Estimation of Rusle Parameters of the Ozat River Basin Using Remote Sensing and GIS

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

In India, soil erosion is a major problem that lowers water availability and agricultural land production. Detachment, transportation and deposition of soil particles from one place to another under the influence of wind, water or gravity forces is known as soil erosion. Therefore, Revised Universal Soil Loss Equation (RUSLE) with Remote Sensing and GIS study was found easy for estimation of soil loss in river basins. The selected watershed for this study was Ozat river basin is situated in Gujarat, having the catchment area 3410 km2. The rainfall erosivity factor (R) was estimated using monthly and annual rainfall data. Sand, silt, clay and organic matter of soil were used to determine the soil erodibility factor (K). The highest and lowest estimated rainfall erosivity factor were found 144.45 $MJ.mm.ha^{-1}.h^{-1}.y^{-1}$ to 147.37 $MJ.mm.ha^{-1}.h^{-1}.y^{-1}$ respectively. The soil

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erodibility was found in the range of 0.139 tonnes-ha-hr/ha-MJ-mm to 0.172 tonnes-ha-hr/ha-MJ-mm. Soil with higher K values are more vulnerable to soil erosion. However, lower K values are more resistant to soil erosion. Combining the utilization of the Remote Sensing and GIS provides faster and real- time information for studies related to natural resources management and the study of various parameters needed for soil loss. Thus, different soil loss estimation model and tools may be applied extremely effectively and efficiently for the planning of natural resources in watershed and the study of different factors in bigger or smaller basins.

1. INTRODUCTION

"Soil is the upper most weathered and disintegrated layer of the earth's crust which is composed of minerals and the organic substances with the capability of sustaining plant life. The top layer of soil is continuously exposed to the actions of atmospheric activities. Wind and water are the two main active forces which are responsible for the dislodging of the top soil layer and transportation of them from one place to another which can be referred as soil erosion. There are various negative impacts of soil loss on agriculture. Soil degradation limits the soils' ability to retain water and nutrients. This leads to the deposition of silt in lower areas of the watershed, which ultimately reduces the production capacity of upland areas and also reduces the nutrients level of topsoil of soil erodible area. Soil erosion is a global concern as it involves depleting nutrient-rich surface soil, greater flow through permeable subsurface and reduced water availability for the plants. Overall it affects the sustainable development goal and ecosystem services" [1]. "Soil erosion is also the most severe problem in the country, with changing economic implications and food security" [2]. "Soil erosion is an obstacle in the path of sustainable development and needs attention for better management through proper planning" [3].

"Soil erosion is a major threat to biodiversity, as it affects crucial aspects of human, animal, and plant lives" [4]. "Though soil erosion is a naturally occurring process, this has been accelerated by human activities such as intensive agriculture, improper land management, deforestation, and cultivation on steep slopes. Removal of vegetation cover and shaping of surface topography induce or accelerate soil displacement and movement. Serious soil erosion is occurring in most of the world's major agricultural regions due to the expansion of agriculture without adequate soil conservation practices" [5]. "Moreover, crop residues are removed for fodder, biofuel, and industrial uses leaving the soil surfaces bared from a protective cover enhancing the vulnerability to lands for erosion. The resulting runoff ultimately transports sediments, organic material, nutrients, and pesticide residues off-site impacting both water and soil quality. When lands are left as fallow to recover, the erosion problem is worsened due to minimal vegetative cover" [6]. "Soil erosion is reported to increase with higher magnitude of rainfall and frequent occurrences of heavy precipitation" [7].

"Soil erosion has a negative influence on the sustainability and productivity of agricultural areas, as well as biodiversity" [8]. "A decrease in soil fertility is also a consequence of soil erosion, which has caused water quality problems and a threat to sustainable agriculture" [9]. "Gujarat is located in Western part of India covering total geographical area of 19.6 Mha, which is about 6% of the total geographical area of the country. Analysis of soil erosion data revealed that soil erosion rates vary enormously across the state, ranging from less than 5 $tha^{-1}yr^{-1}$ in 0.01% area to very severe (>40 $tha^{-1}yr^{-1}$) in 10.64% area. Percentage of area under slight (<10 $tha^{-1}yr^{-1}$), moderate (10-20 $tha^{-1}yr^{-1}$) and severe (20-40 $tha^{-1}yr^{-1}$) soil erosion classes are 16.07, 61.23 and 10.99, respectively. Analysis of the data also revealed that nearly 82.96% area across the state has erosion rates of more than 10 tha-1yr-1, which indicates that soil erosion is a serious problem in major parts of the state. The severity of soil erosion is due to aggressive climatic conditions coupled with steep topography and erodible soils" [10].

In recent years, advancements in Remote Sensing and Geographic Information System (GIS) technologies have provided valuable tools for assessing and monitoring soil erosion on a larger scale. Remote sensing involves the

acquisition of data about the Earth's surface from air borne or satellite sensors, while GIS integrates and analyses spatial information to derive meaningful insights [11-13].

Keeping this in view present study has been planned with following objective i.e., To estimate the rainfall erosivity and soil erodibility factor of Ozat river basin.

## 2. MATERIALS AND METHODS

2.1 Location

Ozat river originates from Visavadar and meets in Arabian sea. It is situated between latitude of 21° N to 22° N and longitude of 70° E to 71° E. The perimeter of a basin is 390.11 Km having catchment area 3410 sq.km. Dhrafad and Ozat dams are located on this river having 169 sq.km. and 1138 sq.km. catchment area respectively. Abajal and Popatdi are right bank tributaries, and Uben and Utavali are left bank tributaries of this

river. Agriculture is the main occupation in the area. Groundwater is the main source of irrigation on study area.

2.2 Data Collected

a. Rainfall data (monthly and annual)

PERSIANN-CDR (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks- Climate Data Record) developed by the Canter for Hydrometeorology and Remote Sensing (CHRS) at the University of California, Irvine (UCI) provides daily rainfall estimates at 0.25o for the latitude band 60N-60S. PERSIANN-CDR is aimed at addressing the need for a consistent, long-term, high-resolution and global precipitation dataset for studying the changes and trends in daily precipitation, especially extreme precipitation events, due to climate change and natural variability. For the present study the monthly and annual rainfall data for the duration 2003 to 2022 were downloaded.
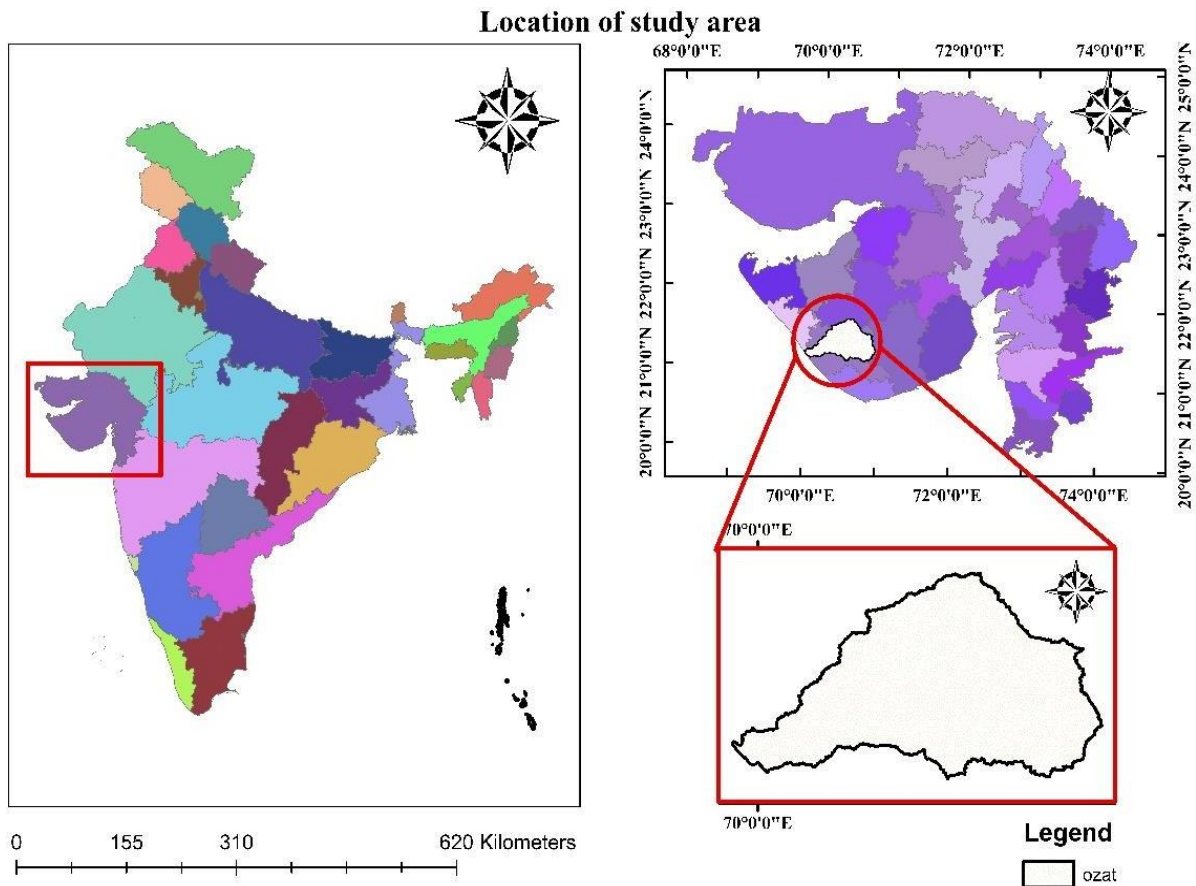
Map 1. Study area map of Ozat river basin

b. Soil data

The FAO Digital Soil Map of the World shows 4931 mapping units consisting of soil associations, which are mixtures of different soil types which defines a total of 106 soil units on the basis of presence of diagnostic properties and 4 non-soil units. For the soil units estimates are provided of physical (% sand, % silt, % clay, bulk density) and chemical properties (pH, organic carbon, CEC, base saturation, C/N ratio, CaCO3-content) in the topsoil and subsoil. DSMW has been superseded by the Harmonized World Soils Database (HWSD), which contains more detailed information on soil distributions for a number of countries, obtained since the publication of all volumes of the Soil Map of the World. For the present study the soil data was downloaded which are available in the ESRI shapefile format.

2.3 Software

ArcGIS is a geographic information system (GIS) used to create, manage, analyze, and map all types of data. ArcGIS connects maps, apps, data, and people in ways that help empower organizations to make data-driven decisions more efficiently. ArcGIS accomplishes this by making it easy for everyone in an organization to discover, use, make, and share maps from any device, anywhere, at any time.

2.4 Rainfall Erosivity Factor (R)

Soil erosion is closely related to rainfall through the combined effect of detachment by raindrops striking the soil surface and by the runoff. According to USLE method, soil loss from the cultivated field is directly proportional to a rain storm parameter, if other factors remain constant.

Because installing rain gauge stations is expensive, they are rarely found all throughout India. Nonetheless, it is crucial to investigate the fluctuation in rainfall since it is the primary driver of soil erosion and it varies both in time and space. In order to overcome the fact that rainfall varies with time and space, the R factor was estimated in this study using the following formula. The Equation, below developed by Wischmeier and Smith [14] and modified by Arnoldus [15] will be used in the computation:

$$R = \sum_{i=1}^{12} 1.735 \times 10 \times \left\{ 1.5 \times \log\left\{ \frac{Pi^2}{P} \right\} - 0.08188 \right\}$$

Where,
R is the rainfall erosivity factor ($\mathrm{MJ.mm.ha^{-1} \cdot h^{-1} \cdot y^{-1}}$),
P_1 is the monthly rainfall (mm),
and P is the annual rainfall (mm)2.5 Soil erodibility factor (K)

2.5 Soil Erodibility Factor (K)

International pipette method: "Pipette method is a standard method for particle size analysis of soils because of its accuracy, but it is time consuming and cannot be employed where large numbers of samples have to be analyzed. Particle size analysis is done by using sieves to separate out coarse sand from the finer particles. The silt and clay contents are then determined by measuring the rate of settling of these two separates from the suspension in water. The time required by the particles of a given size to settle can be calculated using Stokes law. Some of the soil properties that affect soil erodibility include soil texture, drainage condition, soil depth, structural integrity and organic content" [16]. Among the different methods for computing the K-factor, the soil nomograph method, which uses the relative ratios of soil texture, permeability, soil structure and organic matter content [17] is the most commonly used method.

The susceptibility of soil particles to be separated from soil aggregates by any erosive agent is measured by soil erodibility (K), which is determined by the physicochemical properties of the soil. Given that soil qualities are inherent, the soil erodibility factor quantifies the susceptibility to soil erosion. The K factor value is a number between 0 and 1, where a value closer to 0 denotes the least sensitivity to soil erosion and a value closer to 1 denotes the highest susceptibility.

An equation for estimating KRUSLE values given by Wiliams [18]:

$$K_{\mathrm{RUsLE}} = Kw = F_{\mathrm{ocand}} \times f_{\mathrm{ol\text{-}el}} \times f_{\mathrm{orgo}} \times f_{\mathrm{nleand}}$$

Where, f_{csand} is a factor, that lowers the K indicator in soils with high coarse-sand content and higher for soils with little sand; fcrar gives low soil erodibility factors for soils with high clay-to-silt ratios; forec reduces K values in soils with high organic carbon content while, f_{nusand} lowers K values for soils with extremely high sand content:

$$f_{ocand} = \left\{0.2 + 0.3 \times \exp\left[-0.256 \times m_s \times \left(1 - \frac{m_{sult}}{100}\right)\right]\right\}$$

$$f_{ol\text{-}cl} = \left(\frac{m_{slut}}{m_c + m_{sllt}}\right)^{0.3}$$

$$f_{orgo} = \left(1 - \frac{0.25 \times orgC}{\arg C + [3.27 - 2.95 \times \text{ orgc}]}\right)$$

$$f_{hlcand} = \left(1 - \frac{0.7 \times \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + \exp\left[-5.51 + 22.9 \times \left(1 - \frac{m_s}{100}\right)\right]}\right)$$

Where,

m_s - the sand fraction content $(0.05 - 2.00$ mm diameter) [%];

$m_{:llt}$ - the silt fraction content $(0.002 - 0.05$ mm diameter) [%];

m_c - the clay fraction content $(< 0.002$ mm diameter) [%];

org C - the organic carbon content [%]

3. RESULTS AND DISCUSSION

3.1 Rainfall Erosivity Factor (R)

The rainfall erosivity factor (R) values for the study area were calculated by using the equation given by the Wischmeier and Smith [14] and modified by the Arnoldus [15]. For the preparation of R factor map monthly and annual rainfall data were used for the year 2003 to 2022. These data were downloaded from the CHRS data portal (Center for Hydrometeorology and Remote Sensing at the University of California) in which Persian CDR (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Network- Climate Data Record) was used having the resolution of 0.25o× 0.25o. It was given in tiff format. R -factor map was calculated by using the raster calculator in the ArcGIS 10.4 software. After finding the R factor for 20 years, the raster file was converted into the point format by using the 'rater to point' tool in conversion toolbox in ArcGIS. Interpolation was done for the study area. For the Interpolation IDW (Inverse Distance Weighted) was used. It interpolates a raster surface from points using an inverse distance weighted technique. The output value for a cell using the IDW is limited to the range of the values used to interpolate. Because IDW is a weighted distance average, the average cannot be greater than the highest or less than the lowest input.

For the present study area R factor values ranges from 144.46 MJ.mm.ha^{-1}.h^{-1}.y^{-1} to 147.37 MJ.mm.ha^{-1}.h^{-1}.y^{-1}. The R factor was calculated for the 20 years and average R factor map for the study area is shown in Fig. 1. And the values of R factor for the period 2003 to 2022 are given

in Table 1. The low R values are distributed in some portions of the watershed, whereas the high R values are located in the area near the outlet of the watershed. Moderate R values were found in the middle portion of the watershed. The results of this work are compared with the studies conducted around the world like Waseem et al. [19] used the same equation and shown similar result for R factor. Also, Machiwal et al. [20] and Prasannakumar et. al. [16] have used same equation given by Wischmeier and smith and shown similar result for R factor.

3.2 Soil Erodibility Factor (K)

Sand, silt, clay and organic matter content data were used to evaluate the Ozat river basin's soil erodibility factor (K) map. For DSMW FAO data was used. DSMW FAO (Digital Soils Maps of the World) (Food and Agriculture Organization of the United Nations) provides the digital soil map of the world which is given in ESRI (Environmental Systems Research Institute) shapefile format. Study area was extracted from the world data and sand, silt, clay and organic matter content were tabulated as given in Table 2 for the study area. From the values in table, sand fraction content (ms), silt fraction content (msilt), the clay fraction content (mc) and organic carbon content were found out by using the equation proposed by the Williams [18]. The soil type found in the study area were Lithosols, Calcaric Fluvisols and Chromic Vertisols. The values of ms, msilt, mc and orgc for the soil type Chromic Vertisols, Calcaric Fluvisols and Lithosols are given in Table 3.

The K factor value was estimated by substituting all the above value in equation and the K factor value for the study area ranging between 0.139 tonnes-ha-hr/ha-MJ-mm. to 0.172 tonnes-ha-hr/ha-MJ-mm. K factor value for different soil type is given in Table 4. The K factor values refeelct a compound relationship between soil physical properties and their impact on increasing soil erosion [21,22].

It was found that the clay content has low K factor values 0.0139 tonnes-ha-hr/ha-MJ-mm. and 0.140 tonnes-ha- hr/ha-MJ-mm, because the clayey soils are highly resistant to detachment of soil particles. The medium textured soils such as loam have K factor value 0.172 tonnes-ha-hr/ha-MJ-mm. The finding of this research is compared with studies conducted by Waseem et. al. [19] in the case study of Jhelum River basin. They have used FAO data to find K values which were in the

range of 0.14 to 0.16 tonnes-ha-hr/ha-MJ-mm. Also shown the similar K factor values for the study done by Ejaz et. al. [23] which was between 0.139to 0.151 tonnes-ha-hr/ha-MJ-mm. and Ghosh et. al. [24] found K value in the range of 0.120 to 0154 tonnes-ha-hr/ha-MJ-mm. The similar K factor value was found in results given by Machiwal et al. [20].
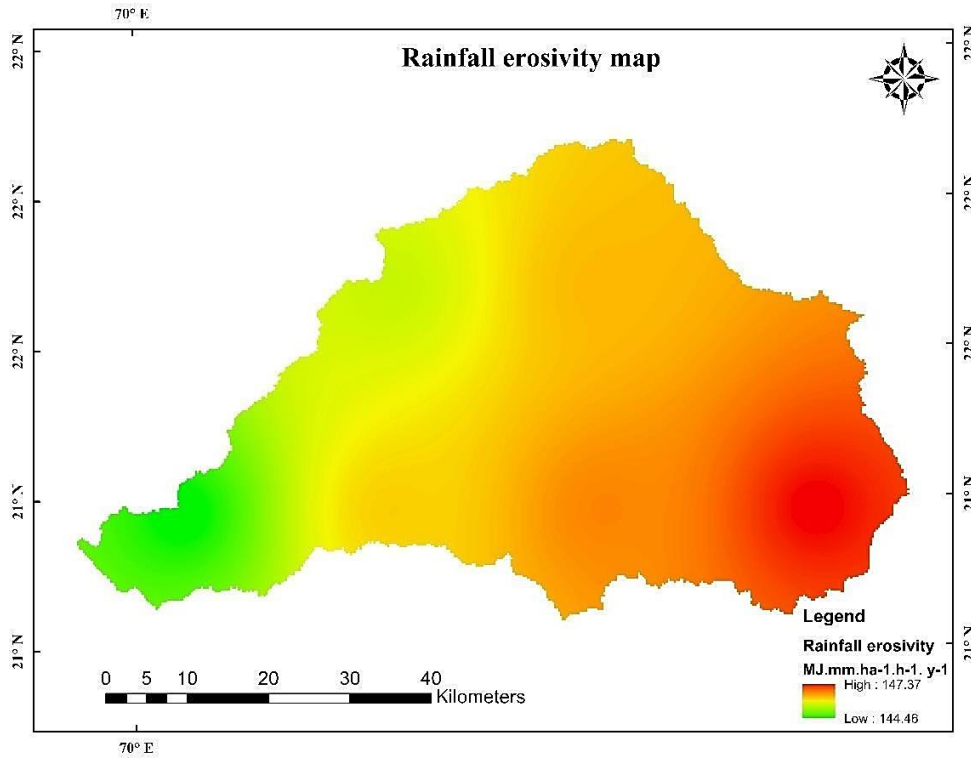

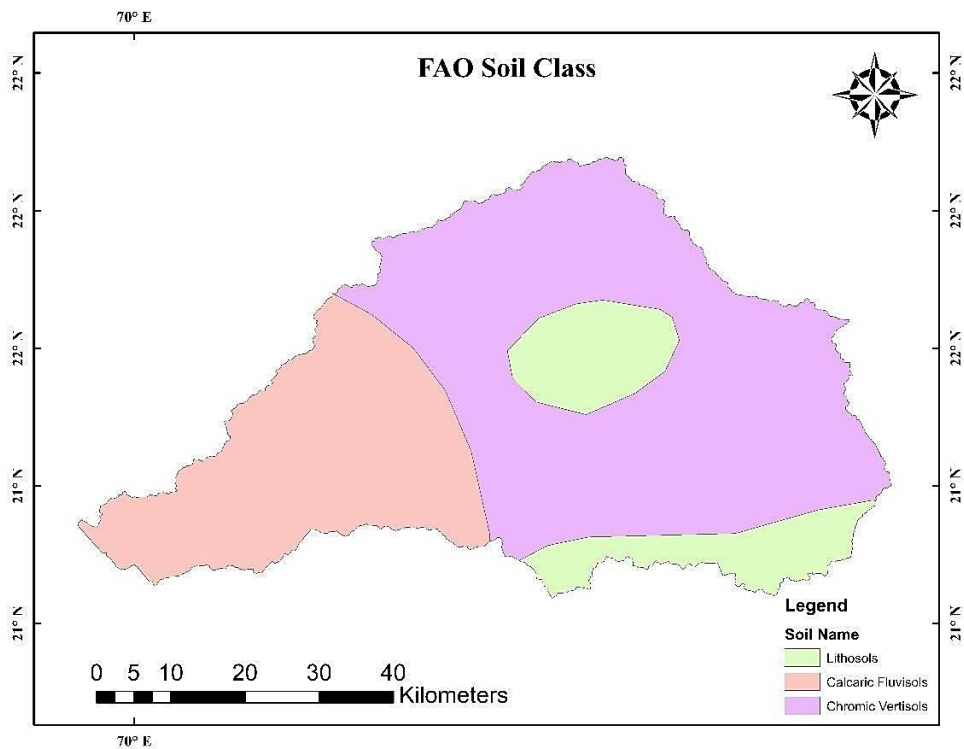**Fig. 1. Rainfall erosivity map of Ozat river basin**
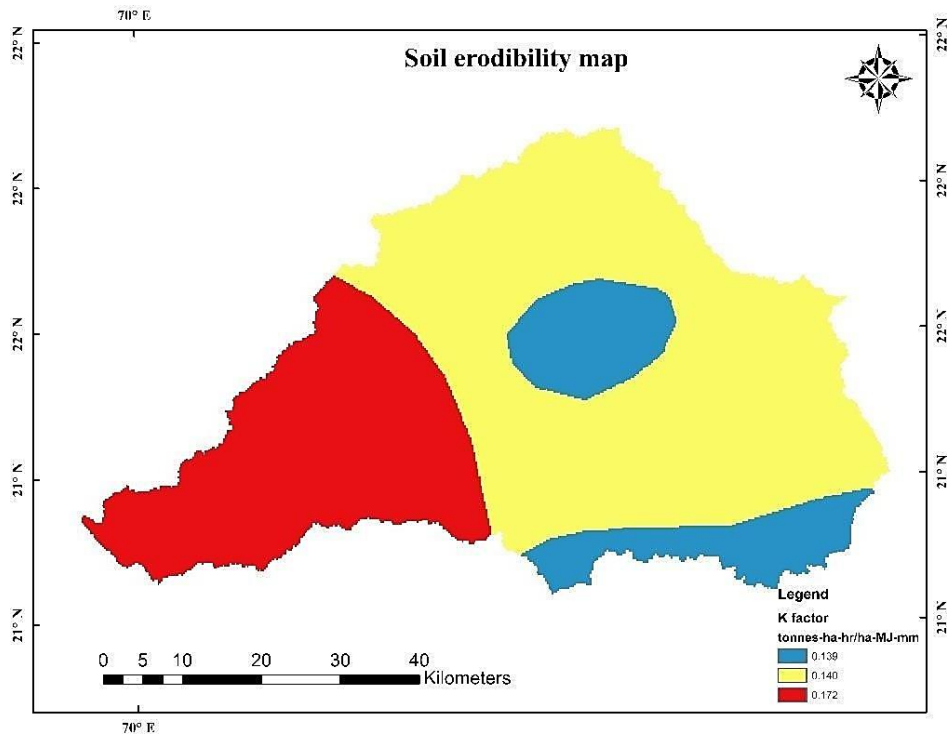

Fig. 2. FAO soil class map of Ozat river basin

Fig. 3. Soil erodibility map of Ozat river basin

Table 1. Rainfall erosivity value for year 2003 to 2022

Year	R factor Value (MJ.mm.ha^{-1}.h^{-1}.y^{-1})
2003	136.49-156.13
2004	144.41-149.14
2005	158.03-168.30
2006	158.84-164.00
2007	179.90-182.28
2008	144.85-152.87
2009	104.65-122.18
2010	153.47-162.34
2011	161.58-167.62
2012	114.71-120.44
2013	154.90-165.42
2014	70.01-122.75
2015	113.25-130.28
2016	138.00-141.64
2017	157.75-160.49
2018	89.13-110.38
2019	170.19-174.75
2020	168.02-173.60
2021	133.81-146.51
2022	155.37-163.20

Table 2. Sand, silt, clay and organic matter content in soil types of study area

Soil sample	ms (sand) Top soil %	msilt (silt) Top soil %	mc (clay) Top soil %	Orgc Organic carbon %
Vc	22.8	24.5	52	0.69
Jc	39.6	38.9	20.8	0.70
I	57.9	16.3	24.9	0.90

Table 3. Sand fraction content (ms), silt fraction content (msilt), the clay fraction content (mc) and organic carbon content of study area

Soil sample	F_{csand}	F_{cl-si}	F_{orgc}	F_{hisand}
Vc	0.20	0.71	0.97	0.99
Jc	0.20	0.88	0.98	0.98
I	0.20	0.76	0.93	0.97

Table 4. K factor values for different soil types of the study area

Sr. No.	Soil	FAO soil class	K factor value tonnes-ha-hr/ha-MJ-mm.
1	Vc	Chromic Vertisols	0.140
2	Jc	Calcaric Fluvisols	0.172
3	I	Lithosols	0.139

Human activities including overgrazing, overcropping, and deforestation also contributed to soil erosion. All of these actions will contribute to desertification, which is the growth of extremely salty, desert-like regions as a result of human activity speeding up soil erosion. The rate of soil erosion is expected to increase in the future. To combat this, more techniques like windbreaks, tree planting, contour ploughing, and stubble planting will be required in order to conserve the soil. Furthermore, constructing stone walls along to the contours of the soil will stop soil erosion downslope and enable rainwater to seep through the soil instead of running off the slope. Additionally, mulching aids in halting soil erosion. Since soil is essential to many basic ecological functions, its conservation is vital. Through the growth of microbial activity, the soil filters the water, supplying the nutrients required for agricultural crops. At the same time, forests work to control greenhouse gas emissions and the planet's temperature.

4. CONCLUSION

The rainfall erosivity factor for the Ozat river basin was ranging between 144.46 MJ.mm.ha^{-1}.h^{-1}. y^{-1} to 147.37 MJ.mm.ha^{-1}.h^{-1}. y^{-1}. The soil erodibility factor of Ozat river basin was ranging between 0.139 tonnes-ha-hr/ha-MJ-mm to 0.172 tonnes-ha-hr/ha-MJ-mm. It was found that the clay content has low K factor values 0.139 tonnes-ha-hr/ha-MJ-mm. and 0.140 tonnes-ha-hr/ha-MJ-mm, because the clayey soils was highly resistant to detachment of soil particles. The medium textured soils such as loam have K factor value 0.172 tonnes-ha-hr/ha-MJ-mm. Soil with higher K values are more vulnerable to soil erosion. However, lower K values are more resistant to soil erosion. The current study will support more sustainable river basin development as well as improved environmental hazard planning and management. A cost-effective and efficient method of estimating soil erosion model parameters is to merge the usage of GIS and remote sensing. Additionally, it might help create management scenarios, give policymakers answers for concerns to soil erosion, and prioritize basin areas for restoration.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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