Assessment of soil erosion risk of marginal plain of the Ganga River: a case study of the lower Chambal watershed in Uttar Pradesh, India

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Abstract
The focus of this study is to assess the annual soil loss in the lower watershed of the Chambal basin within the Agra district. This estimation is carried out using the Revised Universal Soil Loss Equation (RUSLE) in conjunction with Geographic Information System (GIS) tools and remote sensing data. Agra's river channels and their tributaries are particularly susceptible to land degradation and soil erosion due to intense fluvial activity and the presence of infertile soils. These conditions contribute to the formation of ravines and gullies along the riverbanks. To calculate the rainfall-runoff erosivity (R) factor, average annual precipitation data from the past decade were analyzed. Soil data obtained from the Remote Sensing Applications Centre, Lucknow, at a scale of 1:10,000 were used to estimate the K factor for different soil types.

The LS factor was derived from a 30-meter ASTER Digital Elevation Model (DEM). Additionally, the cropping management (C) factor was determined using NDVI values derived from Landsat 8 data, processed with GIS techniques. The P factor which distinguishes between agricultural and non-agricultural land, was also considered. The annual soil erosion estimates revealed that the region is predominantly affected by soil loss ranging from 77 to 1,359 tonnes per hectare per year, mainly concentrated in ravine and gully-affected areas. However, in certain regions, soil loss was estimated to be as high as 19,999 tonnes per hectare per year, highlighting the urgent need for intervention and management by local authorities and administrative bodies.

Keywords: Soil erosion, Agra, RUSLE, Remote Sensing (RS), Geographic Information System (GIS), ASTER DEM.

Introduction

Soil erosion is a serious problem spread across the world, which has a great impact on agricultural and soil productivity as well as water quality[45,49]. Generally, this problem of soil erosion is related to some natural factors like rain, rivers, glaciers and wind. However, soil erosion not only affects the agricultural lands but also the chemicals or pesticides released from the industries reach the rivers, ponds or streams which, apart from causing social or economic problems, also have a visible impact on human health[40]. It also affects the socio-economic value and health of the ecosystem[2,6].

Soil erosion is a natural phenomenon of the earth in which the earth's materials are entertained and transported over the surface[14,38]. Soil erosion was a major issue before the 1990s, but due to lack of information, little progress was made on it, making changes in the Earth's crust a daily problem. The United Nations Environment Programme (UNEP) project Global Assessment of Soil Degradation (GLASOD) and Global Land Degradation Information System (GLADIS) tried to pay attention to improving scientific approaches to estimate soil erosion and its aftereffects on the land[8]. Thereafter, soil erosion was first introduced by Myers[37] which was further followed by various researchers, policymakers and institutions[34].

In 2015, the Guardians magazine published an article in which it was reported that one third of the Arab land in the world is being degraded due to soil erosion or it is being lost at the rate of 10 million hectares annually[44]. Similarly, in Eurasia also, the estimated annual rate of soil erosion has been said to be 20 tonnes per hectare and 2.96 tonnes per hectare respectively[22,28,65]. The estimated land degradation in India is 147 Mha, out of which 7 Mha of area are degraded only by flooded water, chemical reaction or wind erosion[6]. However, 126 Mha and 11 Mha of soils are eroded from the water and wind in India[10,58,62].

The main reason for various types of soil erosion in the State of Uttar Pradesh is human intervention, which covers about 52.12% of the area of this state. Moreover, 11.39 MHa and 2.12 MHa of soil were eroded from the water and wind erosion respectively which covers about 7.98% and 0.72% of areas of Uttar Pradesh. In fact, sodicity or salinity reaction degraded 4.65% of the soil of the State[4].

Ganga plain sediment deposition was initiated during the tertiary and showed an early mature stage of deposition[64]. These depositions refer to intrinsic tectonic activity and form erosional ravinous land and gullied tracts[60]. The zones in which the major ravinous land is present in India, are Narmada, Mahi, Sabarmati and Tapti in Gujrat, Punjab ravines along the Siwalik foothills, Chota Nagpur ravine zone and Yamuna Chambal ravine zone in Uttar Pradesh. Among these four, the Yamuna Chambal ravine is the largest zone[45,48,50].

The annual rate of the soil erosion in the fluvial deposits of the Yamuna - Chambal valley is 18.20 t ha^{-1} $year^{-1}$ estimated using the Morgan-Morgan-Finney model and GIS[25] and 445 t ha^{-1} $year^{-1}$ using the RUSLE and GIS method[27]. Mirzapur's Khajuri watershed is placed at high to very high risk with an estimated land erosion rate of 20 t ha^{-1} $year^{-1}$, which is found in approximately 11% area of the entire watershed[1]. Jhagrabaria watershed, Allahabad, shows that the highly severe zone of the soil erosion is almost negligible, ranging upto 8.08 to 54.08 Mg ha^{-1} $year^{-1}$ which covers only 1% area of the entire watershed[52].

The present study has aimed at estimating the annual soil loss in the lower watershed of the Chambal basin using the RUSLE model integrate with GIS applications. The RUSLE model is a comparative quantitative approach that has been used by various researchers to study soil erosion caused by water. It was modified by the Modelling Inventory and Knowledge Management System of the European Commission (MIDAS) in the year 2015. The USLE equation was modified, formed by Wischmeier and Smith in 1971[52]. The USLE equation was based on soil types, cropping systems, topography, rainfall patterns or management practices that were well known for a few decades.[22,54,55] USLE model has been improved upon by adding additional inputs and the RUSLE model has been initiated[9]. Since the RUSLE model has been initiated for a limited scale of soil erosion estimation (smaller watershed), the extensive occurrence of soil erosion and scarcity of water promote upcoming issues concerning cost, sites, results and mapping[21,29].

The Geographic Information system (GIS) has emerged as a valuable tool for the advancement and effectiveness of the estimation of soil erosion and is acknowledged by various researchers in the past[12,16,17,35,40]. They estimate the soil loss erosion on a pixel-based basis. They used a digital elevation model (DEM) as the primary input which was used for the generation of the terrain model, slope, slope length and slope gradient of the watershed. Because soil contains a lot of nutrients, it is very important for agricultural production or human survival, or once it is destroyed, it takes thousands to billions of years to rebuild it. Therefore, this study will help administrative planners in the conservation of erosion sites where this erosion is very high.

Study Area

Chambal River, a tributary of the Yamuna River, originates from the Janapav Hills of Madhya Pradesh. This river flows over three types of successions covering a distance of 960 km. These successions are Upper Chambal, Middle Chambal and Lower Chambal. The Upper Chambal river flows over the Malwa plateau while the Middle Chambal River and Lower Chambal River flow through the Vindhyan range and Alluvium range respectively[46]. Middle Chambal river shows intense erosion and forms gorges while the lower Chambal watershed shows ravines land. The watershed of the lower Chambal river underlies in between the latitude 78^{0}12’ E – 78^{0}50’ E to longitude 26^{0}45’ N – 26^{0}55’ N (Fig. 1).

The total area of the lower Chambal watershed is 46774 ha in which 16766.15 ha area was eroded and dominated by the deep ravines and gullied tract. A large part of the Lower Chambal river flows parallel to the Great Boundary Fault up to Pinhat, where it meets the Yamuna river[51], which is controlled by basement lineaments, as a result of which it flows in an NW-SE direction[33]. Generally, the watershed exhibits flat topography with an average elevation of 200 meters above the mean sea level (MSL) in the quaternary deposits. These quaternary deposits form the Marginal Gangetic Alluvial Plain. The Mukundra fault separates it from the Middle Chambal valley[46]. The area can be referring to a badland topography situated in the alluvial plain, located in warm temperate zone with an annual average rainfall of about 796 mm[49].

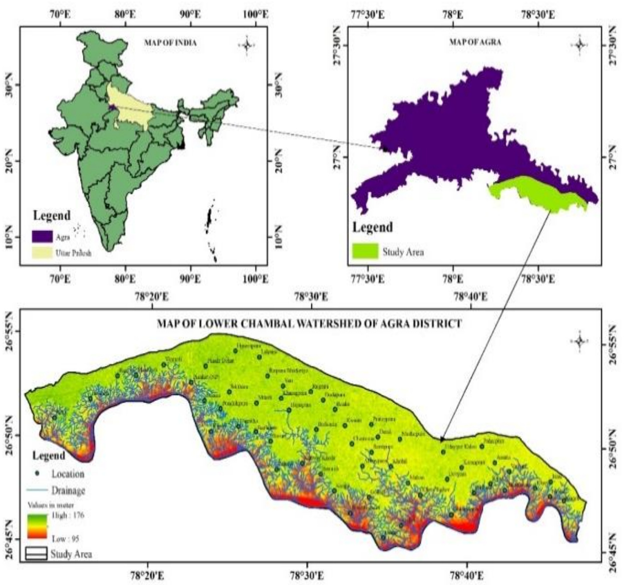

Fig. 1: Location Map of the Lower Chambal Watershed

Material and Methods

The study of annual soil erosion has been done with the help of the RUSLE model and GIS applications[62]. ArcGIS 10.4.1 software has played a major role in preparing thematic maps and managing GIS layers. The different types of data used in this study were taken from many sources. The annual average rainfall (mm/year) data has been collected from the Centre for Hydrometrology and Remote Sensing Data (CHRS) Portal.

Rainfall and runoff erosivity factor (R factor) are the main factor of annual soil loss erosion, which are directly related to water-soil loss erosion and numerous researchers have been using it for many decades[16,21,34,56,60]. The R factor is derived from annual precipitation data collected between 2010 and 2020 in raster format from the CHRS portal or later added to ArcGIS as point data. Point data was raster interpolated using the Inverse Distance Weighted (IDW) tool because the data was too sparse for accurate results. The IDW tool is a well-known tool to fill the gaps between sparse data or to generate consistent output from sparse data. The equation of the R factor reported by Hurni[20] is shown in table 1.

Soil erodibility factor (K factor) was generated using the soil type of the study area[30]. Soil type data has been taken from the Remote Sensing Application Centre, Uttar Pradesh, Lucknow (RSAC UP), Department of Science and Technology (DST). The data has been prepared from LISS IV and CartoSat-1 merge data having a resolution of 5.2 metres. Obtained data was visually interpreted based on the tone, texture, colour on the Satellite image, ground truth verification and lab testing. Soil samples were processed through a Laser Size Particle Analyser (LPSA) and the obtained data were interpreted using the GRADISTAT V.8.0 Excel template was developed and El-Swaify and Dangler[13] provided an equation to estimate the K factor based on the percentage of clay, sand and silt shown in table 1.

Slope length and slope steepness (LS factor) have been generated based on the slope of the lower Chambal basin and this slope has been generated from the Advance Spaceborn Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM). The resolution of the ASTER DEM is 30 metres. The ASTER DEM was downloaded from the Earth Explorer portal in WGS 1984, which was later converted to UTM Zone 44 and the slope of this area was created using ArcGIS 10.4.1. Generally, the Earth Explorer portal is governed by the Geological Survey of the United Stated (USGS). The LS factor was generally calculated using the equation given by Moore and Burch[36] given in table 1.

Table 1
Formulae adopted by given Researchers

S.N.	Equation	Nomenclature
1	$A = R * K * LS * C * P$[53]	A = Annual Soil Loss R = Rainfall and runoff erosivity factor K = Soil erodibility factor LS = Slope Length and Slope Gradient factor C = Cropping management factor P = Conservation Support Practice factor
2	$R = -8.12 + (0.562 \times P)$[20]	R = average annual rainfall erosivity factor (MJ mm ha^{-1} h^{-1}) P = annual rainfall (mm)
3	$K = -0.03970 + 0.00311X_1 + 0.00043X_2 + 0.00185X_3 + 0.00258X_4 - 0.00823X_5$[13]	K = Soil Erodibility Factor X_1 = percent unstable aggregates <0.250 mm X_2 = percent of silt (0.002–0.01mm) and sand (0.1–2mm) X_3 = percent base saturation of the soil X_4 = percent silt present (0.002–0.050mm) X_5 = percent sand in the soil (0.1–2mm)
4	LS = Power (Flow accumulation * (cell size) / 22.13,0.4) * Power (sin (slope 0.01745) / 0.09,1.4)*1.4[36]	L = Slope Length S = Slope Steepness
5	NDVI = (NIR – RED) / (NIR + RED)[56]	NDVI = Normalised Difference Vegetation Index NIR = Near Infrared Band RED = Red Band
6	C = 1.20 – 1.21 * NDVI[19]	C = Cropping management factor NDVI = Normalised Difference Vegetation Index

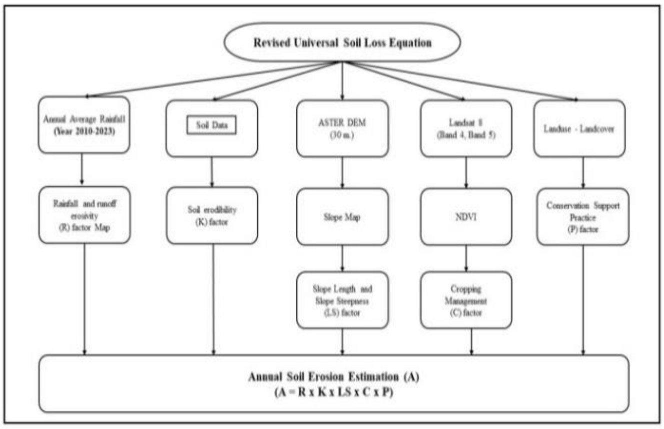

Fig. 2: Work flow for estimation of Annual Soil erosion

Cropping management factor (C factor) was generated using NDVI (Normalised Difference Vegetation Index)[23]. NDVI was generated using the ArcGIS tool Raster Calculator. For NDVI generation, LANDSAT 8 satellite bands NIR (Band 5) and Red (Band 4) have been taken and calculated using the Rouse et al[56] equation, given in table 1. Conservation Support Practice factor (P factor) was generated using Landuse–Landcover (LULC) data. LULC data have been taken from the Remote Sensing Application Centre, Uttar Pradesh, Lucknow (RSAC UP). It was divided into 5 classes: agriculture land, built up area, forest, wasteland and water body[11].

The generated data were used to prepare thematic maps for further calculation and overlaid to calculate the annual soil loss erosion estimation of the lower watershed of the Chambal river in ArcGIS software using the RUSLE equation: "A=R X K X LS X C X P", given by Renard et al[55] where R = Rainfall and runoff erosivity factor, K = Soil erodibility factor, LS = Slope Length and Slope Gradient factor, C = Cropping management factor and P = Conservation Support Practice factor. The detailed methodology is given in fig. 2.

Results

Spatial distribution of Rainfall, Slope, LULC, NDVI and Soil: Rainfall data was generated using the IDW process and indicates that the watershed of the lower Chambal river achieves a versatile rainfall for the estimation of the soil loss. It is higher in the eastern part of the watershed (ranges from 840.56 mm to 850.02 mm) while decreasing towards the western part of the watershed, which ranges from 831.1 mm to 840.55 mm followed by 818.34 mm to 831.09 mm, 806.45 mm to 818.33 mm and 793.9mm to 806.44mm (Fig. 3a). Highly intense and prolonged rainfall impacts soil detachment, soil compaction, increases surface runoff, easily creates rills and gullies and cause water table rise, which are highly prone to soil erosion.

Soil erosion is highly dependent on the slope and steeper slopes are highly vulnerable to soil loss compared to flat plains or at low-angle slopes[24]. The slope of the watershed has been divided into the five classes using ArcGIS software that indicates the higher value of slope covering the southern part of the watershed, reaching up to 15^0 - 32^0 along the ravines and gullied tract and decreasing southern to northern part of the watershed ranges from $10.1^0 – 15^0$, $5.01^0 – 10^0$, $2.01^0 – 5^0$ and $0 – 2^0$ (Fig. 3b).

Generally, LULC provides the spatial extent of the specific area[19]. The LULC was classified into five classes viz. agriculture land, built up land, forest, wasteland and water body (Fig. 3c). LULC shows that the southern part is mostly covered with shrub and scrub types' forest land, followed by waste land, built up land and agriculture land to the north. Agriculture is dominant in this region and covers manmade constructions (roads, dams, buildings etc.), wastelands/ barren lands and water bodies (rivers, canals and minor streams), highly predictable to soil erosion compared to dense vegetation and dense crops.

NDVI mainly suggests the density and health of the vegetation. It is dimensionless and has a value ranging from +1 to -1. When the spectral reflectance of the NIR and Red bands are similar to the earth's surface, it indicates 0 value. The NDVI value ranges from –0.12458 to +0.540037 (Fig. 3d). The lower values in the southern part indicate the lower density of the forest land, while the higher values indicate high density of agriculture land. The low-density vegetation is more prone to soil erosion in comparison to the highly dense vegetated land.

The watershed of the lower Chambal river contains four types of soils: sandy loam, loamy sand, clay loam and loam (Fig. 3e). Sandy loam, loamy sand and loam are highly prone to soil erosion in comparison to clay loam because sandy loam, loamy sand and loam contain a higher percentage of sand with the minor content of silt and clay. Sand easily absorbs the water due to higher porosity, but in saturated soil, the soil is easily detaching from the surface and making it highly vulnerable to soil erosion, while in the clay loam, the clay percentage is high. Generally, the low infiltration capacity of the clay loam has a high water holding capacity and strong binding effects for plants, causing it to be less vulnerable to soil erosion.

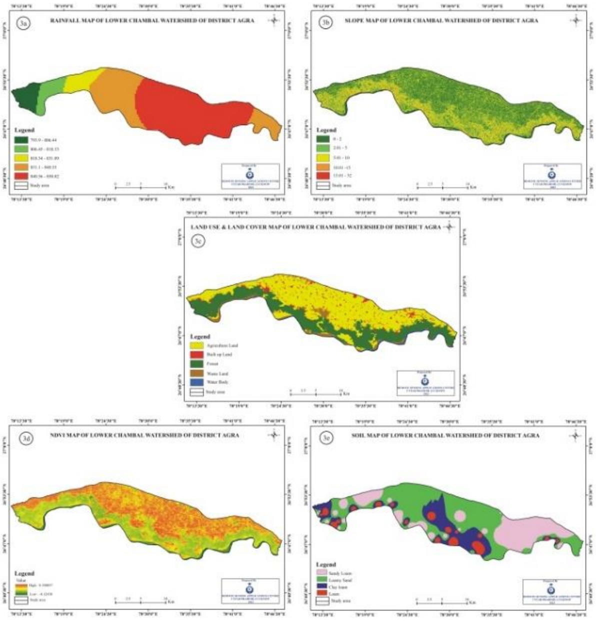

Fig. 3a, 3b, 3c, 3d and 3e: Showing Rainfall distribution map, Slope Map, Landuse-Landcover map, NDVI map and Soil Map respectively

Table 2
Average Rainfall in Milimeters/years and its R factor

S.N.	RAINFALL_MM	R_FACTOR
1	747.75	350.43325
2	750.91	351.58032
3	751.84	351.91793
4	699.32	332.853163
5	832.25	381.10675
6	851.33	388.032796

Table 3
Soil Percent and its K factor

Soil	Sand %	Silt %	Clay %	Organic carbon %	K factor
Clay Loam	29.64	39.64	30.72	0.57	0.170504
Loam	45.72	28.28	26	0.69	0.163758
Loamy Sand	80.52	8.92	10.56	0.23	0.118586
Sandy Loam	80.72	3.28	16	0.32	0.087408

Spatial distribution of soil erosion factor: The annual average of the rainfall and runoff erosivity factor (R factor) ranges from 350.43 to 388.03 MJ mm ha^{-1} h^{-1} calculated from Rainfall Data (Table 2) which is further classified into the five classes viz. 350.43 – 371.39 MJ mm ha^{-1} h^{-1}, 371.40 – 375.90 MJ mm ha^{-1} h^{-1}, 375.91 – 380.64 MJ mm ha^{-1} h^{-1}, 380.65 – 384.25 MJ mm ha^{-1} h^{-1} and 384.26 – 388.03 MJ mm ha^{-1} h^{-1}. The R factor indicates that the eastern part of the watershed receives high rainfall while the western part receives low rainfall (Fig. 4a).

The soil erodibility factor (K factor) provides a quantitative measure of the erodibility of soil under standard conditions of rainfall intensity and surface flow[19]. The K factor ranges from 0.09 t ha/year to 0.17 t h/year in the watershed. The K factor decreases with high and minimal sand percentages[58] while soils with high clay-silt ratio and the presence of carbonic content increase the K factor[64]. The lower Chambal river watershed shows a low value of the K factor where the sand percentages are high or minimal, showing a higher value where the higher percentages of clay and silt are present (Fig. 4b). The soil erodibility K factor of clay loam (0.170), loam (0.164), loam sandy (0.119) and sandy loam (0.087) and values are given in the table 3.

The slope length and slope gradient factor (LS) are important factors in the basic assessment of surface soil and relief eroded by water[3]. The LS factor ranges from 0 to 5.41. Lower slope represents the lower value of the LS factor while in steeper or longer slopes, it increases and signifies a higher value in the watershed (Fig. 4c). The water runoff is higher on steep or longer slopes, which acts as gravitational force on water, which in turn easily detaches the topsoil of the surface due to the high energy of the water and surface, causing high vulnerability to soil erosion[7].

The cropping management (C) factor is an essential factor which suggests how the ground cover contributes to protecting the soil from erosion. It is generally based on the vegetation cover. The low values of the C factor indicate less erosion, while high values of the C factor indicate higher soil erosion[18]. The C factor of the lower Chambal watershed ranges from 0.55 to 1.35, in which lower values indicate highly dense vegetation cover, while higher value indicates the higher erosion rate in lower dense vegetation cover or in ravines and gullied tracts (Fig. 4d).

Conservation Support Practice factor (P) is generally influenced by the estimation of the soil erosion based on the various erosion control practices on the potential soil loss. Generally, it is dimensionless[31]. On the basis of P value ranges given by Foster et al[15], various aspects of soil conservation are assessed. The C factor of the lower watershed of the Chambal River suggests 0.5 and 1 values (Fig. 4e). The P factor values are given in table 4. 0.5 values indicate the erosion could be controlled by the contour ploughing i.e. the practice of ploughing sloping land along lines of constant elevation to conserve rainwater and reduce soil loss from surface erosion.

Table 4
LULC classes and its P factor

S.N.	LULC classes	P Factor
1	Agriculture Land	0.5
2	Built up Area	1
3	Forest	1
4	Waste Land	1
5	Water Body	1

The value of 1 of the P factor is used when no standards are set to prevent land erosion. This value indicates that there is no reduction in erosion due to support practices, meaning the land is left in its natural state without any specific measures to mitigate soil erosion.

Discussion

The pixel-based output of the annual soil erosion of lower watershed of the Chambal River was estimated using RUSLE and GIS application[42]. The soil erosion was calculated by the multiplication of the soil erosion factors (R, K, LS, C and P factors) using raster calculation in ArcGIS. The annual soil erosion of the study area ranges from 0 to 440 t Ha^{-1} yr^{-1} which was classified into six classes: very low (0-6.9 t Ha^{-1} yr^{-1}), low (6.91 – 25.89 t Ha^{-1} yr^{-1}), moderately low (25.9 -63.85 t Ha^{-1} yr^{-1}), moderately high (63.86 – 127.7 t Ha^{-1} yr^{-1}), high (127.71 – 246.77 t Ha^{-1} yr^{-1}) and very high (246.78 – 440.05 t Ha^{-1} yr^{-1}) shown in fig. 5.

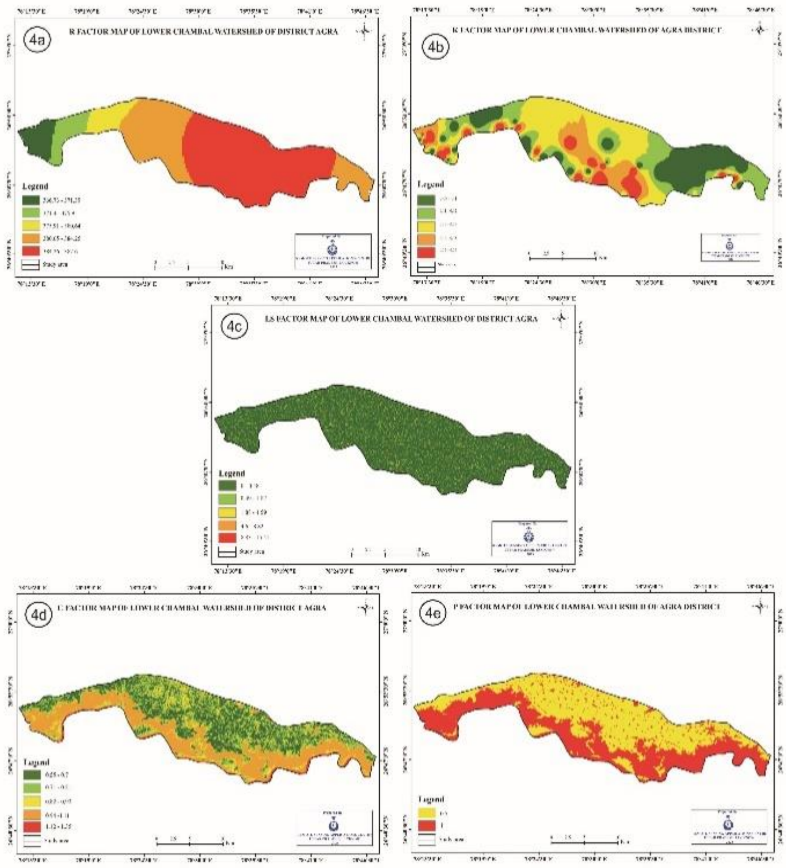

Fig. 4a, 4b, 4c, 4d and 4e: Showing spatial distribution of the soil erosion factor (4a: R factor; 4b: K factor; 4c: LS factor; 4d: C factor and 4e: P factor)

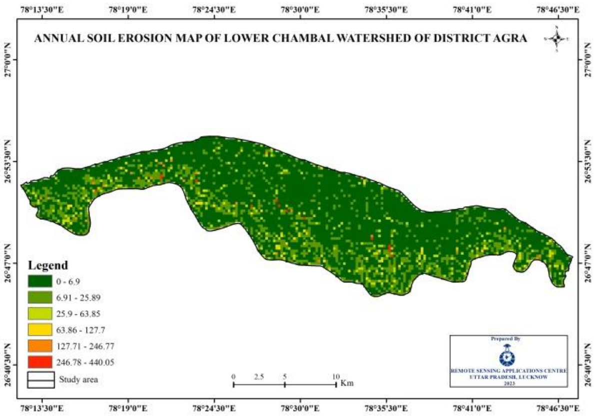

Fig. 5: Showing estimation of the annual soil erosion of Lower Chambal Valley

Very low and low estimations cover almost 79.56 % (36688.34 ha) and 15.53% (7159.57 ha) of the area respectively, almost covered by the nearly flat and highly dense agriculture lands or vegetation covers, while moderately low, moderately high, high and very high comprises area of about, 3.47% (1602.53 ha), 0.84% (385.92 ha), 0.4% (185.61 ha), 0.2% (94.18 ha) respectively. This estimation covers the land formed by rill and gully erosion found in peripheral, shallow, medium and deep ravine land.

Comparative study of various soil erosion estimations in Uttar Pradesh

- The comparative study of RUSLE and USLE soil erosion models using remote sensing and GIS for the Ganga River basin in Fatehpur suggests that the severe zone covers only 2.873% and 2.053% area of the study area[64].

- The Nun Nadi watershed (Yamuna River) estimated the soil erosion estimates using RUSLE and GIS and it was found that the severe risk zone covers only 2.10% of the area, covering ravines and shifting cultivation lands and the least risk zone covers 35.45% of the area which is covered with dense vegetation or agriculture lands[39].

- The Pahuj River Basin (Jhansi, Uttar Pradesh) estimated total soil loss from 0.1 to 3.0 tonnes/ha/per year[5].

- Kumar et al[25] estimated the soil erosion of the Chambal river basin using Google Earth Engine and GIS and showed that the highly severe risk zone covers only 0.093% of the area.

- Suryawanshi et al[59] estimated soil erosion using RUSLE in the Chambal Basin and reported that the 0.33% and 0.76% basin area were under severe risk, while 0.45% and 0.78% were in extremely severe risk.

Mitigation of the soil erosion in land management: Soil is very useful for the growth of any environment which provides many resources to humans along with increasing the production of agricultural fields and forest lands. For this reason, preventing soil erosion can prove to be a useful framework for the improvement of the ecosystem[44]. The present study suggested about 94% area fell under very low to low soil erosion estimation, thus the watershed does not require any execution of preservation measures because the soil loss rate < 10 t ha^{-1} yr^{-1} was supposed to be sustainable[24]. Therefore, soil erosion map can be preventive remedies to investigate soil loss potential zones and use in a mitigation process.

By knowing the highly severe erosion risk zone, efforts can be made to control them with the help of smart management on priority bases and the total sediment yield can be reduced. Therefore, areas of soil erosion caused by water that exceeds 10 t $ha^{-1}yr^{-1}$, can show some variable outcomes[20]. Thus special implementations should be paid to soil conservative measures in moderately high and high risk zone. These implementations could be soil trenches, contour farming, planting cover crops such as clover, vetch, rye etc. during off season, terrace formation on steep slope, strip cropping. Mulching, No -till farming, Riparian buffers, reforestation and afforestation, gully erosion controls using check dams and reshaping gullies wall etc. integrated with the technical knowledge and involvement of the local community. This implementation was based on the particular condition like soil type, climate and landuse practices.

Conclusion

The assessment of annual soil erosion in the lower watershed of the Chambal river using the RUSLE model offers valuable insights into the dynamics of a small watershed. Most notably, the analysis reveals an average annual soil loss of 6.9 tonnes per hectare per year, particularly within vegetated areas. Vegetative cover emerges as a critical factor influencing soil erosion, with higher coverage correlating to lower erosion rates. Fallow lands, gullies and ravines stand out as areas particularly vulnerable to soil loss. The comparative study of research in Uttar Pradesh also indicates that probably most of the region are covered by vegetation and agriculture lands. So, the soil erosion is negligible.

In contrast to the area along the river, the presence of a higher or greater slope and unconsolidated soil, the presence of bandland topography and barren/wastelands is highly remarkable; they are highly prone to soil erosion. Meanwhile, the watershed of the lower Chambal needs more attention to conserve support practices along the Chambal rivers where deep ravines and gullies exist to reduce the risk of the soil erosion.

Integrating the RUSLE model with GIS applications enhances predictive capabilities, as GIS tools facilitate the spatial distribution of soil maps and RUSLE parameters. Furthermore, high-resolution satellite data proves instrumental in visualising land degradation and earth features effectively. While soil erosion-induced land degradation presents a rapid and challenging process to address, it is possible to mitigate its effects through proper crop and land-use management. Environmentalists, organisers and agencies must prioritise the development and implementation of management strategies aimed at promoting environmental sustainability and safeguarding the long-term health of the watershed. Their proactive efforts are crucial for mitigating soil erosion and ensuring the preservation of this vital natural resource.

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