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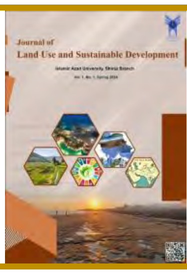

Original Research Article

Impact of Land Management Practices and Vegetation Cover on Soil Erosion in Mashhad Plain, Northeast of Iran

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Abstract

Background and Objectives: This study investigates the effects of land management practices and vegetation cover on soil erosion rates in the Mashhad Plain, Northeast Iran.

Methods: By employing the Universal Soil Loss Equation (USLE) and Geographic Information Systems (GIS) for spatial analysis, the research reveals significant variability in soil erosion risks based on agricultural practices.

Findings: Results indicated that conservation practices notably reduce soil loss rates across various crops. For instance, wheat fields experienced a 41.2% decrease in soil loss from 10.80 to 6.35 tons per hectare per year (t ha^{-1} yr^{-1}), while sugar beet, potato, maize, and alfalfa saw reductions of 34.9%, 33.4%, 37.3%, and 35.1%, respectively. The study also identified high soil erodibility in 5.37% of the area, with K-factor values ranging from 0.390 to 0.485 t ha^{-1} MJ^{-1} mm^{-1}, and noted improved soil stability under alfalfa cultivation due to its perennial nature. Furthermore, the integration of USLE's C and P factors within a GIS framework elucidates the substantial impact of management practices and vegetation changes on soil erosion.

Conclusion: The research advocates for a meticulous evaluation of agricultural strategies, aligning them with the unique geographical and vegetative attributes of the area, to enhance soil preservation and productivity. This comprehensive approach contributes to the prioritization of watershed interventions, ultimately fostering sustainable development in rural landscape management.

Running Title: Impact of Land Management Practices and Vegetation Cover on Soil Erosion

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37	9	6

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Introduction

Soil erosion presents a formidable environmental challenge, undermining agricultural productivity, water quality, ecosystem health, and reducing the storage capacity of rivers and reservoirs. This phenomenon, exacerbated by human activities such as agriculture, deforestation, and urbanization, necessitates effective management and conservation practices to mitigate its impacts (Abeysingha and Ray 2025; Lal, 2001; Pimentel and Kounang, 1998; Mahgoub *et al.,* 2024). Recognizing the severity of soil loss due to erosion, this article emphasizes the application of the Universal Soil Loss Equation (USLE) model, complemented by Geographic Information System (GIS) technology, to evaluate and manage soil erosion dynamics efficiently. The USLE model, a cornerstone in erosion prediction and conservation planning, integrates various factors rainfall erosivity (R), soil erodibility (K), slope (LS), cover-management (C), and support practices (P) to estimate the extent of sheet and rill erosion. Its adaptation to GIS technology has revolutionized the ability to survey, identify, and monitor erosion-prone areas, providing a spatially detailed understanding of soil loss factors across diverse landscapes (Wischmeier and Smith, 1978; Pandey *et al.,* 2007). Through the GIS-based integration of these factors, the USLE model serves as an index method, providing a detailed spatial distribution of soil erosion risk and enabling the prioritization of watersheds for targeted conservation efforts (Dickinson and Collins, 1998; Baban and Yusof, 2001). Advancements in modeling techniques have further refined the accuracy of soil erosion estimates (González-Romero *et* al. 2023). Moreover, the integration of USLE's C and P factors with GIS tools has illuminated the dynamic influence of land management and erosion control practices, revealing variations in soil loss that inform targeted conservation strategies (Amaral *et al.,* 2020; Bagarello *et al.,* 2020; Di Stefano *et al.,* 2019). This comprehensive approach to soil erosion assessment emphasizes the need for a meticulous evaluation of management practices across various crops and environments (Hatefard *et al.,* 2021). By analyzing how different practices impact the USLE model's factors, particularly the cover-management (C) factor, this study underlines the importance of selecting and optimizing agricultural strategies to curb soil erosion effectively. While specific, up-to-date references may be pending, the existing body of research underscores the significant role of ongoing studies in enriching soil conservation efforts (Benzougagh *et al.,* 2022). The present study aimed to evaluate the factors affecting soil erosion and produce a soil loss map using the GIS-based Universal Soil Loss Equation (USLE) model in Mashhad-Chenaran plain, northeast Iran. The objective of this study is to assess the impacts of crop factor (C-factor) and management practices (P-factor) on soil erosion in the Mashhad plain, northeast of Iran.

The use of GIS technology in conjunction with the USLE model not only aids in the precise mapping and analysis of soil erosion risks but also facilitates the implementation of conservation practices that significantly mitigate erosion. Recognizing the critical role of the P factor in conservation, recent research has highlighted how targeted measures can lead to sustainable land management and soil conservation outcomes, demonstrating the effectiveness of integrated approaches in combating erosion (Gilsha Bai *et al.,* 2024; Songara *et al.,* 2024; Hagos *et al.,* 2023; Chand and Lata, 2023). Addressing the specific condition of soil erosion in Iran necessitates delving into the prevalent challenges and dynamics shaped by the country's unique geographic, climatic, and agricultural characteristics. Iran is marked by diverse climatic zones ranging from arid and semi-arid to forested and coastal, which influences the soil erosion rates across different regions. The country faces significant soil erosion issues primarily due to factors such as intensive agricultural practices, deforestation, improper use of water resources, and overgrazing. These activities disturb the soil surface, reducing its cohesiveness and making it more susceptible to erosion by water and wind. In terms of quantifiable data, the annual soil loss from water erosion in Iran is estimated to be significantly high, with reported rates suggesting a considerable variability across different provinces due to variations in rainfall intensity, land use/cover, topography, and soil characteristics. The application of the USLE model, combined with Geographic Information System (GIS) tools in Iran, provides valuable insights into soil erosion dynamics, allowing for a detailed spatial analysis of erosion risks and the effectiveness of various land management practices. This approach assists in identifying priority areas for conservation efforts and in formulating strategies to mitigate soil loss, emphasizing the importance of sustainable agricultural practices and land management in reducing erosion (Bagherzadeh, 2014; Pandey *et al.,* 2007; Karami *et al.,* 2018).Research on soil erosion in Iran not only underscores the challenges posed by natural and human-induced factors but also points towards the potential of integrated technological and management interventions in addressing this issue. While country-wide comprehensive data on soil erosion may vary, localized studies and analyses offer a window into understanding the severity of soil erosion in Iran and the efforts being made to combat it. Given the scope and variability of soil erosion across Iran, it's crucial to continue monitoring, research, and the implementation of region-specific soil conservation measures (Mohammadi, 2021). Bagherzadeh (2014) classified the annual soil erosion in the Mashhad plain into five categories, ranging from 0–0.25 t/ha yr along the trough line of the Kashaf-rud plain to 2–10 t/ha yr in the hills and pediment plains, where higher erosion rates were observed. Integrating GIS and remote sensing with traditional conservation practices can provide a balanced approach to managing soil erosion effectively, contributing to the sustainability of Iran's natural resources and agricultural productivity. The convergence of the USLE model, GIS technology, and advanced erosion modeling techniques underscores the indispensability of integrating reliable models with sustainable agricultural practices for comprehensive soil erosion management (Mohammadi *et al.,* 2021; Kabolizadeh *et al.,* 2022). By delineating effective management and conservation strategies, this article contributes to the advancement of soil conservation and sustainable agricultural practices, steering efforts towards environmental preservation and the achievement of sustainable development goals.

The research was carried out in the Mashhad plain, located in the Khorasan-e-Razavi province in northeastern Iran, covering an area of 9974.16 km², located between 35° 59′ N to 37° 04′ N and 58° 22′ E to 60° 07′ E. The region encompasses terrains below 1,500 meters above sea level (asl), with elevation ranges from 900 to 1,500 meters asl, predominantly above 1,200 meters asl. The plain's general landscape stretches from northwest to southeast, spanning approximately 160 km. The physiographic trend of the study area extends in a NW–SE direction surrounded between two mountainous zones of Kopetdagh at northward and Binaloud at southward as identified through satellite imagery and ground verification (Fig. 1, 2). Geologically characterized by its quaternary period alluvial sediments. Predominant land utilization types in the region include irrigated Wheat, Maize, Potato, Alfalfa, and Sugar beet cultivation. Climatically, it is classified as semi-arid, with an average annual rainfall of 222.1 mm and a mean annual temperature of 15.8 °C, where March is noted as the wettest month averaging 44.8 mm of precipitation, and September as the driest, with 1.2 mm.

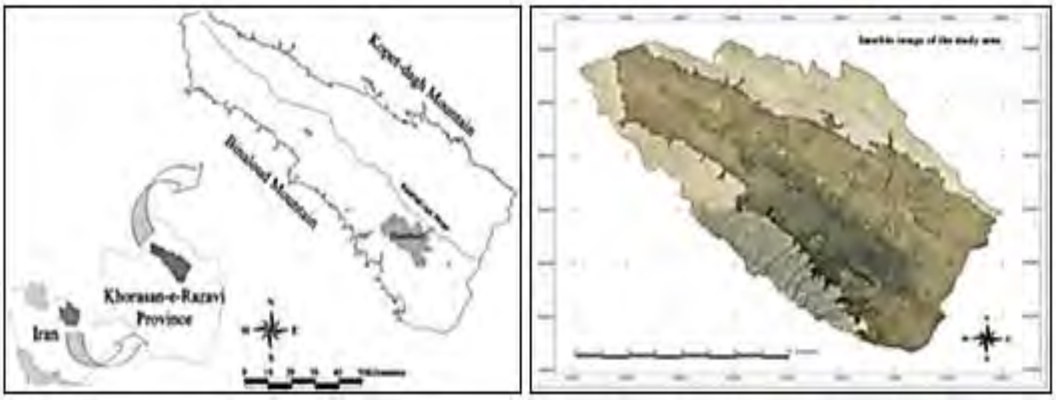

Fig. 1: Geographical position and Satellite image of the study area

Methodology

Data collection

The study utilized a soil profile dataset comprising 49 selected sites, with each site representing a distinct land unit. Climate data files, including monthly averages of temperature and precipitation for the period 1991–2020, were obtained from meteorological stations located nearest to the study sites and compiled from the Iran Meteorological Organization. The physical and chemical properties of the soils, along with the terrain characteristics of the sites, are summarized in Tables 1 and 2.

Table 1: Soil physical and chemical characteristics of the study area

Site	Longitude	Latitude	Sand	Silt	Clay	Texture	ESP (%)	OM (%)	Bulk Density
1	59.745	36.111	32	50	18	silt loam / loam	14.1	1.07	1.407
2	59.683	36.214	39	45	16	loam	4.41	1.26	1.438
3	59.757	36.147	21	57	22	silt loam	10.5	1.1	1.357
4	59.684	36.349	14	56	30	silty clay loam	5.76	1.34	1.298
5	59.835	36.144	45	41	14	loam	21.8	0.52	1.469
6	59.751	36.208	17	61	22	silt loam	5.09	0.88	1.349
7	59.839	36.207	25	64	11	silt loam	2.04	0.67	1.466
8	59.843	36.270	39	33	28	clay loam	10.5	0.95	1.356
9	59.770	36.336	33	41	26	loam	5.63	0.76	1.355
10	59.608	36.350	32	54	14	silt loam	2.18	0.88	1.444
11	59.618	36.406	41	47	12	loam	0.58	0.67	1.484
12	59.699	36.400	39	49	12	loam	0.43	0.47	1.48
13	59.540	36.410	34	52	14	silt loam	5.49	1.03	1.448
14	59.466	36.476	33	53	14	silt loam	4.96	0.59	1.446
15	59.544	36.473	37	49	14	loam	0.88	0.48	1.454
16	59.629	36.470	41	40	19	loam	2.61	0.6	1.416
17	59.700	36.466	33	47	20	loam	0.73	0.48	1.394
18	59.392	36.482	54	34	12	sandy loam	2.75	0.72	1.509
19	59.215	36.506	64	26	10	sandy loam	1.46	0.78	1.555
20	59.316	36.553	15	53	32	silty clay loam	4.41	1.43	1.29
21	59.392	36.538	30	49	21	loam	3.59	1.17	1.381
22	59.470	36.538	43	40	17	loam	3.73	1.17	1.437
23	59.549	36.535	22	53	25	silt loam	12.8	1.02	1.34
24	59.627	36.532	30	51	19	silt loam	2.18	0.84	1.395
25	59.236	36.597	24	50	26	silt loam / loam	3.31	2.34	1.338
26	59.318	36.608	26	59	15	silt loam	10.1	0.93	1.422
27	59.396	36.605	32	47	21	loam	1.75	0.48	1.385
28	59.475	36.602	33	47	20	loam	1.31	0.22	1.394
29	59.084	36.618	32	55	13	silt loam	2.18	1.03	1.455
30	59.010	36.684	26	62	12	silt loam	0.88	0.81	1.455
31	59.088	36.681	28	50	22	silt loam / loam	3.45	2.78	1.37
32	59.166	36.677	24	58	18	silt loam	3.17	1.6	1.392
33	59.322	36.671	25	51	24	silt loam	0.58	1	1.352
34	59.394	36.670	32	51	17	silt loam	0.88	0.52	1.416
35	58.935	36.749	14	58	28	silty clay loam	6.02	1.91	1.308

Site	Longitude	Latitude	Sand	Silt	Clay	Texture	ESP (%)	OM (%)	Bulk Density
36	59.013	36.746	36	60	4	silt loam	7.71	1.09	1.636
37	59.092	36.743	44	31	25	loam	59.8	0.91	1.382
38	59.170	36.740	58	31	11	sandy loam	0.58	0.41	1.53
39	58.782	36.818	34	48	18	loam	0.88	0.62	1.411
40	58.861	36.815	26	48	26	loam	12.2	0.72	1.342
41	58.939	36.812	25	48	27	clay loam / loam	8.59	1.03	1.334
42	58.707	36.884	34	56	10	silt loam	0.58	0.93	1.497
43	58.786	36.881	29	49	22	loam	13.3	0.59	1.372
44	58.554	36.953	32	52	16	silt loam	0.43	0.86	1.425
45	58.633	36.950	48	40	12	loam	0.58	0.88	1.498
46	58.711	36.947	25	52	23	silt loam	6.42	1.84	1.358
47	58.558	37.016	32	54	14	silt loam	0.43	1	1.444
48	58.636	37.013	30	52	18	silt loam	0.58	0.59	1.403
49	58.697	37.012	24	58	18	silt loam	0.29	0.76	1.392

Table 2: Land terrain values of the study area

Site	Slope		Aspect	Sub soil	Internal drainage[3]
	%	class[1]	degree	stoniness class[2]	
1	1.00	F	3.00	C	M
2	1.00	F	3.00	C	M
3	1.00	F	3.00	C	M
4	2.00	A	7.00	F	V
5	2.00	A	3.00	C	M
6	1.00	F	3.00	C	M
7	4.00	G	3.00	F	M
8	1.00	F	7.00	F	V
9	1.00	F	7.00	F	M
10	4.00	G	3.00	F	M
11	2.00	A	7.00	F	M
12	4.00	G	5.00	F	M
13	2.00	A	3.00	F	M
14	2.00	A	3.00	F	M
15	2.00	A	7.00	F	M
16	1.00	F	5.00	F	M
17	2.00	A	7.00	F	M
18	2.00	A	3.00	F	H
19	2.00	A	3.00	C	H
20	2.00	A	3.00	F	V
21	2.00	A	3.00	F	M
22	5.00	G	5.00	F	M
23	1.00	F	7.00	F	M
24	2.00	A	7.00	F	M
25	1.00	F	3.00	C	M
26	1.00	F	7.00	F	M
27	2.00	A	7.00	F	M
28	1.00	F	7.00	F	M
29	2.00	A	3.00	C	M
30	2.00	A	3.00	C	M
31	1.00	F	3.00	C	M
32	1.00	F	3.00	F	M
33	2.00	A	7.00	F	M
34	2.00	A	7.00	F	M
35	1.00	F	3.00	C	V
36	2.00	A	3.00	C	M
37	2.00	A	7.00	F	M
38	2.00	A	7.00	F	H
39	1.00	F	5.00	C	M
40	1.00	F	3.00	F	M
41	2.00	A	7.00	F	V
42	1.00	F	3.00	F	M

Site	Slope %	Slope class[1]	Aspect degree	Sub soil stoniness class[2]	Internal drainage[3]
43	1.00	F	5.00	F	M
44	2.00	A	3.00	F	M
45	2.00	A	3.00	F	M
46	2.00	A	7.00	F	M
47	2.00	A	3.00	F	M
48	2.00	A	7.00	F	M
49	7.00	U	7.00	F	M

[1] Slope class: F: flat, A: almost flat, G: gently undul, U: undul.
[2] Sub soil stoniness class: F: few, C: common.
[3] Internal drainage: H: rapid, M: moderate, V: very slow.

USLE model

The USLE model estimates potential soil loss across the study area under different management practices, integrating the R, K, LS, C, and P factors in a GIS environment for spatial analysis (Govers *et al.,* 2017). To ensure the model's reliability, validation compares the predicted soil loss rates with actual data on soil erosion or sediment yields, using statistical methods like regression analysis (Ebrahimi *et al.,* 2021). Statistical analyses evaluate differences in soil loss estimates under different management practices, identifying the most effective soil conservation practices for future land management decisions. This comprehensive approach to evaluating soil erosion under different management practices using the USLE model emphasizes accurate data collection and variable C and P factors integration.

The USLE model was conducted to ascertain the mean annual rate of soil erosion and its spatial distribution across the designated research zone. The USLE formula (Eq. 1) serves to estimate the degradation of soil at specific locales by multiplying six principal factors, each quantifiable at any given point within the landscape. This model is adept at forecasting the average soil erosion over extended periods. The formula for estimating soil erosion is delineated as below:

$$A = R \times K \times L \times S \times C \times P$$

where, 'A' signifies the yearly soil erosion (t ha^{-1} yr^{-1}), 'R' denotes the rainfall erosivity factor (MJ mm^{-1} ha^{-1} h^{-1} yr^{-1}), 'K' represents the soil erodibility factor (t ha^{-1} MJ^{-1} mm^{-1}), 'L' constitutes the slope length factor, 'S' embodies the slope steepness factor, 'C' symbolizes the crop management factor, and 'P' refers to the conservation practice factor.

This equation combines considerations for both erosivity and erodibility. Erosivity encompasses the capability of rain to initiate soil erosion, summarized by the erosivity factor 'R,' which evaluates the kinetic energy of rainfall. Erodibility indicates the susceptibility of soil to erosion, depending upon various soil attributes, captured by the 'K' factor, which sums up the soil's physical properties. The equation further integrates management aspects, splitting into land and crop management. Land management takes into account the topographical variables such as the slope's extent ('L') and angle ('S'), as well as the conservation practice factor ('P') (Tables 3 and 4). Crop management is reflected through the factor 'C,' illustrating the comparative soil loss between cultivated versus barren lands, hence influenced by vegetation cover. Similarly, the 'P' factor assesses the differential in soil erosion between fields with and without conservation efforts. These variables collectively contribute to the input parameters necessary for the USLE erosion prediction model. The components of the USLE equation are categorized into three groups: erosivity, erodibility, and management. These components were evaluated based on the geomorphology and precipitation data. Specifically, the erosivity factor 'R' is calculated using rainfall intensity data when available. The annual and monthly precipitation data over 30 years from 1994 to 2023 were obtained from four local weather stations to compute the 'R' factor using the formula provided by Wischmeier and Smith (1978):

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

In this equation, 'R' stands for the rainfall erosivity factor (express drivers in megajoules per millimeter per hectare per hour annually), 'Pi' references the rainfall each month (in millimeters), and 'P' denotes the total annual rainfall (in millimeters).

Rainfall and erosivity data (R factor) are retrieved from local meteorological stations.

Table 3: The values of R, K, L, S, C, and P factors with respect to management practices at each land unit

					C - factor (Conventional)					C - factor (Conservational)					P - factor	
Land Unit	R - factor (MJ mm^{-1} ha^{-1} h^{-1} yr^{-1})	K - factor (t ha^{-1} MJ^{-1} mm^{-1})	L - factor	S - factor	Wheat	Sugar beet	Potato	Maize	Alfalfa	Wheat	Sugar beet	Potato	Maize	Alfalfa	Conventional	Conservational
1	136.71	0.303	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
2	136.71	0.357	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
3	136.71	0.315	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
4	136.71	0.253	1.828	0.349	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
5	136.71	0.399	1.572	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
6	136.71	0.377	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
8	136.71	0.298	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
7	136.71	0.485	1.828	0.349	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
9	136.71	0.326	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
10	136.71	0.392	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
11	136.71	0.444	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
12	136.71	0.464	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
13	136.71	0.342	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
14	136.71	0.396	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
15	136.71	0.450	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
16	136.71	0.362	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
17	136.71	0.400	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
18	136.71	0.338	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
19	136.71	0.298	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
20	136.71	0.226	3.480	0.259	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
21	136.71	0.352	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
22	136.71	0.326	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
23	136.71	0.278	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
24	136.71	0.343	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
25	136.71	0.221	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
26	136.71	0.413	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
27	136.71	0.393	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
28	136.71	0.407	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
29	136.71	0.367	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
30	99.45	0.459	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
31	136.71	0.229	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
32	136.71	0.330	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
33	136.71	0.307	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
34	136.71	0.366	1.572	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
35	99.45	0.257	3.480	0.349	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
36	99.45	0.462	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
37	136.71	0.278	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
38	136.71	0.333	1.572	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
39	99.45	0.414	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
40	99.45	0.362	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
41	99.45	0.328	3.480	0.349	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
42	99.45	0.430	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
43	99.45	0.395	2.548	0.117	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
44	99.45	0.367	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
45	99.45	0.395	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
46	99.45	0.260	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
47	99.45	0.387	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
48	99.45	0.363	2.548	0.181	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7
49	99.45	0.392	2.126	0.699	0.6	0.75	0.73	0.71	0.45	0.4	0.55	0.53	0.51	0.35	0.8	0.7

Table 4: Statistical values of the USLE components

	R - factor ($MJ\ mm^{-1}\ ha^{-1}\ h^{-1}\ yr^{-1}$)	K - factor ($t\ ha^{-1}\ MJ^{-1}\ mm^{-1}$)	L - factor	S - factor
Min	99.45	0.22	1.57	0.12
Max	136.71	0.49	3.48	0.70
Average	126.06	0.36	2.51	0.18
STD	17.00	0.07	0.37	0.10
CV	0.13	0.18	0.15	0.53

Estimation of Soil Erodibility Factor

The 'K' factor, indicating soil erodibility (tons per hectare per megajoules per millimeter), was determined based on the soil's texture characteristics utilizing the Wischmeier and Smith (1978) methodology. The 'K' value computation involves four vital parameters, articulated as:

$$K = (27.66 \times m^{1.14} \times 10^{8} \times (12 - a)) + (0.0043 \times (b - 2)) + (0.0033 \times (c - 3))$$

Here, 'm' quantifies as silt percentage plus very fine sand percentage times (100 minus clay percentage), 'a' is the organic matter percentage, 'b' corresponds to the structure code (where 1 indicates very structured or particulate, down to 4 which is solid), and 'c' represents the profile permeability code (ranging from 1, indicating rapid, to 6, indicating very slow).

Slope Length and Steepness Factor Computation

The 'L' factor relates to the ratio of field soil loss compared to that of a standard 22.13 m slope, calculated as:

$$L = \left(\frac{\lambda}{22.13}\right)^{m}$$

Where 'λ' denotes the slope length in meters, and 'm' is a dimensionless exponent ranging from 0.2 to 0.5, with varying values for different slope steepness, as delineated by Wischmeier and Smith (1978). The slope steepness 'S' map was derived using the equation:

$$S = 0.065 + 0.045s + 0.0065s^{2}$$

Where 's' represents the slope in percentage. The 'S' percentage was derived from a Digital Elevation Model (DEM) with a 30 m grid size, while the field slope length ('l') was deduced from the distance between contour lines with a 100 m height difference.

Crop Management Factor

The crop management factor ('C') reflects the expected ratio of soil erosion from cropped land under specific conditions versus the

Clay soils are characterized by a low 'K' value due to their resistance to detachment. Similarly, sandy soils maintain low 'K' values attributed to their high infiltration rate, which minimizes runoff, and the difficulty in transporting eroded sediment. Conversely, silt loam soils exhibit moderate to high 'K' values due to the moderate to easy detachability of soil particles, coupled with moderate to high runoff and sediment transportability. Silt soils present the highest 'K' values due to their tendency to form crusts easily, thereby generating high runoff rates and volumes (Tables 3 and 4).

erosion from clean-tilled fallow on identical soil and slope conditions under comparable precipitation. Field surveys and satellite imagery assess land use patterns and crop management practices for determining the C and P factors (Chanie Haile *et al.*, 2025; Govers *et al.*, 2017). To calculate the C factor, vegetation cover types and management practices are assessed using remote sensing data and field observations (De Jong et al., 1999). The effectiveness of soil conservation measures (e.g., contouring, terracing) in reducing runoff velocity and soil detachment is evaluated to derive the P factor values (Zheng, 2006). In the context of agricultural practices, the C-factor represents the soil erosion potential of different crops. Under conventional practices, the C-factor values for Wheat, Sugar beet, Potato, Maize, and Alfalfa were 0.6, 0.75, 0.73, 0.71, and 0.45, respectively. However, when adopting conservation practices, these values decreased to 0.4, 0.55, 0.53, 0.51, and 0.35, respectively. Essentially, conservation practices help mitigate soil erosion by reducing the impact of these crops on the land (Table 3).

P-factor

The P factor, defined by Wischmeier and Smith (1978), is the ratio of soil loss under a specific support practice to soil loss with up-and-down-slope cultivation. Lower P factors indicate more effective conservation practices in reducing soil erosion. For conventional and conservation practices, the P factors are 0.8 and 0.7, respectively (Table 3).

Statistical analysis

The GIS is used for spatial analysis and visualization of erosion risk (Renard *et al.,* 1997). Statistical analysis compares model results with observed erosion indicators or sediment yields, using regression analysis to validate the model's predictive accuracy (Ebrahimi *et al.,* 2021).

Results and Discussion

R-factor

For producing R factor map, the interpolation values of rainfall data for the years 1994–2023 were spatially distributed on topographic counter map and have been digitized in Arc-GIS ver. 10.8.2 (Fig. 2). The spatial distribution of rainfall was increased uniformly over the elevation ranges from 900 to 1,600 m asl. The R values were found to be in the range of 99.45–136.71 MJ mm ha^{-1} h^{-1} yr^{-1} (Tables 3 and 4). It was evident that most of the area in the southeast (67.22 %) has R value of 131.011 – 136.710 MJ mm ha^{-1} h^{-1} yr^{-1}, having a climatologically highest erosion R-factor compared to 20.04 % of the study.

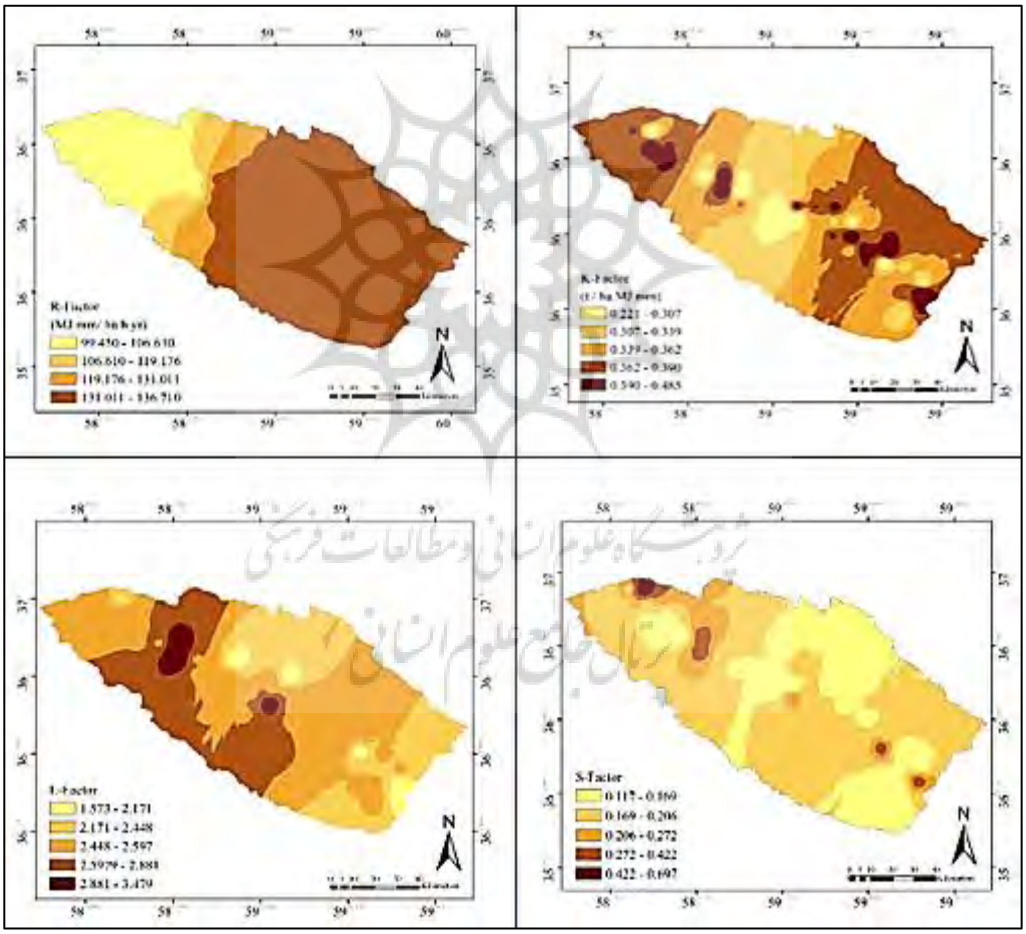

Fig. 2: Factor maps of rain erosivity, soil erodibility, slope length and slope steepness in the study area

Area in the northwest of the region with R value of 99.450 –106.610 MJ mm ha^{-1} h^{-1} yr^{-1} as the lowest rain erosivity (Tables 3 and 4; Fig. 2). The average R factor at the plain was obtained at 126.06 MJ mm ha^{-1} h^{-1} yr^{-1}. The highest value of R factor was observed in the elevation range of 1,500 – 1,600 m asl at the edge of the plain and the lowest value of R factor was found to be in the elevation range of 900–1,000 m asl in the central parts of the plain.

K-factor

The values of K factor in the corresponding land units ranged from 0.221 to 0.485 t ha^{-1} MJ^{-1} mm^{-1}. The mean values of K-factor were observed at alluvial plains, gravelly colluvial fans, pediment plains and hills with 0.36 t ha^{-1} MJ^{-1} mm^{-1} (Tables 3 and 4; Fig. 2). In consistent with our study, Bagherzadeh and Keshavarzi (2021) indicated that areas with higher erodibility levels were associated with soils that had increased amounts of very fine sand and silt particles, reduced soil organic matter, a transition from fine granular to massive and blocky structures, and decreased soil permeability. It was revealed that 5.37% (535.84 km^2) of the study area has the highest soil erodibility of 0.390 – 0.485 t ha^{-1} MJ^{-1} mm^{-1} in scattered parts in the northwest and southeast of the plain, vice versa 4.58 % (456.92 km^2) specially in the central part of the region with K-factor of 0.221 –0.307 t ha^{-1} MJ^{-1} mm^{-1} as the lowest soil erodibility (Fig. 2).

L & S factors

The values of L factor in the corresponding land units varied between 1.57 and 3.48. The mean values of L-factor were observed with 2.51 (Tables 3 and 4; Fig. 2). It was revealed that 2.63% (262.01 km^2) of the study area has the highest slope length factor of 2.881 – 3.479 focused in the northwest and middle part of the plain, while 2.83 % (282.37 km^2) has the lowest L-factor of 1.573 – 2.171, laid from southeast to northwest of the region (Fig. 2).
The values of S factor in the corresponding land units ranged from 0.12 to 0.70. The mean values of S-factor were observed with 0.18 (Tables 3 and 4; Fig. 2). It was demonstrated that 0.42% (42.37 km^2) of the study area has the highest steepness factor of 0.422 – 0.697 in the northwest of the plain, while 34.94 % (3485.21 km^2) specially in the central part and some scattered parts in southeast and northwest of the region with S-factor of 0.117 –0.169 as the lowest Steepness factor (Fig. 2).

Soil Loss Rates

The study employed the Universal Soil Loss Equation (USLE) model to comprehensively examine soil erosion rates, revealing considerable variability linked to land management practices. Across all crops analyzed, conservation practices consistently lead to lower soil loss rates compared to conventional methods. For wheat, the mean soil loss rate drops from 10.80 t/ha yr to 6.35 t/ha yr, a reduction of 41.2%. Sugar beet shows a decrease from 13.26 t/ha yr to 8.63 t/ha yr, indicating a 34.9% reduction. For potato, soil loss rates fall from 11.28 t/ha yr to 7.51 t/ha yr, approximately 33.4% less. Maize sees a reduction from 9.45 t/ha yr to 5.92 t/ha yr, or 37.3%. Alfalfa demonstrates the most significant stability with a drop from 7.61 t/ha yr to 4.94 t/ha yr, a 35.1% reduction (Table 5). These results underscore the critical importance of implementing conservation practices in agriculture to significantly reduce soil erosion and promote sustainable land management, enhancing overall soil health and ensuring long-term agricultural productivity. Areas subjected to intensive farming, especially with crops like Sugar beet and Maize, were found to have elevated soil loss rates. In contrast, lands cultivated with Alfalfa demonstrated substantially reduced erosion rates. This reduction is attributed to Alfalfa's perennial nature and its effective ground cover, which minimizes soil disturbance. This highlights the significant role of such practices in enhancing soil structure and long-term sustainability (Cao *et al.,* 2023; Moghadam *et al.,* 2015; Eskandari Damaneh *et al.,* 2022; Gu, 2011; Zare *et al.,* 2017).

Table 5: The USLE soil loss rates with respect to management practices at each land unit

Land Unit	Soil loss rates (t/ha.yr)									
	Conventional practice					Conservational practice				
	Wheat	Sugar beet	Potato	Maize	Alfalfa	Wheat	Sugar beet	Potato	Maize	Alfalfa
1	5.91	7.39	7.19	7.00	4.43	3.45	4.74	4.57	4.40	3.02
2	6.95	8.68	8.45	8.22	5.21	4.05	5.57	5.37	5.17	3.55
3	6.14	7.67	7.47	7.27	4.60	3.58	4.92	4.75	4.57	3.13
4	10.59	13.24	12.88	12.53	7.94	6.18	8.49	8.19	7.88	5.41
5	12.09	15.11	14.71	14.30	9.07	7.05	9.70	9.34	8.99	6.17

Land Unit	Soil loss rates (t/ha.yr)									
	Conventional practice					Conservational practice				
	Wheat	Sugar beet	Potato	Maize	Alfalfa	Wheat	Sugar beet	Potato	Maize	Alfalfa
6	7.34	9.17	8.93	8.68	5.50	4.28	5.89	5.67	5.46	3.75
8	5.81	7.27	7.07	6.88	4.36	3.39	4.66	4.49	4.32	2.97
7	20.33	25.41	24.73	24.05	15.24	11.86	16.30	15.71	15.12	10.37
9	6.35	7.93	7.72	7.51	4.76	3.70	5.09	4.91	4.72	3.24
10	11.86	14.82	14.43	14.03	8.89	6.92	9.51	9.16	8.82	6.05
11	13.45	16.81	16.36	15.91	10.08	7.84	10.78	10.39	10.00	6.86
12	14.03	17.54	17.08	16.61	10.53	8.19	11.26	10.85	10.44	7.16
13	10.35	12.94	12.59	12.25	7.76	6.04	8.30	8.00	7.70	5.28
14	11.99	14.98	14.58	14.18	8.99	6.99	9.61	9.26	8.92	6.12
15	13.62	17.02	16.57	16.11	10.21	7.94	10.92	10.53	10.13	6.95
16	7.06	8.83	8.59	8.36	5.30	4.12	5.66	5.46	5.25	3.60
17	12.09	15.11	14.71	14.31	9.07	7.05	9.70	9.35	8.99	6.17
18	10.22	12.77	12.43	12.09	7.66	5.96	8.20	7.90	7.60	5.22
19	9.01	11.27	10.97	10.67	6.76	5.26	7.23	6.97	6.70	4.60
20	6.83	8.53	8.31	8.08	5.12	3.98	5.48	5.28	5.08	3.48
21	10.65	13.31	12.95	12.60	7.98	6.21	8.54	8.23	7.92	5.43
22	9.86	12.33	12.00	11.67	7.40	5.75	7.91	7.62	7.33	5.03
23	5.41	6.76	6.58	6.40	4.06	3.16	4.34	4.18	4.02	2.76
24	10.37	12.96	12.61	12.27	7.78	6.05	8.32	8.01	7.71	5.29
25	4.30	5.37	5.23	5.09	3.22	2.51	3.45	3.32	3.20	2.19
26	8.05	10.06	9.79	9.52	6.04	4.69	6.45	6.22	5.99	4.11
27	11.90	14.88	14.48	14.09	8.93	6.94	9.55	9.20	8.85	6.08
28	7.93	9.91	9.65	9.38	5.95	4.63	6.36	6.13	5.90	4.05
29	11.10	13.87	13.50	13.13	8.32	6.47	8.90	8.58	8.25	5.67
30	10.10	12.63	12.29	11.95	7.58	5.89	8.10	7.81	7.51	5.16
31	4.46	5.57	5.42	5.27	3.34	2.60	3.57	3.44	3.31	2.27
32	6.42	8.03	7.81	7.60	4.82	3.75	5.15	4.96	4.78	3.28
33	9.28	11.60	11.29	10.98	6.96	5.41	7.45	7.17	6.90	4.74
34	11.07	13.84	13.47	13.10	8.30	6.46	8.88	8.56	8.24	5.65
35	7.84	9.80	9.54	9.28	5.88	4.57	6.29	6.06	5.83	4.00
36	10.18	12.72	12.38	12.04	7.63	5.94	8.16	7.87	7.57	5.19
37	16.42	20.52	19.97	19.43	12.31	9.58	13.17	12.69	12.21	8.38
38	10.06	12.58	12.24	11.91	7.55	5.87	8.07	7.78	7.48	5.14
39	5.86	7.33	7.13	6.94	4.40	3.42	4.70	4.53	4.36	2.99
40	5.13	6.41	6.24	6.07	3.85	2.99	4.12	3.97	3.82	2.62
41	7.23	9.04	8.79	8.55	5.42	4.22	5.80	5.59	5.38	3.69
42	6.10	7.62	7.42	7.22	4.57	3.56	4.89	4.71	4.54	3.11
43	5.60	7.00	6.81	6.63	4.20	3.27	4.49	4.33	4.16	2.86
44	8.08	10.10	9.83	9.56	6.06	4.71	6.48	6.25	6.01	4.13
45	8.69	10.86	10.57	10.28	6.51	5.07	6.97	6.71	6.46	4.43
46	5.73	7.17	6.98	6.79	4.30	3.35	4.60	4.43	4.27	2.93
47	8.53	10.66	10.38	10.09	6.40	4.98	6.84	6.59	6.34	4.35
48	7.99	9.99	9.72	9.45	5.99	4.66	6.41	6.17	5.94	4.08
49	31.27	39.09	38.05	37.01	23.45	16.22	22.30	21.49	20.67	14.19

The zonation of soil loss rates

Wheat

The maps compare soil loss rates for wheat cultivation under conventional and conservational practices, represented soil loss rates from 2.51 to 31.27 t/ha yr (Fig. 3). Conventional cultivation shows high soil loss areas (18-31.27 t/ha yr) in the northern and central parts, with moderate soil loss (9-18 t/ha yr) scattered throughout, and low soil loss (2.51-9 t/ha yr) mainly in the southern region. Conservational cultivation has fewer high soil loss areas (18-21 t/ha yr) primarily in the north, reduced moderate soil loss, and extensive low soil loss (2.51-9 t/ha yr) indicating better soil conservation. This comparison highlights the effectiveness of conservational cultivation in reducing soil erosion, essential for sustainable agriculture and environmental conservation, as the maps visually demonstrate that conservation practices result in lower and less widespread erosion, promoting long-term soil health and sustainability.

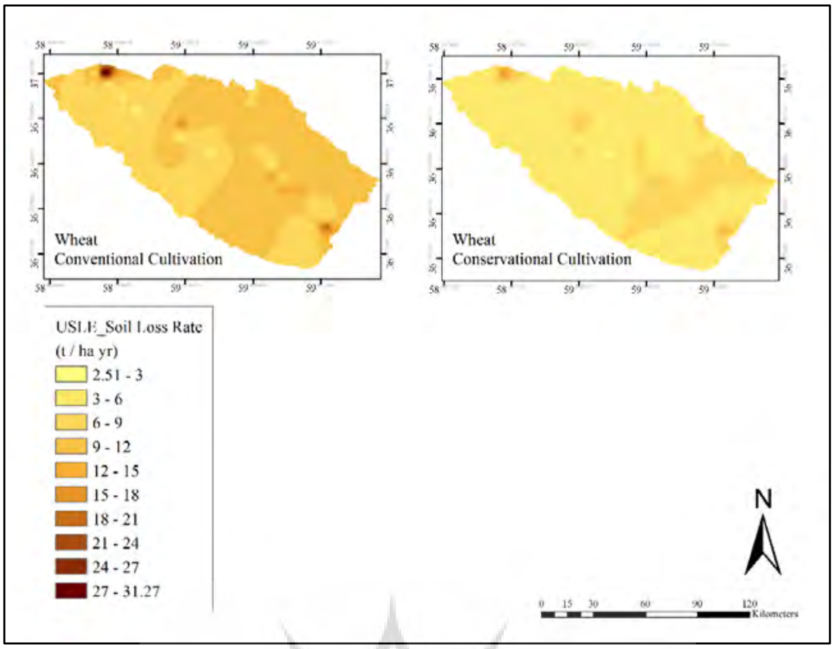

Fig. 3: The Zonation of Soil loss rate for Wheat cultivation in Mashhad Plain

Sugar beet

The maps compare soil erosion rates for sugar beet cultivation under conventional and conservational practices, showed soil loss rates from 3.45 to 38.96 t/ha yr (Fig. 4). Conventional cultivation has significant high erosion areas (up to 38.96 t/ha yr) in the northwestern and southeastern regions, moderate erosion (6 - 15 t/ha yr) scattered in the central and northeastern parts, and lower erosion rates (3.45 - 6 t/ha yr) in the southwestern region. In contrast, conservational cultivation shows fewer high erosion areas (around 27 t/ha yr) mainly in the northwestern and southeastern parts, with moderate erosion reduced in extent and primarily in the central region, and low erosion rates (3.45 - 6 t/ha yr) more extensive across the map. This comparison highlights conservational practices' effectiveness in reducing soil erosion, emphasizing the importance of such methods for long-term soil health and environmental sustainability. The maps visually demonstrate that conservation practices result in lower and less widespread erosion, crucial for sustainable agriculture and environmental conservation.

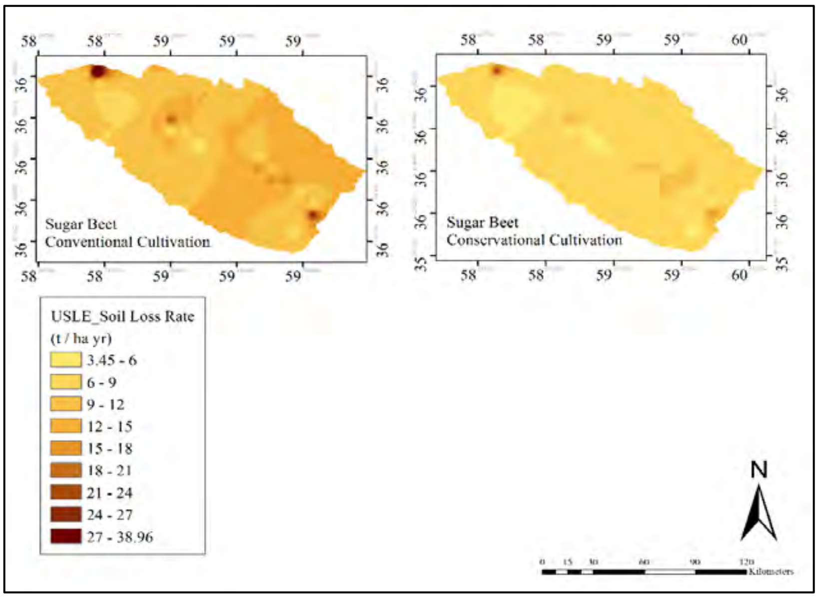

Fig. 4. The Zonation of Soil loss rate for Sugar Beet cultivation in Mashhad Plain

Potato

The maps compare soil loss rates for potato cultivation under conventional and conservational practices, revealed soil loss rates from 5.24 to 38.05 t/ha yr (Fig. 5). Conventional cultivation has higher soil loss areas (24 - 38.05 t/ha yr) in the northwestern and southeastern regions, with moderate soil loss (15 - 21 t/ha yr) scattered centrally and northeastern, and lower soil loss (5.24 - 12 t/ha yr) across most regions. Conservational cultivation shows significantly reduced high soil loss areas, smaller patches in the northwest and southeast, less widespread moderate soil loss, mainly central, and extensive low soil loss (5.24 - 12 t/ha yr), indicating effective soil conservation. This comparison highlights conservational cultivation's effectiveness in reducing soil erosion, essential for sustainable agriculture and environmental conservation. The maps demonstrate how conservation practices result in lower and less widespread erosion, emphasizing the importance of such methods for long-term soil health and environmental sustainability.

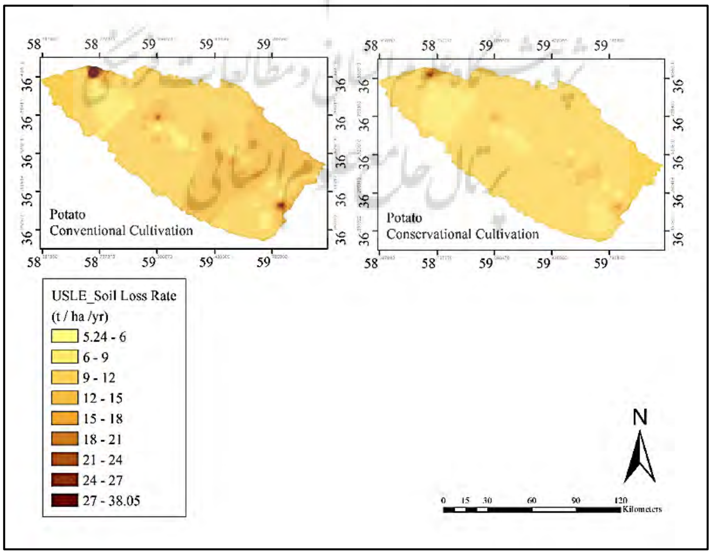

Fig. 5: The Zonation of Soil loss rate for Potato cultivation in Mashhad Plain

Maize

The maps compare soil loss rates for maize cultivation under conventional and conservational practices, exhibited soil loss rates from 3.20 to 37.01 t/ha yr (Fig. 6). In conventional cultivation, high soil loss areas

(27 - 37.01 t/ha yr) are concentrated in the northwestern and southeastern regions, with moderate soil loss (12 - 24 t/ha yr) scattered throughout, and low soil loss (3.20 - 6 t/ha yr) prevalent in the central and southwestern regions. Conservational cultivation shows a significant reduction in high soil loss areas, with smaller patches in the northwestern and southeastern regions, while moderate soil loss areas are also reduced and less widespread. Low soil loss areas are more extensive under conservational practices, covering larger portions of the central and southwestern regions. This comparison highlights the effectiveness of conservational cultivation in reducing soil erosion, underscoring the importance of sustainable practices for environmental conservation.

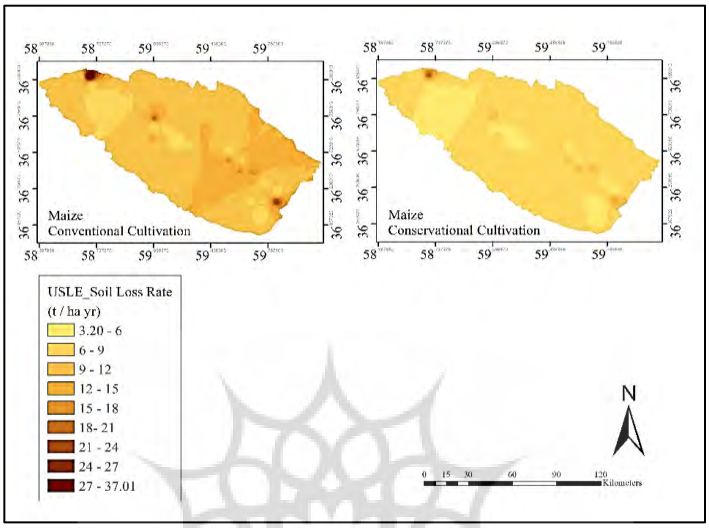

Fig. 6. The Zonation of Soil loss rate for Maize cultivation in Mashhad Plain

Alfalfa

The maps illustrate the soil loss rates for alfalfa cultivation under conventional and conservational methods (Fig. 7). Conventional cultivation shows higher soil loss rates, with significant areas in the northern and central regions experiencing rates between 12 to 23.45 tons per hectare per year (t/ha yr). Most of the conventional map indicates soil loss rates ranging from 3 to 9 t/ha yr, with critical areas predominantly in the northwestern and southeastern parts. In contrast, conservational cultivation demonstrates lower soil loss rates overall, with fewer and smaller patches of critical areas. The majority of the conservational map displays soil loss rates between 2.19 to 6 t/ha yr, highlighting effective soil conservation. The comparison reveals that conservational cultivation significantly reduces soil erosion, with lighter colors and fewer high soil loss areas. The effectiveness of conservation practices is evident as they help preserve soil health and reduce erosion risks, making it a more sustainable agricultural method. These findings emphasize the importance of adopting conservational practices to ensure long-term soil preservation and environmental sustainability.

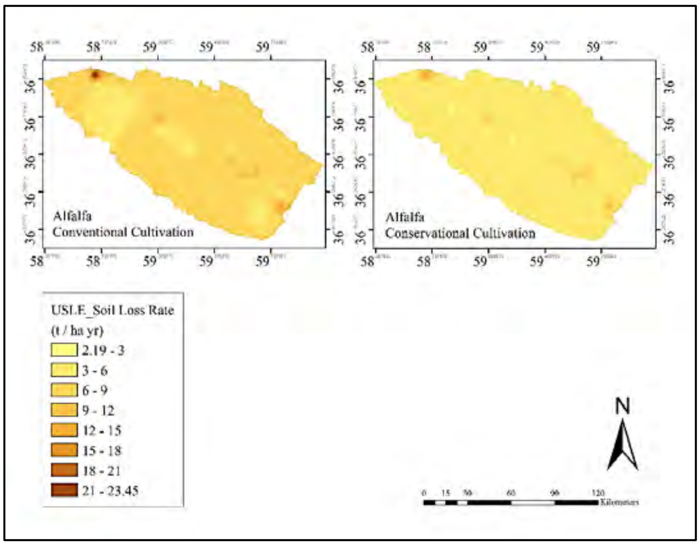

Fig. 7. The Zonation of Soil loss rate for Alfalfa cultivation in Mashhad Plain

Model validation

To validate soil loss data in the USLE model under both conventional and conservation management systems, the results were compared with the ImpelERO model. The ImpelERO model, developed by De la Rosa et al. (1999), estimates soil erosion by integrating an expert system and neural networks, similar to the Universal Soil Loss Equation. This model uses soil survey data, expert knowledge of erosion processes, and information about land and management qualities to predict the soil erosion vulnerability index, erosion risk class, soil loss rate, and soil depth reduction. The model combines expert decision trees and soil data with an artificial neural network to assess crop and land management interactions, ultimately reducing soil erosion through optimal agricultural strategies. The procedure involves three main steps: defining a target vulnerability index for specific field units, calculating the closest vulnerability index using neural networks, and selecting optimal management strategies using decision trees. This approach, part of the MicroLEIS DSS framework, helps identify the best practices to minimize soil loss for selected crops under conventional and conservational management systems (Afshar *et al.,* 2016, 2018). The comparison of the USLE and ImpelERO models under both conventional and conservation management systems showed in Table 6. In terms of correlation strength, conventional management shows R-squared values ranging from 0.56 to 0.7438, indicating moderate to strong positive correlations, with the highest correlation for wheat (0.7438) and the lowest for sugar beet (0.56) (Fig. 8). Conservation management also displays moderate to strong correlations, with R-squared values ranging from 0.6129 to 0.6752, the highest for silage corn (0.6752) and the lowest for wheat (0.6129) (Fig. 9). Both systems show strong alignment between the models' predictions, with conventional management having slightly higher correlations overall, suggesting more consistent model predictions under typical conditions. Regression slopes under conventional management are generally less than 1, except for alfalfa (0.7209), indicating that USLE tends to predict higher soil erosion for smaller ImpelERO values. Under conservation management, slopes vary more, with some close to or greater than 1 (e.g., wheat at 0.9197 and alfalfa at 1.5709), indicating that USLE predictions can increase more rapidly compared to ImpelERO. The different slopes reflect the models' varying sensitivities to soil erosion factors, with USLE predicting higher erosion rates more quickly under conservation practices, possibly due to differences in model algorithms or input sensitivities. Intercepts under conventional management are positive, indicating that USLE predicts a baseline level of soil erosion even with low ImpelERO predictions, such as wheat with an intercept of 4.0527. In contrast, conservation management intercepts vary more widely and are generally lower, with examples like alfalfa having a negative intercept (-2.1119), suggesting potential overestimation or sensitivity issues for very low ImpelERO predictions. Overall, both figures demonstrate that the ImpelERO and USLE models are consistently correlated, regardless of the management system, implying they can be trusted for predicting soil erosion under different conditions. The slopes and intercepts highlight differences in how each model reacts to various management practices, with USLE's tendency to predict higher rates more rapidly under conservation practices suggesting greater sensitivity to certain factors. Given the strong correlations, either model can be used for predicting soil erosion, considering the specific conditions and characteristics of the management system being analyzed. By comparing the models under both conventional and conservation systems, we gain a comprehensive understanding of their behavior and reliability, aiding in more informed decision-making for soil conservation strategies.

Table 6: The mean values of soil loss rates by USLE and ImpelERO models with respect to management practices

Management System	Model	Wheat	Sugar beet	Potato	Maize	Alfalfa
				(t/ha.yr)		
Conventional	USLE	9.64	11.75	11.43	10.48	6.78
	ImpelERO	8.90	11.72	11.48	10.48	6.78
Conservation	USLE	5.58	7.67	7.39	7.12	4.88
	ImperERO	5.28	7.83	7.60	6.55	4.45

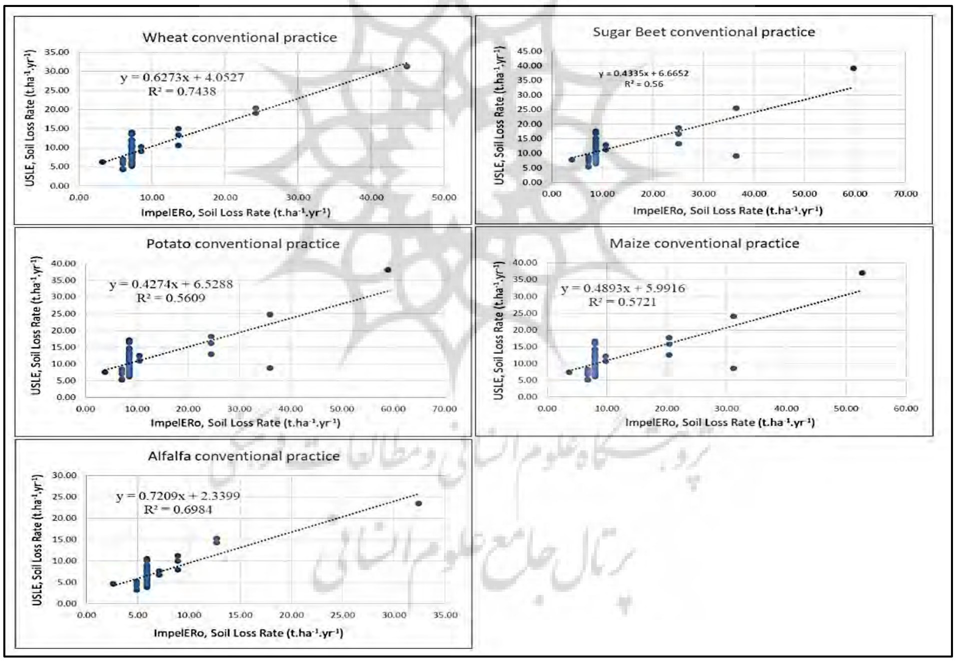

Fig. 8: The correlation between USLE and ImperERO soil loss rates by conventional practice

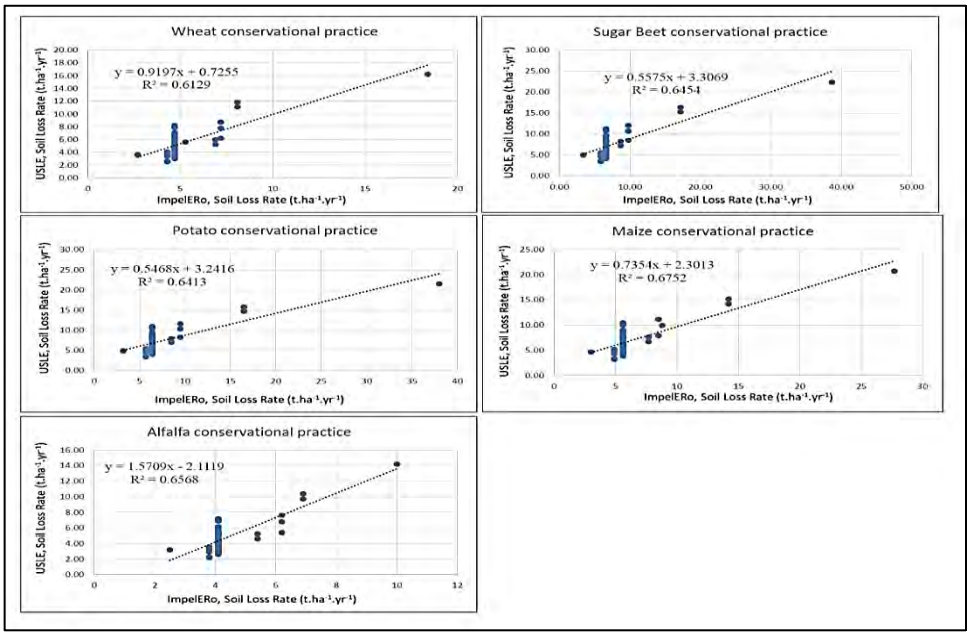

Fig. 9: The correlation between USLE and ImperERO soil loss rates by conservational practice

Conclusion

The study underscores the significant role of conservation practices in reducing soil erosion across various land units and agricultural practices. The R-factor map highlighted that areas with higher elevation tend to have increased rain erosivity, particularly in the southeast region, indicating a higher potential for erosion in these zones. The K-factor analysis revealed that soil erodibility varies significantly across different land units, with the highest soil erodibility found in scattered parts of the northwest and southeast. The L and S factors further emphasized the impact of topography on erosion, showing that slope length and steepness play crucial roles in soil loss rates. Areas with higher L and S values, particularly in the northwest and central parts, are more prone to erosion. The application of the Universal Soil Loss Equation (USLE) model provided a comprehensive view of soil erosion rates, demonstrating that conservation practices significantly reduce soil loss compared to conventional methods. Across all crops studied, conservation practices resulted in notable reductions in soil loss rates, with Alfalfa showing the most substantial stability due to its effective ground cover. The study's findings highlight the critical importance of adopting conservation practices to mitigate soil erosion, ensure sustainable land management, and enhance long-term agricultural productivity. By implementing these practices, we can protect soil health and reduce the negative impact of erosion, ultimately promoting environmental sustainability.

Author Contributions

Ehsan Afshar, the corresponding author, has contributed in supervising in the data analysis, interpreted the results, and preparing the manuscript. Ali Bagherzadeh prepared all the maps and figures and interpretation of the results.

Conflict of Interest

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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