIR is Near Infrared Band-5, and Red is Red Light Band-4 in LANDSAT 8.

The C factor values for bare soil and forest land cover were assumed to be 0 and 1 and above, respectively, C factor values range from 0 for well-protected soil to 1 and above for bare soil (Pierce et al., 1986; Vicenta et al., 2007). The standard methodology for the NDVI map preparation in Landsat 8 is NDVI = (Band 5 – Band 4) / (Band 5 + Band 4) is applied. These band combinations were used as inputs for the Arc Toolbox function, which produced an NDVI map. The 9-band Operational Land Imager (OLI) and 11-band Thermal Infrared Sensor are provided by the Landsat 8 satellite (TIRS). The C factor maps were generated by using the following formula which was derived by regression analysis.

$$C\ factor = 1.02 \quad 1.21 \times NDVI \tag{10}$$

NDVI = Normalized Difference Vegetation Index

NDVI map extracted for the study area used as input in the above formula processed in Raster calculator in ArcGIS platform to derive C factor map.

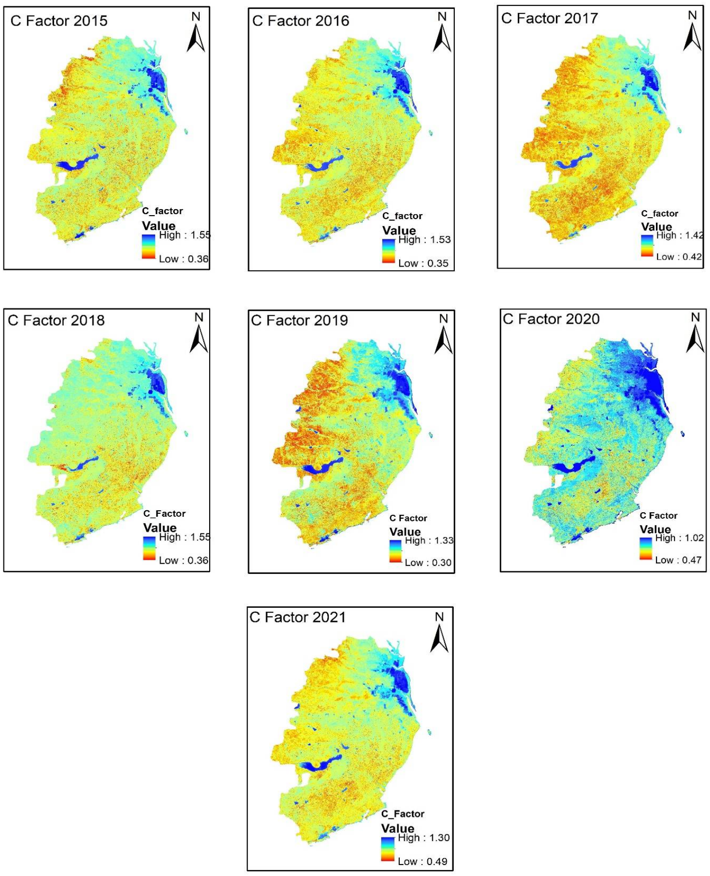


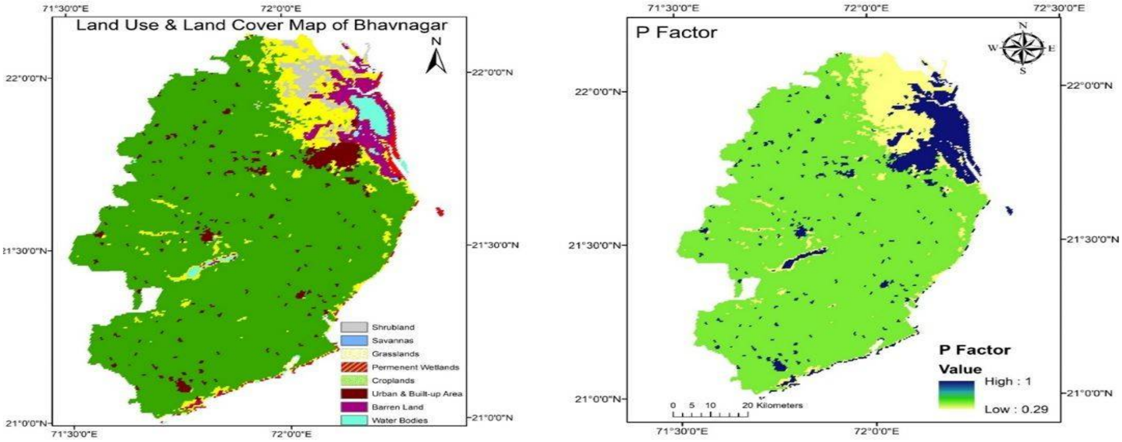
Fig. 4 C Factor Map of Bhavnagar District from the year 2015 to 2021

E. Support Practice Factor (LS)

By creating LULC maps of the research area, it was possible to identify land uses and management strategies. USGS MODIS Land cover map version 6 was used to prepare land use & land cover map. According to the land use pattern, the maps were further divided into 8 classes open shrubland, savannas, grassland, permanent wetland, cropland, Urban and built-up land, Barren Land, and Water bodies. Also, these LULC maps were categorized using Arc Toolbox's Reclass tool. Standard P values were assigned between 0 and 1 based on the land use and management techniques used based on numerous kinds of literature. The lower P factor indicates efficient conservation measures to stop soil erosion [24].The assumed values for P factor for different LULC classes is shown in Table.3. The P factor map and LULC map of the study area is shown in Fig.5(a) and (b).

Table.3 Values for P-factor as per Land Cover class of study area

Sr.No.	Class	P-Factor
1	Open Shrublands	0.29
2	Savannas	0.60
3	Grassland	0.41
4	Permanent Wetlands	0.80
5	Croplands	0.50
6	Urban & Built-Up Lands	1
7	Barren Lands	1
8	Water Bodies	1



(a) (b)

Fig.5 (a) LULC map of the study area (b) P Factor map of the Bhavnagar District

F. Annual Soil Loss (A)

The formula A = R x K x LS x C x P has been used to determine the average yearly soil loss (A). In the ArcGIS platform, to generate an annual soil loss map Raster calculator operation is processed. Above five-factor maps were used as input into the derivation of the Annual soil loss map. According to soil loss risk, the annual soil erosion rate is categorized into 5 classes viz., Low risk 0-200 t ha-1 yr-1, High risk 200-500 t ha-1 yr-1, Very High Risk 500-1000 t ha-1 yr-1, Severe Risk 1000-2000 t ha-1 yr-1, and very severe above 2000 t ha-1 yr-1. Following are the images for the annual soi loss with its risk category. The annual soil loss maps shown in fig.6.

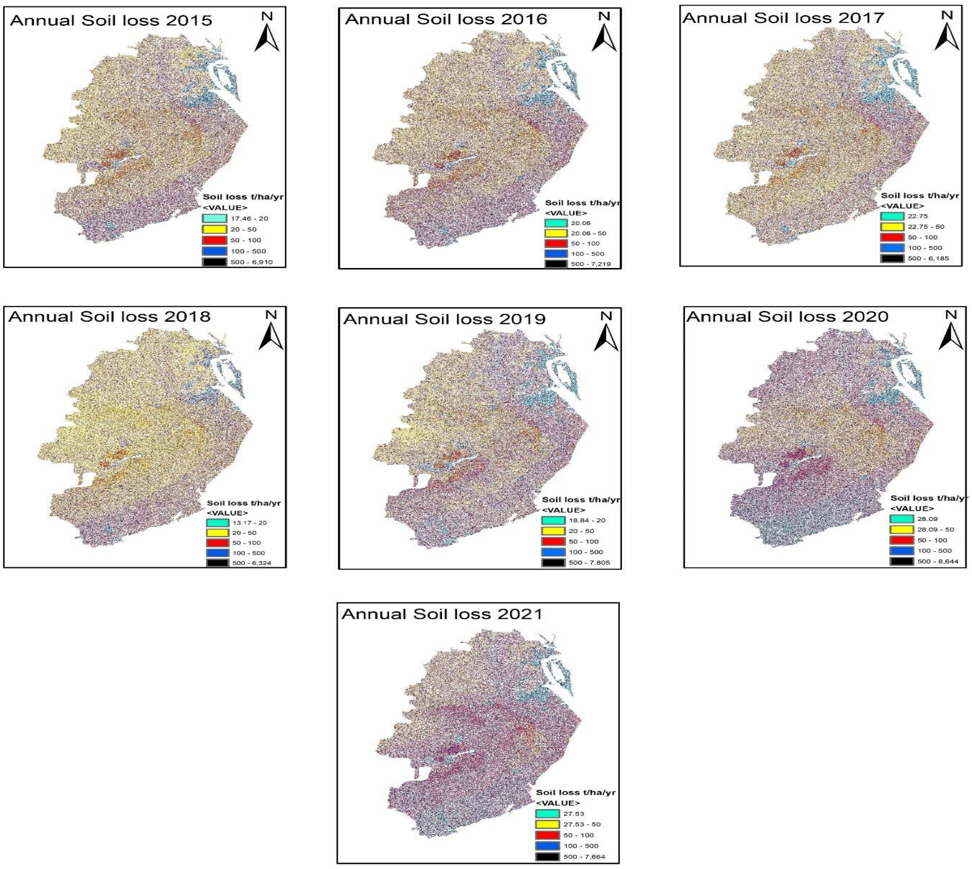


Fig.6 Annual soil loss of the Bhavnagar District from the year 2015 to 2021

V. RESULTS

A. Rainfall Erosivity Factor (R)

The severity of a raindrop's descent is expressed by its erosivity (R), which is a function of the raindrop's kinetic energy and the intensity of the rainfall at its peak within 30 minutes [25], [26]. It determines the impact of rainfall and how much and rapidly soil is lost during a precipitation event. Rain's potential to be more abrasive and its correlation exists with soil loss are both factors that contribute to erosion. [3], [27]. The mentioned procedure in the methodology section was followed to generate R-factor maps for the study area. The Annual Mean R factor values shown for the year from 2015 to 2021 shown in Table.4.

Table.4 Annual R Factor (Mean) from the year 2015 to 2021 for Bhavnagar District

Sr.No.	Year	Mean Annual R Factor (MJ mm ha-1 h-1 yr-1)
1	2015	301.68
2	2016	329.47
3	2017	311.91
4	2018	252.40
5	2019	384.14
6	2020	383.07
7	2021	388.50

The year 2018 had the lowest annual mean R-factor, which was 252.4 MJ mm ha-1 h-1 yr-1. In the year 2021, 388.5 MJ mm ha-1 h-1 yr-1 was the highest annual mean R-factor ever recorded. Highest R – Factor value indicates a higher capacity of rainfall erosivity in the study area which is shown near Palitana and Mahuva talukas of Bhavnagar District. Low R factor values are mostly shown near Gariyadhar, Vallabhipur, Bhavnagar, and Ghogha taluka of Bhavnagar district.

B. Soil Erodibility Factor (K)

The word "soil erodibility" refers to the susceptibility of soil particles to detachment as a function of soil texture, structure, permeability, and organic matter content [3], [19]. The methods previously mentioned were used to produce the K factor map for the research area. Figure 3(a) shows the soil series of Bhavnagar District which contains 50 % alluvial soils (JC), 39% Clayey soils (VC), and 11% lithosols(I). The result showed that the K – Factor value of the study region ranges from 0.13 t ha h ha-1 MJ-1 mm-1 to 0.17 t ha h ha-1 MJ-1 mm-1.

C. Slope Length and Steepness Factor (LS)

The USGS SRTM DEM satellite data was used to prepare the slope length and steepness factor (LS-factor). The process was carried out by the approach mentioned in the methodology section. The slope length and steepness factor (LS) of the Bhavnagar district ranges from 0 to 1000.

D. Cover Management Factor (C)

The Cover and Management Factor (C) is the ratio of soil loss from cropped land to similar loss from clean-tilled, continuous fallow land under particular conditions. The Normalized Difference Vegetation Index (NDVI), employed to compute the vegetation index in this study, was utilized to detect variations in vegetation conditions. The NDVI map was generated from LANDSAT 8 images from USGS Earth Explorer. NDVI Value ranges from -0.444 to 0.542 in the study region. Then, the NDVI images were used to prepare the Cover and Management (C) factor. The C factor value ranges from 0.22 to 1.55 for the Bhavnagar district.

E. Support Practice Factor (P)

The soil loss ratio in response to particular conservation activities is known as the support practice factor (P-factor) or conservation practice factor [6]. The P factor values change depending on the types of land use and cover, as well as the management techniques used in various cover classes. The more effective conservation solution to prevent soil erosion is the one that has a lower P factor value [24]. The P factor values range from 0 to 1.

The region with conservation efforts is shown by the low P factor. Their biggest value is seen in non-conservation regions like developed land and plantation areas with strip and contour cropping. In this study, the P factor value ranges from 0.29 to 1.

F. Annual Soil Loss (A)

For estimating the annual soil loss, the Rainfall Erosivity Factor (R), Soil Erodibility Factor (K), Slope Length and Steepness Factor (LS), Cover and Management Factor (C), and Support Practice Factor (P) parameters of the Revised Universal Soil Loss Equation (Renard et al., 1991) were integrated (A). The annual soil erosion rate is then categorized into risk classes based on its magnitude: Low risk (0–20 t ha-1 yr-1), Medium Risk (20–50 t ha-1 yr-1), High Risk (50-100 t ha-1 yr-1), Very High Risk (100 – 500 t ha-1 yr-1), Extreme Risk (Above 500 t ha-1 yr-1). The mean of annual soil loss for the year of 2015 to 2021 is shown in fig.7(a).

In the Study area, the Mean Soil Erosion rate is 155.19 tonnes/ha/yr, 164.82 tonnes/ha/yr, 155.30 tonnes/ha/yr, 131.70 tonnes/ha/yr, 176.90 tonnes/ha/yr, 203.43 tonnes/ha/yr, 209.6 tonnes/ha/yr for 2015, 2016, 2017, 2018, 2019, 2020 and 2021 respectively. The average of seven years erosion rate is 170.99 tonnes/ha/yr. The greatest mean soil erosion of 209.6 tonnes/ha/yr in 2021 was due to high rainfall events occurring in this region. According to reports, solely precipitation erosion causes 56% of soil loss, and rivers account for 29% of losses [28], [29]. In this study, the Result shows that the Extreme Risk erosion category falls into the streamlines of the river at all locations. In this study, it is observed that river bank areas (Fig.7c) have seen severe Average yearly soil loss above 1500 tonnes/ha/yr from 2015 to 2021. Due to stronger water forces, less vegetation, steeper slopes, and sandy loam soils, riverbanks have seen extreme soil loss. Mainly Shetruji River and its tributaries which is perennial river up to some extent of Palitana taluka have severe soil loss as per the observed result of the annual soil erosion map (Fig.7b & 7c). In Fig.6, blue coloured pixels showed very high-risk category which is shown near shetruji river area and region between Bhavnagar to Dholera.

In the Study region, the Soil loss risk category is divided into 5 classes, Low risk, Medium Risk, High risk, Very High risk, Extreme risk, and No Erosion class. As per Table.5 result showed that 45.06% area of Bhavnagar district is under the No soil erosion category which is made up of Urban and built-up lands and soil with strong bonding with its roots with good conservational measures. After that, the average percentage of the high-risk and very high-risk categories is 20.73%, and 19.40% respectively, which indicates almost 40% area is under a severe risk zone, which needs considerable action plans. While, Sum of the mean of the percentage of Low risk and medium-risk categories is 10.889%, which indicates less worried for that area. Table.5 shows an area covered in hectares as per annual soil erosion risk category for the year 2015 to 2021.

Table.5 Area covered in Hectares as per annual soil loss risk category for Bhavnagar District

Sr	Year	Area covered in Hectares as per Risk category											
		Low Risk	%	Medium Risk	%	High Risk	%	Very High Risk	%	Extreme Risk	%	No Erosion	%
1	2015	12	0.0019	77288	12.75	125035	20.64	107733	17.78	22736	3.75	272975	45.06
2	2016	3	0.0005	69531	11.48	127012	20.97	113709	18.77	22549	3.72	272975	45.06
3	2017	0	0	83019	13.7	122865	20.28	106139	17.52	20781	3.43	272975	45.06
4	2018	362	0.059	114850	18.95	109247	18.03	91017	15.02	17328	2.86	272975	45.06
5	2019	46	0.007	60813	10.03	127891	21.11	119725	19.76	24329	4.01	272975	45.06
6	2020	0	0	34953	5.76	128381	21.19	140848	23.25	28622	4.72	272975	45.06
7	2021	0	0	21191	3.5	138745	22.9	143555	23.7	27740	4.58	272975	45.06

G. Effect of Soil Erosion on Various LULC Classes

In this study, for the semi-arid regions, results are mentioned here for Soil erosion as per Land use and Land cover of the study area. As per the Result, data derived from the MODIS land cover image Bhavnagar district has 8 classes of land cover which are open shrublands, savannas, grasslands, Permanent wetlands, croplands, urban and built-up lands, barren lands, and water bodies, and highest area contributed to Croplands has 478551 hectares, and the Least area contributes to Savannas has 243 hectares. Table.6 shows area covered by different LULC classes of the study area.

Table.6 LULC wise area distribution for the study area

Sr.No.	Land Use & Land Cover Classes	Area Covered in Hectares
1	Open shrublands	10657
2	Savannas	243
3	Grasslands	50925
4	Permanent Wetlands	6435
5	Croplands	478551
6	Urban and Built-up lands	23485
7	Barren lands	24327
8	Water bodies	11156

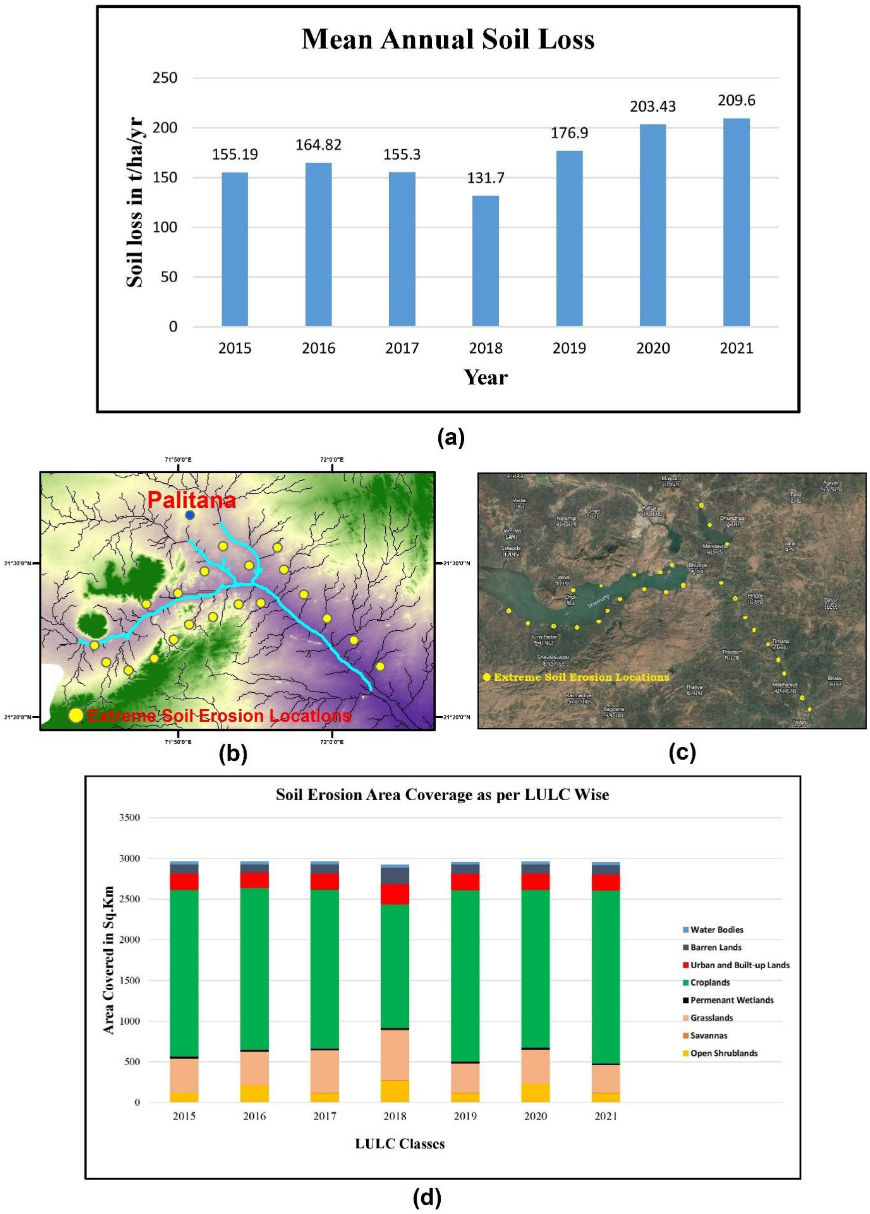


Fig.7 (a) Mean annual Soil loss (b)&(c) Extreme Erosion locations near Palitana Taluka of Bhavnagar District (d) Area covered for Soil erosion as per LULC, for the study area from the year 2015 to 2021

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The result showed in fig.7d indicates that the Croplands Cover has a major area covered under soil erosion in all classes from 2015 to 2021, While the least area covered under soil erosion occurred in Savannas Cover from all the LULC Cover classes from 2015 to 2021. In fig.5(a) pink coloured area shows barren land, and in fig.6, blue pixel shows very high risk soil erosion occured in bareen land cover class which is placed between Bhavnagar city to Dholare village towards coastal direction.

VI. STATISTICAL ANALYSIS

To comprehend the degree to which each element impacts soil erosion, some common statistical techniques have been applied. Also, an effort has been made to determine if there are some factors that have a more significant impact on erosion than others. Sensitivity analysis was done to examine how the local geo environment's effects compared to the components used to quantify soil loss. For sensitivity analysis, RUSLE five parameters and soil loss data were taken and analysed by Bivariate Relationships and multivariate relationships in an Excel spreadsheet. The result showed that the C factor (cover management factor) is the most influencing for soil erosion, after that LS factor (slope length and steepness factor) is regulate soil erosion up to some extent than R, K, and P factors.

A. Bi-Variate Relationships

First, it was determined that the bivariate relationship has been between soil loss and the five parameters of rainfall erosivity (R), soil erodibility (K), slope length-gradient (LS), and crop (C), and Support practice factor (P) with the results shown in Table.7

Table.7 Bi-variate Relationships between Annual Soil loss and RUSLE Parameters

Sr.	RUSLE Parameter	Regression Line Equation	R^2 Value
1	Rainfall Erosivity Factor (R)	A = 1.22R – 33.18	0.09
2	Soil Erodibility Factor (K)	A = 13.9K – 100.65	0.07
3	Slope length & Steepness Factor (LS)	A = 1.02LS + 57.82	0.56
4	Cover management Factor (C)	A = 73.32C – 48.51	0.79
5	Support Practise Factor (P)	A = 37.59P – 45.75	0.12

The result depicts in Table 7, shows that among other factors, the C factor plays a dominant role in influencing soil erosion in this study area. It is having greater correlation (R2 = 0.79) with annual soil loss. Fig.8 shows graphical representation of the relationships between the Soil loss and R, K, LS, C and P factor respectively. On other hand, the LS factor (slope length and steepness) is also well correlated (R2 = 0.56) to annual soil loss, but it is less sensitive than the crop management factor. While other factors like R, K, and P have R2 values of 0.09, 0.07, and 0.12 respectively, which are less sensitive to soil erosion.

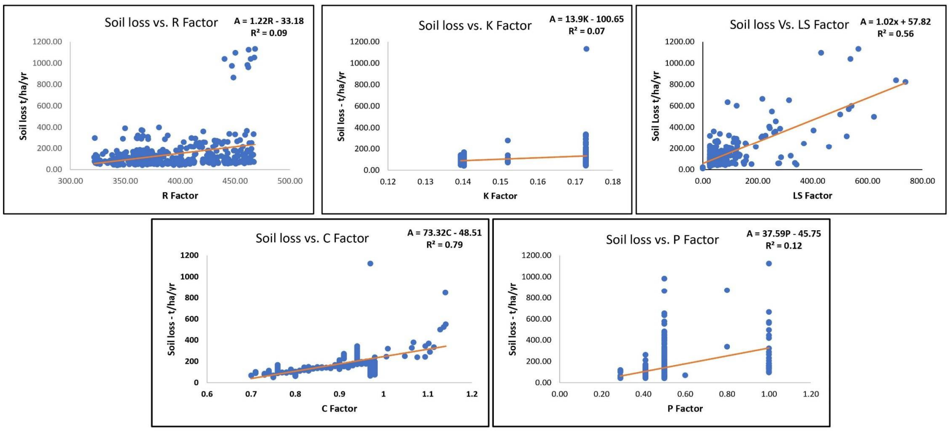

Fig.8 Bi-variate Relationships between Annual soil loss and R, K, LS, C, and P factors

VII. CONCLUSION

In this study we found that the lowest annual R factor of 252.40 MJ mm ha-1 h-1 yr-1 was recorded in Gariyadhar Taluka for the year 2018. The highest annual R factor of 388.50 MJ mm ha-1 h-1 yr-1 was recorded in the Palitana and Mahuva talukas for the year 2021. The results showed that the least K factor of 0.13 t ha h ha-1 MJ-1 mm-1 in Talaja Taluka and Palitana taluka, whereas the greatest value of 0.17 t ha h ha-1 MJ-1 mm-1 was seen in coastal regions like, Ghogha taluka, and Mahuva taluka and Bhavnagar taluka. The slope length and steepness factor (LS) was ranging between 0 to 1000 and higher values are observed at the bank of the river stream and hilly terrain. The least value was observed at cropland cover and urban & built-up land cover of the Bhavnagar district. The greatest LS factors were seen on the bank of the Shetruji river in Palitana taluka of Bhavnagar district. The mean cover management factor (C) was 0.82, 0.80, 0.80, 0.85, 0.74, 0.85, and 0.85 for the years 2015, 2016, 2017, 2018, 2018, 2019, 2020, and 2021 respectively. It is a unitless parameter and it depends on the vegetation cover of the land. The support practice factor (P) is also a unitless parameter and ranges between 0.29 to 1 for different Land use and land cover class. The highest values are provided to built-up land and water bodies and the least value is provided whereas some amount of conservation practices is done.

We conclude that the mean of annual soil loss ranges between 131.70 to 209.6 tonnes/ha/year in the study region for the years 2015 to 2021. The highest mean value of soil loss was 209.6 tonnes/ha/year was observed in the year 2021, and the lowest value of soil loss 131.70 was observed in the year 2018. The extreme risk for soil loss locations located at the bank of the shetruji river of Palitana Taluka (Latitude 21027'36" N, Longitude 71050'44" E) and very high-risk soil loss occur nearby the above location and another site which is in the surrounding area of Ghogha taluka have latitude 21040'10" N, 72013'01" E. The lower vegetation area of Bhavnagar district observed from the NDVI map is most of the barren land between Bhavnagar and Dholera towards the coastal direction. But due to the clayey soils in this land, high erosion cannot take place in this region.

After a detailed analysis of the study region from the result it has been concluded that lack of vegetation cover and conservation practices very high risk and high-risk potential soil loss occurred in the Palitana taluka and Ghogha taluka mostly. As the bare land is vulnerable to soil erosion, proper vegetation cover should be adopted in that area to avoid the risk of erosion. The study is based on remote sensing and geographic information systems (GIS), which may be monitored in the future to assess the important changes over time. Farmers and policymakers will find the research to be very useful in implementing the necessary actions to reduce soil losses.

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