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Integrating Mean Weight Diameter and Environmental Sensitivity Index for Modeling Soil Erosion Risk and Land Degradation in Soils under Different Agricultural Land Uses

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Abstract: The study area is located between latitudes (36°42'24.52" N – 36°24'38.40" N) and longitudes (43°38'14.98" E – 43°22'14.58" E), covering an area 1245 km². The elevation ranges from 283 to 1015 m above sea level. The climate classified as a transitional zone between semi-arid and Mediterranean climates. Twenty-five sites were selected within the study area. Approximately 2 kg of soil was collected per site, with samples carefully selected to ensure homogeneity. The samples were then transported to the laboratory, air-dried, gently crushed using a wooden hammer, and sieved through a 2 mm mesh sieve. Subsequently, they were stored in plastic containers for further physical and chemical analyses. Laboratory analyses included the determination of soil organic matter, calcium carbonate (CaCO₃) content, and particle size distribution, and Environmental Sensitivity Index equations were applied. The results indicated that the dominant soil textures in the study area ranged from clay to clay loam. This variability is primarily attributed to differences in soil organic matter content and calcium carbonate levels, which reached maximum values of 2.28% and 37.2%, respectively. Furthermore, the results revealed relatively uniform sorting values across most sites, indicating a generally homogeneous particle size distribution, except for site, which exhibited a high sorting value of 2.420, reflecting poorer sediment uniformity. The study demonstrates that both water and wind erosion processes in the region are controlled by a complex interaction of natural and anthropogenic factors acting simultaneously, which significantly influence soil stability and susceptibility to detachment and transport.

Keywords: Erosion, USLE, SEI, Sorting, Land use.

Introduction

Water erosion has been the subject of numerous studies that have looked at it from a variety of angles, including how to measure it, what causes it, and how it affects the ecosystem. Kefi and Yoshino (2010) pointed out the significance of studying water erosion both inside and outside of watersheds, stressing that, especially when using contemporary spatial analysis techniques, looking into the environmental factors influencing this process helps manage watersheds and lessen soil degradation. According to Ganasri and Ramesh (2016); Adeyeri et al. (2024); Kafroshy and Alkhaled (2025), soil loss rates are directly correlated with the energy of raindrops falling and the intensity of precipitation for short periods of time, making rainfall intensity the most important climatic factor in promoting water erosion.

In a study conducted in Iraq's Abu Ghraibat Basin, Maarof et al. (2025) demonstrated that soil erosion is highly related to land use and prevailing climate conditions Alhashyme & Khaled (2025). The study showed that sites with limited plant cover and those heavily exploited for agriculture have the highest rates of erosion. Dutucu et al. (2025) also stated that changes in land use play a critical role in influencing the future direction of soil

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erosion. Quinton and Fiener (2024), in a study analyzing the causes of erosion in agricultural lands on a global scale, demonstrated that human activities, especially agriculture and the conversion of forests to farmland, are the main reason for the acceleration of soil erosion compared to natural rates. Yanqing et al. (2025) also stated that human activities represent the most influential factor in increasing soil erosion compared to natural factors.

The Modified Global Soil Loss Equation (RUSLE) is one of the most well-known and often utilised formulas in the world. Its usefulness in semi-arid situations was proved by Akbari et al. (2022), who showed its potential for identifying geographical heterogeneity in loss rates. Wischmeier and Smith (1978) developed an equation to estimate the average annual soil loss caused by water erosion, which later became known as the Universal Soil Loss Equation (USLE).

$$A = R \times K \times LS \times C \times P \quad (1)$$

Where: A: Annual soil loss rate (tons/hectare/year)., R: Rainfall-runoff Erosivity, reflecting the ability of rainfall to break down and transport soil., K: Soil Erodibility, expressing the soil's susceptibility to breakdown and transport., LS: Topography, representing the effect of slope length and steepness on accelerating surface runoff., C: Vegetation cover and soil management, reflecting the role of vegetation cover in protecting the soil from rainfall., P: Supporting practices, encompassing the impact of agricultural methods and measures that reduce surface runoff.

According to Akpa et al. (2024), the RUSLE model's effectiveness in estimating soil loss under various climatic circumstances was examined in a reevaluation of the model's dependability in semi-arid regions. Ho et al. (2026) showed that the RUSLE model is a useful tool for estimating sedimentation volume and erosion risk when combined with remote sensing and geographic information systems (GIS). Lukić et al. (2022) noted the application of the MEDALUS model in Southeast Europe, which revealed a clear variation in land sensitivity to environmental degradation (Azimi et al 2025). Similarly, Gül and Esen (2024) demonstrated that the Environmental Sensitivity Index (ESAI) used in semi-arid forest systems revealed high levels of desertification susceptibility. Alhamdany and Alnaser (2024) also showed that the application of the MEDALUS model indicated that most of the studied sites fell within the critical categories for desertification, with some areas falling within the fragile categories. Abbood et al. (2025) reported that the application of the MEDALUS model and its modified version in southern Iraq demonstrated high efficiency in assessing desertification risks using several environmental scenarios. This study relied on integrating 19 environmental criteria within a spatial analysis using GIS.

Wu et al. (2019) showed that changes in soil erosion sensitivity are directly reflected in long-term variations in (Normalized Difference Vegetation Index) NDVI maps. These results demonstrate that, especially in arid and semi-arid areas, plant loss is both an environmental indicator and a direct predictor of the beginning or escalation of erosion processes. In a study carried out in Iran's semi-arid Saravan region, Ebrahimi et al. (2024) discovered that spectral indices exhibited a correlation with field measurements ranging from 0.52 to 0.88, showing their great potential to explain erosion and deterioration. Meanwhile, Mahgoub et al. (2024) found that spectral indices are substantially connected with the C factor, and that increasing vegetation cover (higher NDVI) reduces erosion rates significantly. The study also found that these indices can be utilised as a quantitative alternative to assessing vegetation cover in erosion models.

As a result, monitoring soil erosion in northern Iraq using RS and GIS techniques is an important scientific step toward identifying geographical variations in soil loss rates and developing practical strategies to reduce their consequences. This helps to achieve sustainable agricultural development and conserve natural resources for future generations. The study aims to:

Implement long-term methods to decrease soil erosion and track how land usage affects its rate of progression and Identify the spatial factors affecting soil erosion intensity and estimate the areas of soil exposed to erosion in the study region by applying the modified global soil loss equation and using remote sensing and GIS techniques.

Materials and Methods

Description of the Study Area

The study area, which spans many administrative units and villages with a variety of geomorphological features and land uses, is located in the northeastern part of the Nineveh Governorate. The study sites were chosen to reflect the region's prevailing environmental conditions and geographic differences in soil attributes. The region is located between latitudes ($36^{\circ}42'24.52''$ N - $36^{\circ}24'38.40''$ N) and longitudes ($43^{\circ}38'14.98''$ E - $43^{\circ}22'14.58''$ E). With an area of 1274.737 km² and elevations ranging from 283 to 1015 m above sea level, the topography is remarkably diverse as showed in (Figure 1).

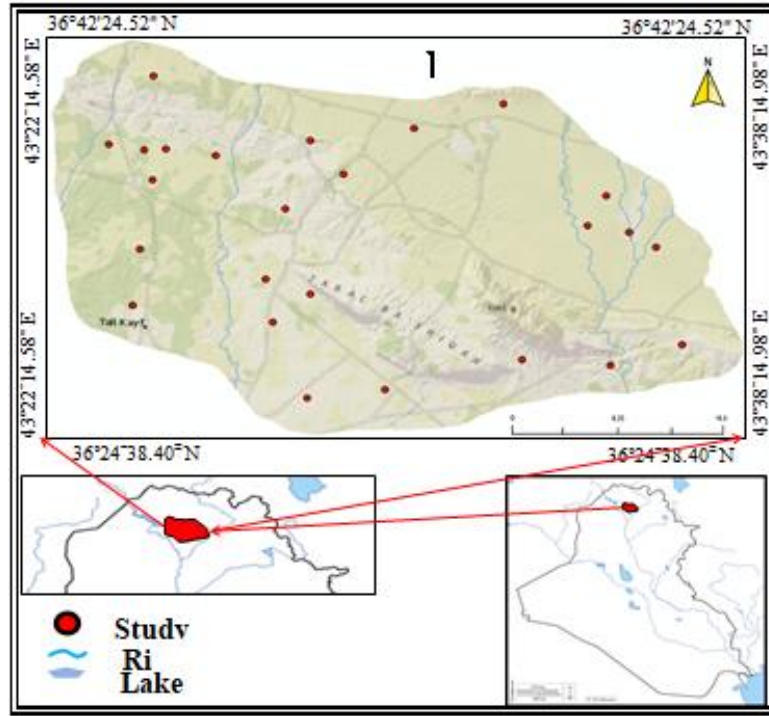


Figure 1. The study area

Climatic Characteristics of the Study Area

The climate of northern Mosul is classified as a transitional climate between semi-arid and Mediterranean, and it lies within the continental climate zone of northern Iraq. It is characterized by significant temperature variations and distinct seasons between summer and winter. Summers are hot and dry, with temperatures soaring during June, July, and August, sometimes exceeding 40°C. Winters are relatively cold, with seasonal rainfall concentrated between November and April. Average annual rainfall ranges from 300 to 450 mm, depending on topography and elevation.

Table 1. The climatic data rates for the weather station in Nineveh.

Date	Temperature rate		Relative humidity		Total solar radiation		Wind speed rate		Max. wind speed		Wind direction	Evaporation rate
	AT	Avg	RH	Avg	SLR	Total	WS	Avg	WS	Max		
	C°		%		Mj/m2		m/s		m/s		m/s	mm
2015	22.30		42.26		16.37		2.83		6.62		196.83	2.83
2016	22.35		41.62		17.55		2.84		6.59		201.62	2.84
2017	22.43		42.14		15.76		3.02		6.80		193.65	3.02
2018	22.68		45.56		16.94		3.40		7.26		201.85	3.40
2019	22.34		47.04		16.92		2.95		8.23		189.76	2.95
2020	22.39		43.96		17.81		5.27		7.48		192.02	5.27
2021	23.39		43.10		16.63		2.51		7.14		209.59	5.74
2022	22.80		44.89		14.99		2.55		6.54		206.69	5.76
2023	16.79		57.65		13.87		2.17		7.48		178.58	3.87
2024	20.69		48.85		15.85		2.51		3.29		246.72	3.78
2025	22.23		48.46		16.67		2.08		5.92		183.85	4.83

Table (1) shows the climatic data averages for the Nineveh and surrounding areas meteorological station for the years (2015-2025), showing the maximum and minimum temperatures. The highest temperature reached approximately (31.49) in 2021, and the lowest was (12.47) in 2023. The total solar radiation reached its peak at (17.81) in 2020, and the average wind speed ranged between (17.81-5.27) m/s. The amount of evapotranspiration ranged between (2.83 - 5.76) mm. This pattern is prevalent in northern Iraq, with a clear influence of topographical elements on the higher rainfall levels in Duhok compared to Mosul.

Field Work

According to Renard et al. (1997), each of the chosen sites was represented by 16 composite soil samples at a depth of (0–15) cm using the grid method, representing an area with dimensions of 100 x 100 m. As indicated in Table (2), the samples were taken from 25 locations in the northern Nineveh Governorate with varying soil grades and land uses. A GPS (Global Positioning System) was used to pinpoint their whereabouts.

Table 2. Study area and their coordinates, and nature of land use..

No	Location	Coordinates		Soil Depth سم	Gravel ratio in 1 m	Tobography	Land use
		N	E				
1	En bakri	36.683438°	43.122926°	24	4	Undulated	Wheat
2	Shekan	36.646563°	43.346618°	30	1	Undulated	Wheat
3	Baryma	36.529393°	43.221895°	25	0	Level land	Potato
4	Bashiqa	36.446593°	43.325450°	25	1	Level land	Olive
5	Kelkji	36.574458°	43.495979°	80	2	L. Sloping	Wheat
6	Batnaya	36.55100°	43.114618°	35	7	Undulated	Wheat
7	Khorsibat	36.497122°	43.229075°	25	1	Level land	Wheat
8	Telyara	36.439353°	43.259807°	35	1	L. Sloping	Wheat
9	Fadlyra	36.519004°	43.260068°	30	0	Level land	Olive
10	Khoshaba	36.623483°	43.177410°	25	9	Level land	Wheat
11	Telkef	36.507921°	43.109344°	30	0	Level land	Wheat
12	Jarghan	36.635931°	43.257653°	25	1	Undulated	Wheat
13	Sharqia	36.630771°	43.085575°	40	1	Undulated	Wheat
14	Dermati	36.471340°	43.441744°	20	11	Foot hell	Wheat
15	Mamrshan	36.666621°	43.422397°	25	1	Undulated	Wheat
16	Malon	36.583636°	43.237575°	30	5	Undulated	Barley
17	Telsqef	36.604098°	43.123645°	35	0	Level land	Wheat
18	Zenawa	36.597454°	43.511759°	80	2	Level land	Corn
19	Karmilk	36.569789°	43.531336°	70	0	Level land	Wheat
20	Doghat	36.628127°	43.134835°	30	2	Level land	Wheat
21	Mandan	36.468158°	43.517746°	50	1	Flood Plain	Wheat
22	Nveria	36.626703°	43.115903°	80	3	Undulated	Wheat
23	Bardarsh	36.484073°	43.578345°	30	3	Level land	Wheat
24	Narqizlia	36.611118°	43.286892°	30	1	Undulated	Wheat
25	Ismawa	36.558255°	43.554962°	50	4	Level land	Wheat

Laboratory Analyses: Physical Properties

- 1- Particle Size distribution of soil : Soil texture was estimated using the hydrometer method with chalcone as a dispersing agent for soil particles. The hydrometer reading was taken with the temperature of the suspension in order to adjust the hydrometer reading and determine the soil texture based on the texture triangle and according to the method described by Gee and Bauder, (1986).
- 2- Bulk Density: Estimated using the paraffin wax encapsulation method. Particle Density: Estimated for soil samples using a pycnometer. according to Black (1965).
- 3 - Soil porosity was calculated using the following mathematical relationship, as reported in (klute, 1986):

$$\% \text{ Porosity} = 1 - (\text{Bulk Density} / \text{Partial Density}) * 100 \quad (2)$$

Chemical Properties

- 1- The pH: Soil reaction of the saturated in soil extract using a pH meter as described in Richards, (1954). EC is measured in the soil extract according to Page et al., (1982).
- 2- Calcium carbonate CaCO₃: Estimated by gravimetric method using 1 N hydrochloric acid as described in Hesse, (1971).
- 3- Organic Matter: It is estimated by oxidizing organic carbon with potassium dichromate solution K₂Cr₂O₇, and then tidylating with ammoniacal ferrous sulfate solution, as stated in the method mentioned by Page et al. (1982).

Soil Erodibility Index

This is accomplished using the equation below, and the CORINE (Coordination of Information on the Environment) model is employed based on the ranges of the variables (texture type, depth, gravel coverage) Table (3) European Environment Agency. (1997). with the assistance of Arc Map software

$$SEI = \text{Soil Texture Map} * \text{Soil Depth Map} * \text{Gravel Surface cover Map} \quad (3)$$

Table 3. The classification of soil texture, depth, surface gravel cover, and soil erosion factor according to the CORINE model

Soil Erodibility Class	Class	Surface Gravel Cover (%)	Class	Soil Depth (cm)	Class	Soil Texture	Class
Non-erodible	0	–	0	–	0	Rock Outcrops	0
Low	1	>10	1	>75	1	Low erodibility (Clay, Sandy Clay, Silty Clay)	1
Moderate	2	<10	2	25–75	2	Moderate erodibility (Sandy Clay Loam, Clay Loam, Silty Clay Loam, Sandy Loam, Loamy Sand)	2
High	3	–	–	<25	3	High erodibility (Loam, Silt Loam, Silt, Sandy Loam, Sand)	3

Structural Stability Index

The physical degradation (SSI) of the studied soils are estimated based on Tesfahunegn and Gebru (2020).

$$SSI = OM * 100 / \text{Clay \%} + \text{Silt \%} \quad (4)$$

Using the Modified Global Soil Loss Equation (RUSLE) to Predict Soil Loss Amounts

To estimate A (Annual Soil Loss) we should find the Characters listed below:

First: R : *Erosivity Factor*, The Fournier Index is used according to the formula below

$$FI = \sum_{i=1}^{12} \left(\frac{pi^2}{p} \right) \quad (5)$$

Where is: Pi is Monthly rainfall (mm), P is Total annual rainfall (mm), It is based on private data from the Ministry of Agriculture/Agricultural Meteorology Centre, the website of the UK's Natural Environment Research Council (NERC) and the US Department of Energy, and is then processed in the Arc Map software.

Second: K : *Erodibility Factor*, It is estimated according to Foster et al. (1981), as this factor combines the relationship between soil texture and organic matter content, which are critical elements in influencing soil susceptibility to erosion, in addition to soil structure and permeability.

$$K = [2.1 * 10^{-4} * (12 - OM) M1.14 + 3.25 (SC - 2) + 2.5 (PC - 3)]/100 \quad (5)$$

$$M = [(100 - \% \text{ Clay}) \times (\% \text{ VFS} + \text{Silt})] \quad (6)$$

Where: OM is % organic matter content., SC ; Soil structure classification as in Table (4), PC = Soil permeability class as in Table (5)

Table 4. Soil Structure ranges in calculating the K factor according to Foster et al. (1981)

Structure Code	Soil Structure Class	Description
1	Very Fine Granular	Very small soil aggregates (<1 mm), commonly found in organic matter-rich surface soils.
2	Fine Granular	Granular aggregates (1–2 mm) with good permeability and relatively high resistance to erosion.
3	Medium or Coarse Granular	Granular aggregates (>2 mm), common in many agricultural soils.
4	Blocky, Platy, Prismatic or Massive	Includes blocky, angular blocky, platy, prismatic, columnar, or structureless soils, generally more susceptible to erosion.

Table 5. Soil permeability ranges in calculating the K factor according to Wischmeier & Smith (1978)

Permeability Class	Permeability Description	Approximate Permeability Rate (cm h ⁻¹)
1	Very Rapid	>15
2	Rapid to Moderate	5–15
3	Moderate	1.5–5
4	Slow to Moderate	0.5–1.5
5	Slow	0.13–0.5
6	Very Slow	<0.13

Third: (LS), Topographic Factor, It relies on the effect of slopes on erosion rates, and DEM digital elevation data can be used to obtain some of the equation's data with high accuracy within GIS software. Then, the Wischmeier and Smith (1978) equation is used to calculate the values for each location as follows:

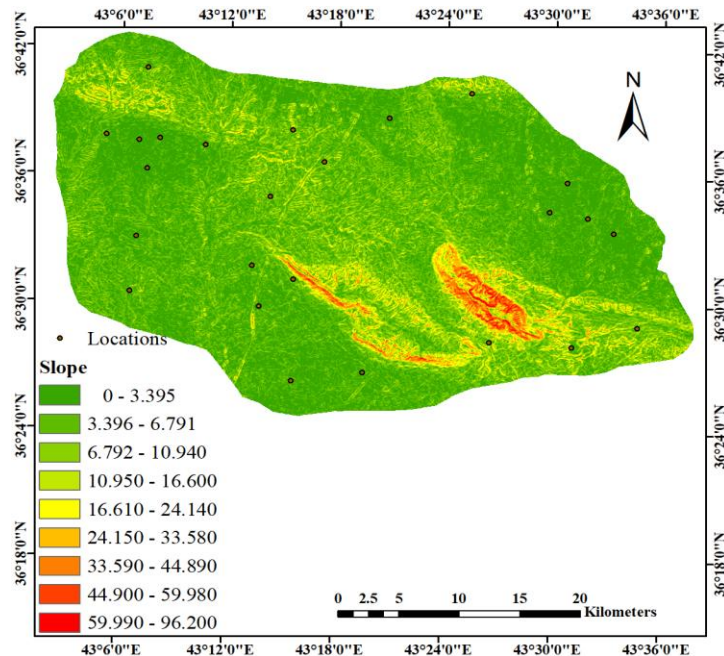


Figure 2. Spatial distribution of slope degree used in calculating the LS

$$LS = \text{Pow}[(\text{Flow Accumulation}) \times \text{Cell Size} / 22.1] \text{m} \text{Pow}[\text{Sin}(\text{Slop}) \times 0.01745 / 0.089665] \text{m} \quad (7)$$

The flow direction is obtained first using the Spatial Analyst Hydrology Flow of Direction steps, which are applied to the DEM map. Then the direction of water exit (Outlet) towards the lowest height is determined. Then the slope is estimated from the Flow Accumulation, according to Figure (2) below, to be applied later in Equation (7) for the LS factor, as reported in Moore and Burch (1986). Where: L = length of slope (m), S = degree of Slop (°) m = 0.6, 1.3, a coefficient defined in terms of the degree of Slop.

Forth: C-Factor, Cropping Management, The C factor is used to determine the effects of both land cover and land management related to different types of vegetation on soil erosion. In this study, we used the Natural Vegetation Differences Index (NDVI) to calculate the C factor. The index is first calculated from the ArcMap program, and then the equation below is applied as reported in Kouli et al. (2009).

$$NDVI = [NIR - R / NIR + R] \quad (7)$$

Where NIR = near-infrared band, R = Red band. Then, the value of the factor (C) is calculated from the following relationship in terms of NDVI, as reported in Woldemariam et al. (2018):

$$C = 1 - NDVI / 2 \quad (8)$$

Fifth: Soil practical Factor, The P factor refers to the extent to which land use management practices such as terraces, contour lines, and tillage affect erosion rates. These practices reduce soil erosion by affecting surface runoff velocity. The values of the soil conservation factor range between (0 and 1). When the value is close to (0), it indicates that the conservation measures are good, while it indicates very poor conservation measures when the values are close to (1) (Ganasri and Ramesh, 2016). Its value in this study was considered to be equal to (1) because no soil conservation measures were followed in the study area. Finally, the map of soil loss quantities (A) is prepared using the modified global equation model for soil loss RUSLE from the product of the maps of (Rainfall factor R, Soil erosion factor K, Topography factor LS, Vegetation cover factor C).

Results and Discussion

Physical Characteristics of Soil Samples

The particle size distribution, shown in Table (6), demonstrated a clear variance among the study areas, as evidenced by the differences in prevailing soil textures. The clay content varied from 22.6% to 65.8%, with the Kelkji site having the greatest at 65.8% and the Mandan sample had the lowest at 22.6%. The silt content ranged between 11.2% and 52.8%, with the Karmilk site having the highest percentage and Kelkji having the lowest. In contrast, the sand content varied from 20.0% to 50.8%, with the Telsqef site having the highest proportion and the Telkef site having the lowest. According to the texture triangle, clayey and clay loam textures were found to be the most common at the study sites, with loam, silty, and sandy clay loam textures appearing in numerous additional areas. This variation is the result of changes in the nature of the parent material and the depositional circumstances. Soil bulk density varied significantly, ranging from 0.78 to 2.02 Mg m⁻³. This variation is due to changes in soil texture, structure, and organic matter content. Moisture content varied from 4.07% to 23.65%, indicating differences in soil water retention ability based on fine particle percentage, porosity, and surrounding environmental variables. Porosity values varied significantly between the study locations, ranging from 23.5% to 70.3%. The Doghat site had the highest porosity value (70.3%), followed by the Bardarsh site (65.5%), and the Dermati site had the lowest value (23.5%), followed by the Mlon site (25.9%). This variation reflects changes in the physical qualities of the soils under study, particularly bulk density and texture.

Chemical Characteristics of Soil Samples

The soil pH measurement results indicated low variance between study locations, with values ranging between (7.5-8.0), indicating that the region's soils generally tend towards a neutral reaction, tending towards alkalinity. The electrical conductivity (EC) data show that the study sites had salinity values ranging from 0.42 to 1.10 dSm⁻¹, indicating that the soils in the region are non-saline to mildly saline. This variance is due to the influence of current environmental circumstances, the composition of the parent material, and the amount of soluble salt accumulating in the soil.

Organic matter contents were consistent throughout research sites, ranging from 13.11 to 22.78 g kg⁻¹. Most semi-arid soils show a decline in organic matter content, indicating deterioration. A lack of organic matter causes poor soil structure and lower stability of soil aggregates, as well as decreased cation exchange capacity and water and nutrient retention, making the soil more susceptible to water erosion. Furthermore, a decrease in organic matter reduces soil resistance to rainwater runoff and increases the likelihood of crust formation and surface runoff, which accelerates land degradation. These findings are consistent with those of FAO and ITPS (2020), which indicated that declining organic matter is a key indicator of soil degradation and deteriorating agricultural land quality.

Calcium carbonate values ranged from 136 to 372 g kg⁻¹, reflecting variations in the nature of the parent material, environmental conditions, and the degree of calcareous precipitation within the soil profile. The highest calcium carbonate value was recorded in the soils of the Jarghan, followed by the Mandan site at 364 g kg⁻¹. It has been observed that the high calcium carbonate content in some locations is related to the nature of the predominant calcareous parent material in the area, as well as the influence of arid and semi-arid climatic conditions that limit leaching processes and promote the precipitation and accumulation of calcareous compounds in the soil. Furthermore, low rainfall and high evaporation rates cause calcium to remain precipitated in the soil profile rather than being transferred to lower depths.

Conversely, the low calcium carbonate content in some locations may be due to variations in the nature of the deposits or to the soil being subjected to relative leaching processes that have reduced the accumulation of calcareous compounds compared to other locations. Variations in soil texture and drainage may also play a role in the different distribution of carbonates within the soil. High levels of calcium carbonate lead to increased soil alkalinity and reduced decomposition and accumulation of organic matter. Conversely, some sites with relatively low CaCO₃ levels have shown a significant increase in organic matter, indicating a relative improvement in environmental conditions conducive to its accumulation.

Table 6. Physical and chemical properties of the study area

No	Location	Particle Distribution		Size	Texture	Bulk Density	Particle Density	Porosity	pH	EC	O.M	CaCO ₃
		Sand	Silt	Clay		Mg.m ⁻³		%		dSm ⁻¹		gkg ⁻¹
1	En bakri	21.0	23.2	55.8	C	1.53	2.65	42.4	7.5	0.63	21.42	300
2	Shekan	27.0	25.2	47.8	C	1.23	2.65	53.5	7.7	0.62	22.08	316
3	Baryma	23.0	29.2	47.8	C	1.21	2.65	54.3	7.6	0.79	22.53	324
4	Bashiqia	27.0	39.2	33.8	CL	1.62	2.65	38.8	7.6	0.71	19.36	320
5	Kelkji	23.0	11.2	65.8	C	1.23	2.65	53.7	7.8	0.91	15.52	164
6	Batnaya	30.8	36.2	33.0	CL	1.36	2.65	48.6	7.6	0.54	19.73	352
7	Khorsibat	27.8	47.0	25.2	L	1.74	2.65	34.2	7.6	0.44	14.14	340
8	Telyara	31.8	43.0	25.2	L	1.64	2.65	38.3	8.0	0.86	22.60	328
9	Fadlya	28.8	35.8	35.4	CL	1.62	2.65	38.9	7.7	1.09	20.81	356
10	Khoshaba	30.0	32.8	37.2	CL	1.47	2.65	44.4	8.0	0.62	13.11	180
11	Telkef	20.0	48.6	31.4	SiCL	1.84	2.65	30.4	7.9	1.10	21.18	328
12	Jarghan	36.0	32.0	32.0	CL	1.94	2.65	26.7	8.0	0.9	21.08	372
13	Sharqia	38.8	29.2	32.0	CL	1.73	2.65	34.6	7.7	0.91	20.71	336
14	Dermati	32.8	33.2	34.0	CL	2.03	2.65	23.5	7.5	0.81	16.21	228
15	Mamrshan	22.2	43.0	34.8	CL	1.44	2.65	45.8	7.7	0.82	16.18	292
16	Malon	41.6	33.2	25.2	L	1.96	2.65	25.9	7.8	1.01	13.80	212
17	Telsqef	50.8	20.0	29.2	SCL	1.80	2.65	31.9	7.6	0.76	20.36	260
18	Zenawa	36.6	35.4	28.0	CL	1.94	2.65	26.7	7.6	0.80	18.56	140
19	Karmlk	22.0	52.8	25.2	SiL	1.24	2.65	53.3	7.6	0.65	19.95	192
20	Doghat	44.0	30.2	25.8	L	0.79	2.65	70.3	7.8	0.62	21.4	136
21	Mandan	33.0	44.4	22.6	L	1.42	2.65	46.3	7.7	0.42	15.52	364
22	Nveria	39.4	29.6	31.0	CL	1.64	2.65	38.2	7.8	0.60	18.50	240
23	Bardarsh	41.4	32.2	26.4	L	0.92	2.65	65.5	7.7	0.52	20.36	164
24	Narqizlia	45.4	28.2	26.4	L	1.37	2.65	48.2	7.6	0.73	22.78	204
25	Ismawa	38.8	36.0	25.2	L	1.11	2.65	58.1	7.6	0.81	21.40	224

Soil Erodibility Index (SEI)

In order to create a spatial distribution map of the soil erosion index, as illustrated in Figures (3, 4, 5, 6), the results of equation (3) and table (3), which shows the percentage of gravel distribution for each location and soil depth in the Materials and Methods table (2) of Work section, were transformed into a map using the (IDW) Inverse Distance Weighting algorithm to determine the spatial distribution of each factor within the equation. According to Table (7) and Figure (3), clay soil type (C), which is the least erodible, was localised in small, dispersed patches and covered an area of 107.205 km², or just 8.4% of the region's total area. Its high clay particle content, which improves soil structure stability and grain cohesion, is responsible for its low Erodibility. With an area of 868.455 km², or 68.1% of the total area, the second, intermediate soil type (CL, SiCL, SCL) was the most common and was categorized as having moderate Erodibility. This broad distribution suggests that the majority of the soil in the research area has a moderate resistance to erosion, where grain separation under the effect of erosion agents is balanced with water retention qualities.

Table 7. Percentage and area of Texture classes in the study area

Class	Texture Class	Area (km ²)	Percentage (%)	Erodibility Classification
1	C	107.205	8.4	Low Erodibility
2	CL, SiCL, SCL	868.455	68.1	Moderate Erodibility
3	L, SiL	299.077	23.5	High Erodibility
Total		1274.737	100	

The third group (L, SiL) is very erodible and accounts for around 299,077 km², or 23.5% of the total area. This category was mostly concentrated in the east and southwest. Its high erosion susceptibility is related to the presence of silt and fine sand, as well as the low clay concentration, which causes the grains to separate and transport by rainwater or wind.

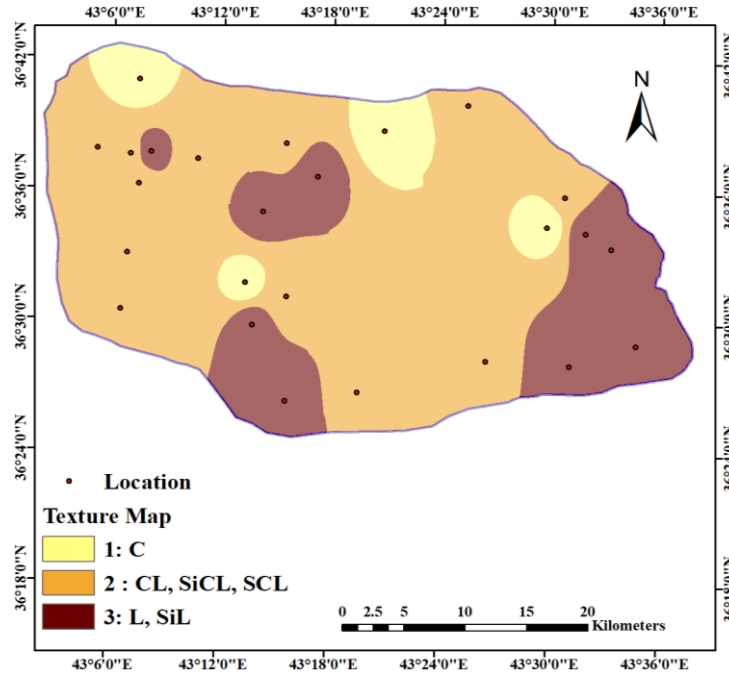


Figure 3. The spatial distribution of texture in the study area.

Soil Depth

Figure (4) shows that soils with a depth of (>75 cm), classified as having low erosion susceptibility, occupied an area of (93,444) km², equivalent to only (7.3%) of the total area (Table 8). These soils were found in limited and scattered areas, particularly in the northeastern parts and some northwestern locations. Their low erosion susceptibility is attributed to the large thickness of the soil profile, which provides a higher capacity for rainwater absorption and reduces surface runoff, in addition to increasing the soil volume available for root anchorage and improving stability. Medium-depth soils (25–75 cm) were the most widespread, covering an area of (675,808) km², representing (53.0%) of the region's area, and were classified as having medium erosion susceptibility. This widespread nature indicates that the majority of the region's land has a medium-thickness soil profile that provides moderate resistance to erosion processes. However, this resistance may decrease in areas with steep slopes or sparse vegetation cover.

Table 8. Percentage and area of Depth classes in the study area

Class	Texture Class	Area (km ²)	Percentage (%)	Erodibility Classification
1	75 >	93.444	7.3	Low Erodibility
2	2575 –	675.808	53.0	Moderate Erodibility
3	25 <	505.485	39.7	High Erodibility
Total		1274.737	100	

Gravel Cover

Figure (5) and Table (9) show that areas with high stone cover ($>10\%$) covered an area of 599,745 km² (47.0%), concentrated in the eastern and northwestern parts, providing better protection for the soil from erosion. In contrast, areas with low stone cover ($<10\%$) covered an area of 674,992 km² (53.0%), spread across most of the central, southern, and western parts, increasing soil vulnerability to erosion due to reduced natural protection. Overall, the results indicate that more than half of the study area has limited stone cover, increasing its sensitivity to erosion according to the CORINE classification.

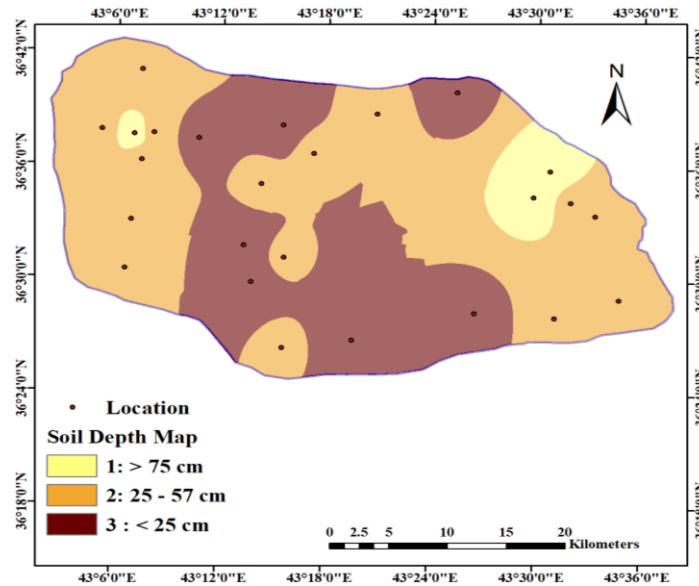


Figure 4. The spatial distribution of Depth in the study area.

Table 9. Percentage and area of Cover classes in the study area

Class	Texture Class	Area (km ²)	Percentage (%)	Erodibility Classification
1	10 >	599.745	47.0	Complete Soil Protection
2	10 <	674.992	53.0	Low Soil Protection
Total		1274.737	100	

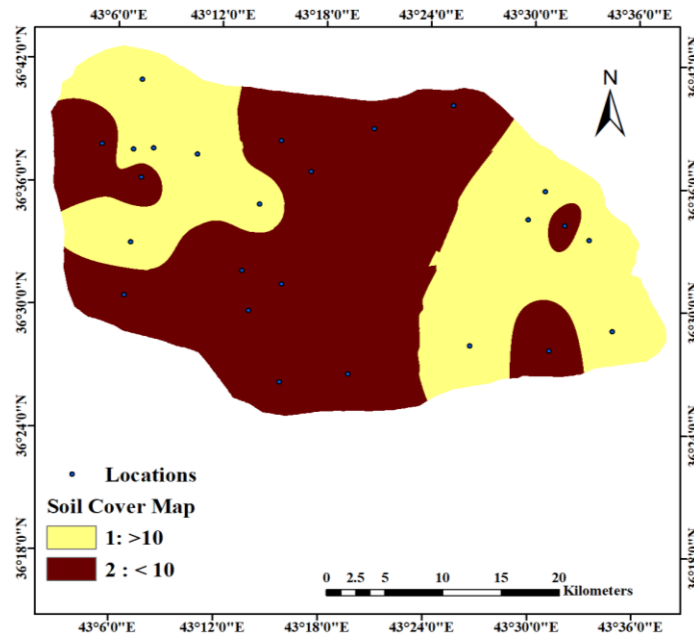


Figure 5 The spatial distribution of Gravel Cover in the study area.

The SEI values were ultimately obtained by multiplying the three maps together. As shown in Table 10, the third, highly eroded soil class (>6) was dominant, covering an area of 1013.409 km², representing 79.5% of the total study area, as illustrated in Figure 6. This class was prevalent in most of the central, southern, and western

parts of the area. In contrast, the intermediate class (3–6) covered approximately 224.136 km² (17.6%), concentrated in the northeastern and northwestern parts. The sparse class (0–3) was limited to 37.192 km² (2.9%) and appeared in limited and scattered areas, specifically in the locations of Ain Bakri, Nafiriya, Zinawa, and Kelkji. These results indicate that the majority of the study area has a high susceptibility to erosion due to the influence of the soil's natural properties, making it more sensitive to soil loss according to the CORINE methodology.

Table 10. Percentage and area of SEI in the study area

Class	Texture Class	Area (km ²)	Percentage (%)	Erodibility Classification
1	0 - 3	37.192	2.9	Low Erodibility
2	3 - 6	224.136	17.6	Moderate Erodibility
3	> 6	1013.409	79.5	High Erodibility
Total		1274.737	100	

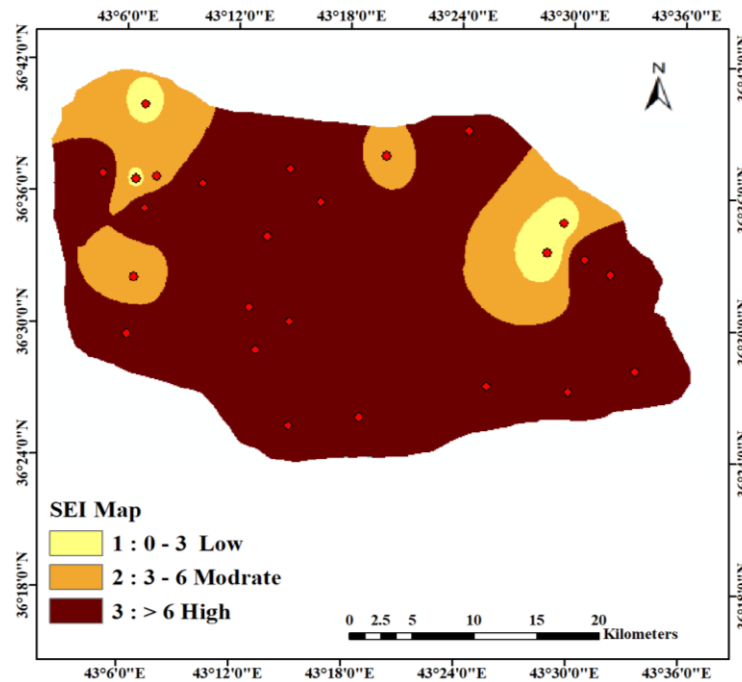


Figure 6. The spatial distribution of SEI in the study area.

Annual Soil Loss

Erosivity Factor

According to the Fournier index, the factor (R), representing the rate of soil loss due to the impact of raindrops, was calculated by determining the amount of rainfall in the study area based on the established monthly rainfall data. However, the calculation of equation (5) relied on the sum of the squares of the rainy months divided by the total annual rainfall. Figure (7) shows the spatial distribution and variation of rainfall rates during the rainy year in the study area, based on the rainfall data collected in (NCF) format and then transferred to ArcMap software for data processing within the ArcToolbox. The rainfall ranged from (181) mm/year in the southern and southeastern parts to (237) mm/year in the northwestern parts of the study area, with the highest rates recorded in the En bakri area.

The rainfall factor (R-factor) map in figure (8) clearly indicates an increase from south to north. Because of the greater intensity and influence of rainfall in those areas, the R-factor values steadily rise towards the northern portions of the research area. Low values in MJ.mm.ha⁻¹.h⁻¹ (54.4–64.4) The southern and southeastern regions had the highest concentrations of •yr⁻¹, whilst the majority of the center region had medium values (64.41–74.4). The highest values were found in the northern and northwest strip. This gradient is due to increased rainfall with higher topographic elevations in the northern half of the research area, which results in higher kinetic energy of raindrops and enhanced surface runoff capacity for separating and moving soil particles. These findings also show that the northern regions are more vulnerable to water erosion than the southern regions, particularly when

a high R factor coincides with low vegetation cover or weak soil resistance to erosion, necessitating the implementation of soil and water conservation measures in these areas in order to reduce soil loss and maintain productivity.

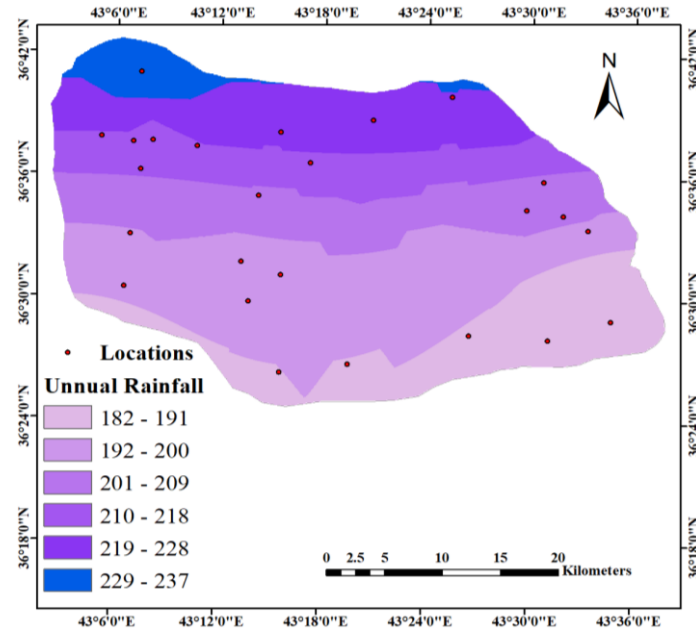


Figure 7. Annual rainfall rates distribution for the period (2015-2025)

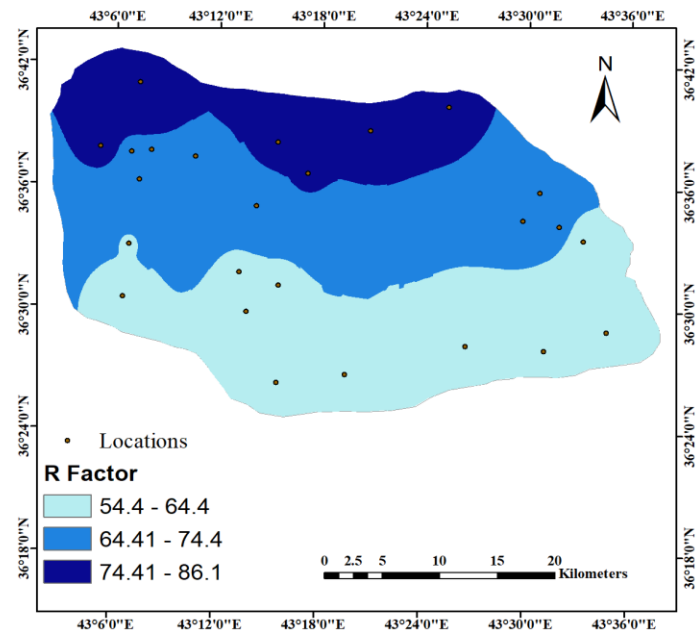


Figure 8. Spatial distribution of Erosivity Factor (R)

Table (11) shows the results of the rainfall erosion potential. The first class occupied the largest area, at (502.334) km² (39.41%), followed by the third class at (30.78%), and then the second class at (29.81%). These results indicate that the study area has a rainfall erosion potential ranging from moderate to high, due to variations in rainfall intensity and spatial distribution. These results are consistent with the CORINE concept, which considers climate, particularly rainfall energy, as a major determinant of environmental sensitivity to erosion. They also align with the R factor in the RUSLE model, which expresses the Erosivity potential of rainfall. Higher R values lead to increased energy of raindrops and surface runoff, thus increasing the likelihood of soil particle separation and transport, especially in areas with steep slopes or limited vegetation cover. Therefore, areas in the highest class require greater attention when developing soil management and conservation measures to reduce the risks of water erosion. These results are consistent with the findings of Samara and Khalid (2021).

Table 11. Erosivity factor classes in the study area

Class	Texture Class	Area (km ²)	Percentage (%)
1	64.4 - 54.4	502.334	39.41
2	74.4 - 64.41	380.098	29.81
3	86.1 - 74.41	392.304	30.78
Total		1274.737	100

Erodibility Factor

The calculation of the K factor was based on the components (M, OM, SC, PC) according to Equation (5) , and their values are shown in Table (2) and (3). The results in Table (12) show that the study area is predominantly characterized by high soil erosion susceptibility. The high Erodibility soils occupied the largest area, covering (554.828) km², or (43.53%) of the total area. This was followed by the moderate Erodibility soils, covering (375.464) km² (29.45%), and then the low Erodibility soils, covering (344.445) km² (27.02%). Figure (9) illustrates that soils with high Erodibility are mainly found in the southern and southeastern parts and some central areas, while soils with lower Erodibility are concentrated in the northern and northeastern parts. These results are consistent with what Esfandiar et al. (2018) stated, as he explained that high K-factor values reflect increased soil susceptibility to separation and transport by rainwater due to weak structural stability and low soil resistance to erosion.

These results indicate how soil characteristics, including texture, organic matter content, structure, and permeability, affect the K factor. Soils with little organic matter content and weak structure are more susceptible to erosion, whereas more cohesive and structurally robust soils are less affected. These findings are in line with the RUSLE model idea, which was introduced by Renard et al. (1997) as a measure of the inherent sensitivity of soil to erosion and precipitation transport. Additionally, they are consistent with the CORINE approach, which highlights the importance of soil qualities in determining environmental sensitivity to water erosion.

Table 12. Erosivity factor classes in the study area

Class	Texture Class	Area (km ²)	Percentage (%)	Erodibility Classification
1	0.25 - 0.04	344.445	27.02	Low Erodibility
2	0.30 - 0.21	375.464	29.45	Moderate Erodibility
3	0.41 - 0.31	554.828	43.53	High Erodibility
Total		1274.737	100	

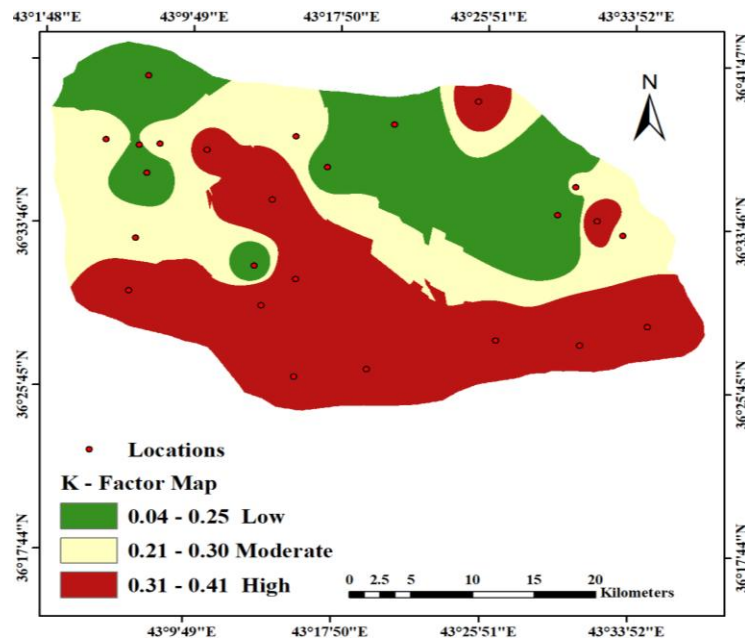


Figure 9. Spatial distribution of Erodibility Factor (K)

Topographic Factor LS- Factor

The results for LS- Factor, which cover an area of 1088,958 km², or 85.43% of the study's entire area, indicate the dominance of the second class with a moderate influence, as shown in Table 13 and Figure 10. The high-impact class, on the other hand, was restricted to a 56,864 km² (4.46%) area. This indicates that the majority of the region has limited slope lengths and fairly steep slopes, which means that topography has a moderate effect on water erosion. There are few places with steeper slopes where the high impact is focused. These results are in line with those of Moore and Burch (1986) and Panda et al. (2005), who showed that the LS factor rises with slope length and steepness, increasing surface runoff energy and soil erosion risk. On the other hand, topography that contributes less to erosion processes is reflected in low and medium values.

Table 12. Topographic factor classes in the study area

Class	Texture Class	Area (km ²)	Percentage (%)	Erodibility Classification
1	1.44 - 0.19	128.810	10.11	Low Topographic Effect
2	2.70 - 1.45	1.088.958	85.43	Moderate Topographic Effect
3	3.95 - 2.71	56.864	4.46	High Topographic Effect
Total		1274.737	100	

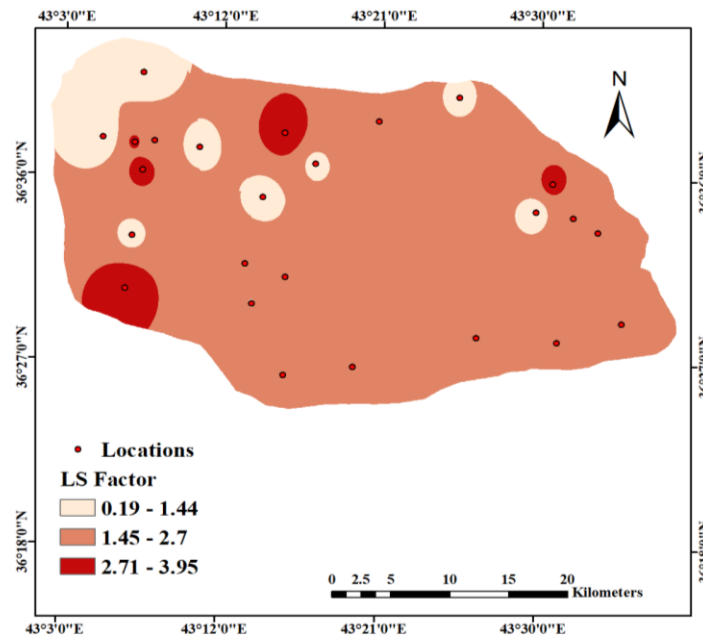


Figure 10. Spatial distribution of Topographic Factor (LS)

Cropping Management C factor

The spatial distribution of the C Factor values, which varied from (-0.30 to 0.65), is shown in Figure (11) and clearly shows the variation in vegetation density within the study area. While values between 0.31 and 0.50 dominated most of the region, indicating a degree of moderately dense vegetation, negative values were found in a small number of locations that represented watercourses or non-vegetated surfaces. Additionally, scattered areas which indicate areas with dense, highly active vegetation—recorded values higher than 0.50. These results are in line with those of Xue and Su (2017), who explained that low NDVI values indicate little to no vegetation cover, which increases the soil surface's susceptibility to runoff and erosion, while high values reflect increased biomass and photosynthetic activity of plants.

Based on the values of the Vegetation Differences Index, the vegetation cover factor was calculated according to Equation (17) in the Materials and Methods section. Figure (12) and the results in Table (13) for the C-factor show that the Very High Soil Protection and High Soil Protection varieties were the most widespread, covering an area of 349.052 km² (27.38%) and 352.735 km² (27.67%) respectively, totaling 55.05% of the study area. This indicates that the vegetation cover provides a high level of protection in more than half of the area. In contrast, the Very Low Soil Protection variety occupied only 111.002 km² (8.71%), representing areas with limited vegetation cover and therefore the most vulnerable to water erosion. These results are consistent with what Xiong et al. (2023) showed, as they explained that low C factor values reflect increased effectiveness of vegetation cover in protecting the soil, while high C factor values are associated with low efficiency of vegetation cover and a high risk of water erosion.

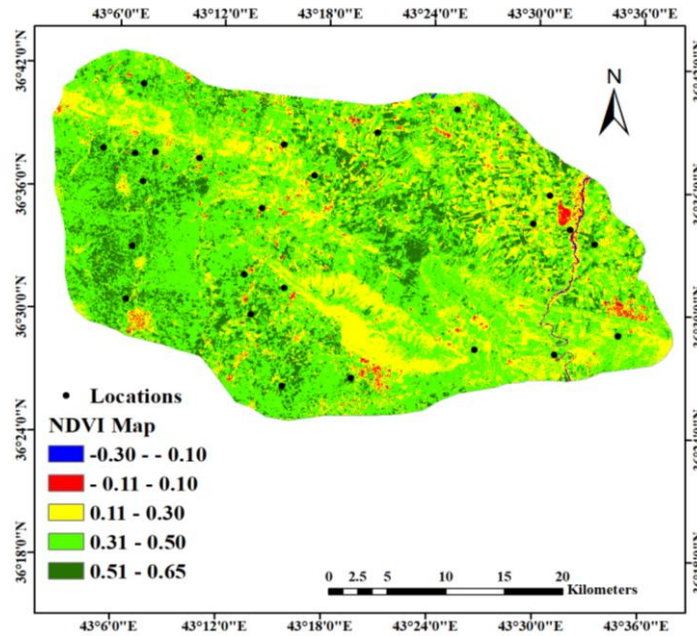


Figure 11. Spatial distribution of NDVI of the study area

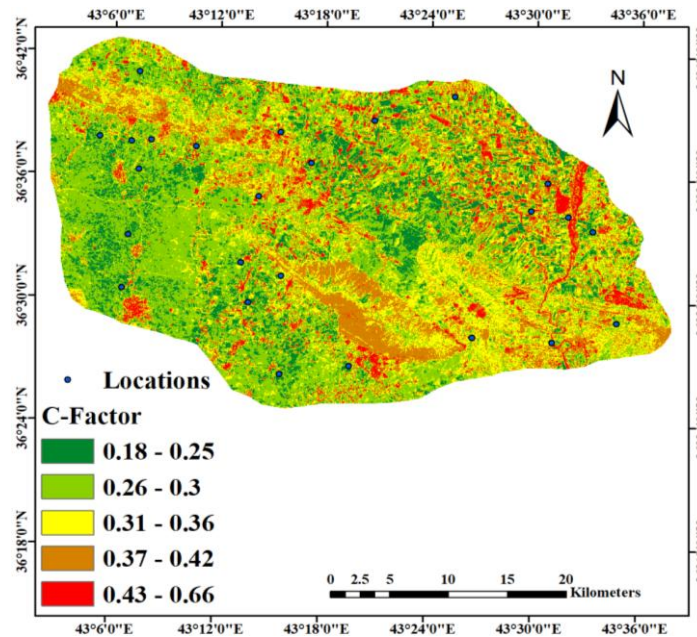


Figure 12. Spatial distribution of Cropping Management Factor (C)

Table 13. Cropping management factor classes in the study area

Class	Texture Class	Area (km ²)	Percentage (%)	Erodibility Classification
1	0.25 - 0.18	349.052	27.38	Very High Soil Protection
2	0.30 - 0.26	352.735	27.67	High Soil Protection
3	0.36 - 0.31	252.609	19.82	Moderate Soil Protection
4	0.42 - 0.37	209.339	16.42	Low Soil Protection
5	0.66 - 0.43	111.002	8.71	Very Low Soil Protection
Total		1274.737	100	

Soil Management and Practice Factor (P-Factor)

The Soil Conservation Factor (P) represents the impact of agricultural and management practices used by most farmers to reduce water erosion, such as contour plowing on sloping areas, strip farming, and terracing, to decrease runoff velocity and increase water infiltration into the soil, thus reducing soil loss. Accurate data for

the study area indicating the widespread application of organized soil conservation practices were not available; therefore, a value of $P = 1$ was adopted, representing the baseline condition where no supportive erosion control measures are in place. This aligns with the RUSLE model methodology, which states that P equals 1 in the absence of soil conservation practices, while its value decreases as the effectiveness of these practices in reducing runoff and soil loss increases, as reported by Renard et al. (1997).

After completing the calculation of all the indicators, the annual soil loss rate (the global equation for soil loss) was calculated. We were able to estimate and calculate it through the ArcMap program by multiplying the four indicators as maps to obtain a map of its own. Its results were close to the computational data for each point after converting it to point values representing the locations of the (25) study area according to Table (14).

Table 13. Values used to calculate the annual soil loss rate for the study area

No.	Location	Rainfall (mm)	R Factor	SC	PC	Texture Factor (m)	K Factor	LS Factor	C Factor	A (t ha ⁻¹ yr ⁻¹)
1	En bakri	232	86.1	3	3	1865.24	0.14	0.57	0.26	1.79
2	Shekan	223	79.4	2	2	2568.24	0.13	1.82	0.45	8.45
3	Baryma	198	62.7	3	2	2829.24	0.18	2.42	0.23	6.28
4	Bashiq	191	58.4	4	3	3985.24	0.33	1.66	0.37	11.84
5	Kelkji	204	66.7	2	2	1101.24	0.04	0.93	0.3	0.74
6	Batnaya	200	63.9	3	2	3899.4	0.27	1.12	0.24	4.64
7	Khorsibat	195	61.0	3	3	5161.2	0.41	1.43	0.4	14.31
8	Telyara	191	58.3	2	2	5086.4	0.32	1.76	0.28	9.19
9	Fadly	197	62.5	4	3	3992.28	0.33	1.69	0.32	11.15
10	Khoshaba	214	73.7	3	3	3755.44	0.3	1.07	0.27	6.39
11	Telkef	192	59.1	3	2	4500.16	0.31	3.95	0.25	18.09
12	Jarghan	221	78.1	3	3	3808.0	0.28	3.88	0.43	36.48
13	Sharqia	218	76.1	3	3	3617.6	0.27	0.19	0.24	0.94
14	Dermati	190	58.0	3	3	3841.2	0.3	2.19	0.25	9.53
15	Mamrshan	227	82.5	3	3	4042.4	0.31	1.36	0.28	9.74
16	Malon	208	69.5	3	3	4577.76	0.36	0.93	0.29	6.75
17	Telsqef	211	71.1	3	2	3044.4	0.2	3.27	0.24	11.16
18	Zenawa	208	69.4	2	2	4132.8	0.26	3.11	0.35	19.64
19	Karmilk	202	65.2	2	2	5295.84	0.34	1.85	0.24	9.84
20	Doghat	215	74.3	3	2	3947.44	0.27	1.42	0.27	7.69
21	Mandan	186	55.2	2	2	5139.36	0.35	2.01	0.28	10.87
22	Nveria	215	74.1	3	2	3560.4	0.25	2.87	0.33	17.55
23	Bardarsh	184	54.4	3	3	3989.12	0.3	2.17	0.22	7.79
24	Narqizlia	217	75.6	2	2	3768.32	0.22	1.24	0.26	5.36
25	Ismawa	198	62.6	2	2	4338.4	0.27	2.46	0.3	12.47

Table (14) and Figure (13) show the results of the annual soil loss rate, The medium risk class for erosion was the most common, with an area of 642,254 km², representing 50.38% of the total area. The low risk class covered 610,854 km² (47.92%), whereas the high risk class only covered to 21,629 km² (1.70%). These results show that most of the study area experiences low to medium soil loss rates, which reflects the positive impact of plant cover and the region's moderate topography. High loss rates were concentrated in a few places with increased slope and low vegetation cover, particularly at Jarghan, Zenawa, and Telkef. These results are consistent with those of Kumar et al. (2022), who found that spatial variability in the annual soil loss rate in the RUSLE model is caused by the interaction of rainfall, soil erosion ability, topography, and vegetation cover, and that areas with higher vegetation cover also moderate slopes typically have low to moderate loss rates. They also agree with the results of Sidharthan et al. (2024), who found that including RUSLE elements into a GIS environment gives an accurate and reliable spatial representation of erosion-risk areas and is helpful in the identification of priority locations for soil conservation measures.

Table 14. Classification of Annual soil loss, areas, and percentage within the study area.

Class	Texture Class	Area (km ²)	Percentage (%)	Erodibility Classification
1	10.0 - 0.601	610.854	47.92	Low Erosion Risk
2	20.0 - 10.1	642.254	50.38	Moderate Erosion Risk
3	38.6 - 20.1	21.629	1.70	High Erosion Risk
Total		1274.737	100	

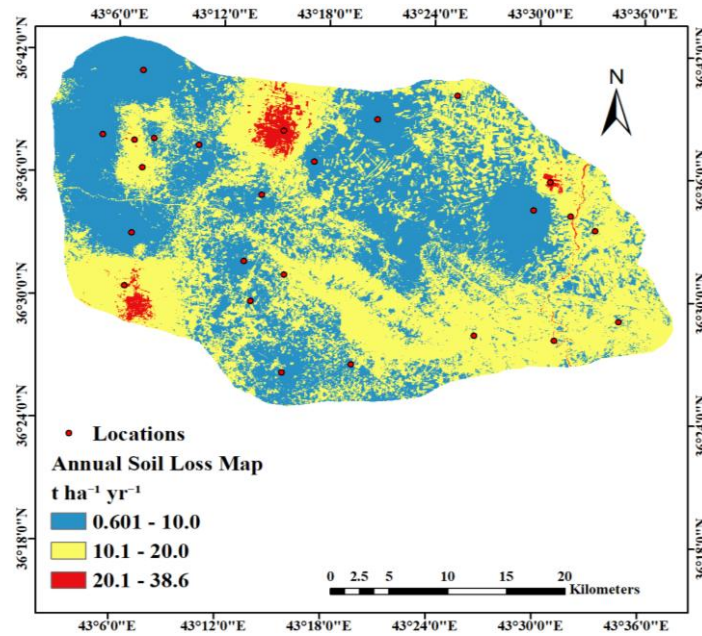


Figure 13. Spatial distribution of annual soil loss in the study area

Conclusion

The results of the RUSLE model showed that the topographic factor (LS) was one of the most influential factors in the distribution of water erosion, as the medium topographic influence category occupied about 85.43% of the study area, while high LS values were associated with increased soil loss rates in steep areas. Also The results of the Normalised Difference Vegetation Index (NDVI) and the C-factor showed that increasing the density of vegetation cover effectively contributed to reducing the impact of raindrops and the speed of surface runoff, as the very high and high protection categories constituted more than half of the area, resulting in a reduction in erosion rates in most parts of the study area.

The combination of remote sensing techniques and geographic information systems with the RUSLE model has proven extremely effective in characterising the spatial variability of erosion factors and producing accurate maps of the annual rate of soil loss, providing a solid scientific foundation for sustainable planning and land management in northern Nineveh Governorate.

Recommendations

The study recommends conducting long-term time-based monitoring of water erosion rates using multi-time satellite data and modern digital models, with the aim of tracking spatial and temporal changes in soil loss, and assessing the impact of climate change and land-use change on the future development of erosion.

The study recommends expanding the use of artificial intelligence and machine learning technologies, as well as remote sensing and geographic information systems, to improve the accuracy of water erosion modelling and predicting areas most vulnerable to future degradation, thereby contributing to decision-making and sustainable land resource management.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

* The authors declare that this study complies with scientific research ethics and that all data were collected, analyzed, and reported honestly and transparently.

Conflict of Interest

* The author declares that there is no conflict of interest.

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