Pol. J. Environ. Stud. Vol. XX, No. X (XXXX), 1-12
DOI: 10.15244/pjoes/187595 ONLINE PUBLICATION DATE:

Original Research

Assessing Soil Erosion Risk in Kazakhstan: A RUSLE-Based Approach for Land Rehabilitation

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Received: 1 February 2024
Accepted: 18 April 2024

Abstract

Soil degradation is increasing in Kazakhstan, leading to severe losses in land productivity. The Almaty region, the country's leading agricultural and industrial province, is among the most affected areas. The objective of this study is to evaluate, for the first time, the applicability of the revised model of the Universal Soil Loss Equation (USLE) for estimating the rate of soil erosion and identifying areas susceptible to soil erosion in the Almaty region. The revised USLE (RUSLE) factors, including rainfall erosivity, soil erodibility, slope length, and steepness, were represented using data on soil, topography, and land use/vegetation cover from the region. Using the RUSLE model's algorithms, we generated an erosion risk map, emphasizing areas with a high potential for erosion. The results show higher soil erosion rates in agricultural areas with steep slopes and inadequate environmental practices – annual soil losses in the region are as high as 26,279 t/ha/year in high-risk areas. On average, approximately 88% of the region's territory loses up to 103 t/ha/year, while 9% loses about three times as much. Such potential soil erosion risks warrant the implementation of efficient soil conservation strategies in the region to protect soils, ensure desired agricultural productivity, and support the journey in achieving the Sustainable Development Goal (SDG) 15.

Keywords: land degradation, RUSLE model, Almaty region, Kazakhstan, soil loss, soil erosion

Introduction

Environmental degradation resulting from soil erosion has become an emerging challenge in recent years, leading to significant agricultural productivity losses and posing a substantial threat to sustainable development. Geological erosion, in contrast to the erosion resulting from improper management and irrational use of soil and land resources, does not pose massive adverse consequences on natural resources. However, the latter form of erosion, known as accelerated erosion, is highly detrimental to the environment and agricultural production systems [1].

The Intergovernmental Panel on Climate Change (IPCC) reveals that crop cultivation without

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conservation measures erodes soils 100 times faster than their formation rate [2]. The erosion risk increases due to temperature changes caused by greenhouse gas (GHG) emissions, reducing agricultural productivity and land value while impacting the environment and human health.

Soil erosion modeling plays a crucial role in enhancing land management practices by identifying areas susceptible to soil erosion, estimating potential rates of soil erosion, and identifying potential causal factors. The increasing risk of soil erosion warrants urgency to develop a pertinent model to assess soil erosion losses and provide evidence-based justification for integrated agro-landscape management practices. Since all natural and anthropogenic factors of the erosion-accumulative process have a pronounced spatial character, the most adequate toolkit to address this challenge is the application of geographic information systems [3].

The Universal Soil Loss Equation (USLE), an empirical model, was formulated in the 1930s by the National Runoff and Soil Loss Data Center, USA, to estimate annual soil loss and forecast water erosion in regions characterized by temperate climates [4]. The USLE equation represents an empirical predictive model for use as a management tool in soil conservation planning and practice. Its success stems from its simplicity, which makes it easy for non-technical extension and advisory staff to understand and use it [5].

Using GIS technologies in conjunction with economic assessment methods can yield timely and precise data regarding shifts in agricultural production and variations in land fertility based on the type and extent of degradation [6]. According to Morgan & Morgan [7], mathematical models of soil erosion are valuable in land management when they can accurately predict soil loss under specific conditions and effectively simulate the impact of soil conservation practices. Land with high erosion susceptibility can be suitable if the intended use is known to protect the land if other land qualities are not limiting factors. However, it may not be appropriate for land use cases with minimal or no protection [8].

The soil cover of Kazakhstan is characterized by significant heterogeneity, primarily influenced by the arid climate, relief, and soil-forming rocks. According to the qualitative characterization of data by the Land Administration of the Ministry of Agriculture of the Republic of Kazakhstan [9] there are more than 90 million ha of eroded and erosion-prone land in Kazakhstan. Approximately 201,700 ha of land is subject to water and wind erosion. In agricultural areas, the area affected by water erosion is 4.9 million ha, of which 1.2 million ha is arable land. The total area of land subject to wind erosion is 24.2 million ha, of which 0.5 million ha is arable land.

Evaluating the country's economic aspects of soil conservation necessitates prioritizing erosion control in natural and agricultural settings to sustain agricultural productivity. Identifying critical areas for allocating limited funding towards erosion control is necessary. Erosion forecasting models aid in planning and implementing strategic land management for natural and agricultural environments. Research using models can assist conservationists in identifying areas where implementing soil conservation measures will significantly reduce soil loss.

Land degradation in Kazakhstan became increasingly evident in the early 1950s due to the rapid conversion of natural steppe and fallow areas into agricultural and industrial zones. Collective farms and state farms extensively utilized forests for cattle grazing until 1993. The arable land in Kazakhstan increased from 7 million ha in 1953 to 35 million ha in the 1980s, accounting for approximately 12% of the country's total land area. The conversion of large territories into arable land has also increased pressure on pasture lands. Overexploitation has led to the degradation of 48 million ha of pastures. As a result, soil fertility has declined by 30-60% due to wind and water erosion, leading to hazardous dust storms that affect an area of up to 9 million ha in specific years [10]. Anthropogenic overload and irrational use of natural resources have led to modern environmental problems, which have undoubtedly impacted the soil cover in Kazakhstan. The ecological destabilization has resulted in soil cover degradation across all natural zones of the [11].

Kazakhstan is actively working to prevent desertification and land degradation at the state level. These measures aim to fulfill the United Nations Convention to Combat Desertification (UNCCD) responsibilities and achieve the Sustainable Development Goal (SDG) 15 targets. The results of this study in addressing SDG 15.3 will allow Kazakhstan to determine the level of degradation and track the dynamics of the processes, as well as develop accurate and locally adapted strategies to improve soil fertility and prevent further degradation in the Almaty region.

This study aimed to assess the erosive capacity of soils by employing the RUSLE, which belongs to a group of empirical soil loss models [12]. The main advantage of RUSLE over USLE is its ability to estimate the coverage control coefficient (C). Instead of the experimental plot data used in USLE to estimate the C factor in RUSLE [13]. information on vegetation form, decomposition, and tillage practices is considered. The model predicts the erosion risk of selected areas and effectively determines soil loss within a large region [14].

Material and Methods

Study Area

The study area is between 42°12'N latitude to 46°32'N latitude and 73°43'E longitude to 80°48'E longitude. The total area is 105,263 km^2 and borders the

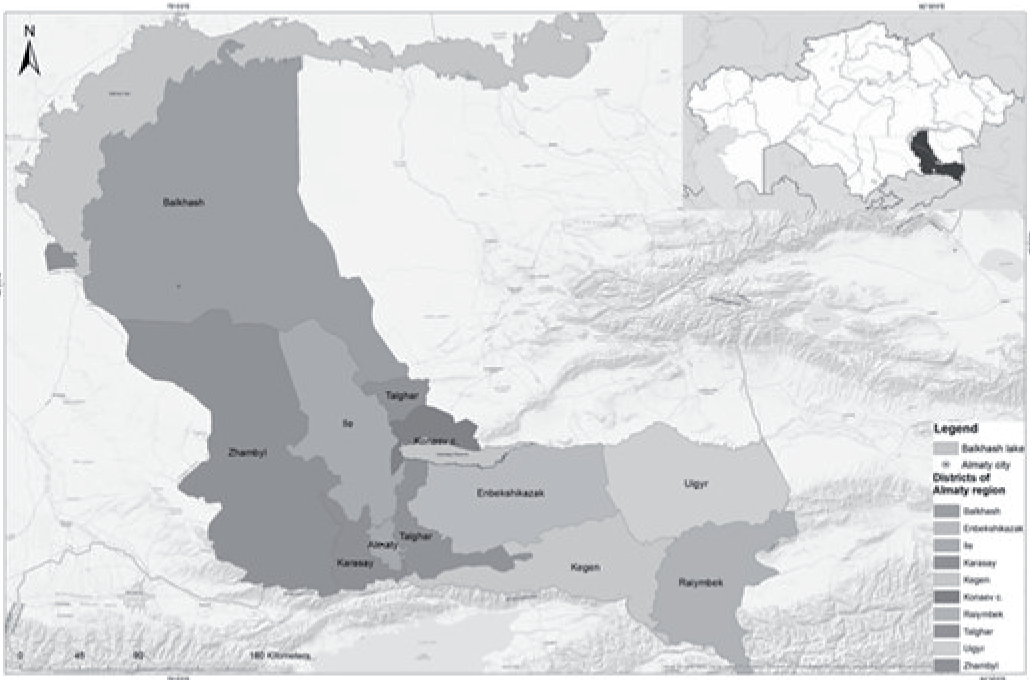

Fig. 1. Study area map representing the Almaty region in Kazakhstan.

following regions of Kazakhstan: Zhambyl in the west, Karaganda in the northwest (the water border runs along Lake Balkhash), and Zhetysu region in the northeast. The southeastern border runs along the Kazakh Chinese State border; the southern border runs along the Kazakh-Kyrgyz State border (Fig. 1).

By the Resolution of the Government of the Republic of Kazakhstan [15], the current borders of the Almaty region exclude from its territory the lands of the Zhetysu region, which has a total area of 1,1848 thousand ha.

Today's territory of the Almaty region is 10.5 million ha (9 districts and one city of regional significance). Agricultural land 4.2 million ha, including arable land – 457.8 thousand ha, of which irrigated – 239.6 thousand ha, perennial plantations – 18.8 thousand ha, deposits – 55.3 thousand ha, hayfields – 63.1 thousand ha, pastures – 3.5 million ha [16].

Climatic Conditions of the Region

The climatic diversity in the region is attributed to its geographical features. The northern part consists of a plain with ridges and dunes, while the southern part is characterized by mountain ranges that create variations in vertical belts. The region's climate is predominantly continental, with the foothills of the Trans-Ili Alatau experiencing sufficient humidity, moderately warm summers, and mild winters. The flat area experiences significant daily and annual air temperature variations, with cold winters and long, hot, and dry summers. January is the coldest month in the region. The temperature ranges from -15°C in the north (Bakanas Weather Station) and northeast (Kyrgyzsay Weather Station) to -6°C in the mountains and -8°C in the foothills (Kegen, Assy, Narynkol Weather Station) in the south. July is the warmest month in the region. In the north, specifically at the Bakanas Weather Station, the temperature reaches 25°C. In the south, temperatures range from 8°C in the mountains to 26°C in the foothills, as recorded at the Kegen, Assy, and Narynkol Weather Stations [17]. The amount of precipitation per year on the plains is about 300 mm, and in the foothills and mountains ranges from 500 to 1000 mm [18].

Soil Type Distribution

The Almaty region encompasses both flat and mountainous terrains. Various climatic conditions have influenced the development of diverse soil and vegetation types. Vertical zonation and horizontal differentiation affect soil formation. The higher foothill plains have chestnut soils and subtypes, whereas the lower portion has gray soils. A lot of this belt's soils are gravelly. Desert-steppe and desert zone intrazonal soils are widespread at lower absolute elevations. Meadow chernozems, takyr-like soils of various salinities, solonetz, and solonchaks, are intrazonal soils. A sandy massif with a sandy foundation dominates the Balkhash area, where soil formation begins early.

The foothill and river valley soils have long been processed for agriculture. Therefore, arable land soils have been substantially transformed and cultivated. In the mountainous part, mountain-meadow soils are widespread in the alpine and subalpine zones at altitudes from 2700 to 3800 m. Below, up to about 1700-1800 m, podzolic, sometimes chernozem-meadow soils predominate in the coniferous forest zone. Chernozems predominate in the mountain-steppe area up to about 800 m high. In the grass-tipchak and grass-wormwood mountain steppes, mountain chestnuts predominate, turning into gray soils at less than 650 m.

Zonal and intrazonal soils possess agro-reclamation qualities that suit pasture utilization. Due to their limited natural moisture content, the soils in the Almaty region are generally used for irrigated agriculture, depending on their type and subtype. Undeveloped massifs serve as low-productivity pasture lands during the early spring season. This phenomenon is common in regions with brown desert, meadow brown, and gray-brown soils. Takyrs and takyr-like soils of the Southern Balkhash region, the Balkhash-Alakol depression, and the ancient delta of the Ile River are not used for agricultural activities as they are under natural forest. Dark chestnut soils are more fertile and generally used for rain-fed agriculture, gardening, and horticulture. Mountain forests' dark gray soils are part of the forest and pasture lands. The destruction of forests in the areas has led to the activation of water erosion and land degradation. Mountain forest dark-colored soils serve as high-value summer pastures. The area under mountain meadow soils is highly suitable for summer pastures, which can lead to pasture digression [19].

Data Sources and Methodology

The RUSLE model is a widely utilized method for estimating long-term rates of soil loss in agricultural fields under different management practices. It considers the impact of precipitation, soil properties, topography, vegetation, and support factors on soil erosion and loss. Equation (1) was used to calculate the average soil loss per unit area in the region [20].

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

Where A refers to average annual soil loss per unit area (t/ha/year), R rainfall erosion capacity (MJ mm ha/h/year), K soil erodibility, LS slope length and steepness, C cover management, and P support practices. Each of the above factors was evaluated in the study area using Arc GIS 10.8.2 software and depends on precipitation data, soil data, and DEM, respectively.

Precipitation Data

Precipitation erosivity refers to the capacity of precipitation to cause soil erosion, resulting from the combined influence of various precipitation characteristics during a specific event [21].

This study used monthly precipitation data from the Republican National Hydrometeorological Service of Kazakhstan (2023). Data sets were collected from 10 stations in the Almaty region over a period of 22 years, from 2000 to 2022. The Inverse distance weighted (IDW) interpolation method was used to determine the geographical distribution of average annual precipitation in the study area.

The following formula (2), developed by Leprun, 1981 [22] was used to calculate the coefficient of precipitation erosion:

$$R = 0.13 \times {M_x}^{1.24} \quad (2)$$

Where R is a rainfall erosivity factor (MJ mm ha/h/year); M_x is average monthly precipitation (mm).

Data on Soil Properties

Soil property datasets were obtained from the Digital Soil Map of the World (hereafter referred to as the DSMW) [23]. This database combines a raster image file with an attribute database that lists various features of different soil types. K-factor modeling with DSMW involves importing raster layers using the software. Simultaneously, the K coefficient is influenced by four elements outlined in Williams's formula, 1995 [24]: soil structure and texture, organic matter content, coarse soil fragments, and permeability.

The K factor was calculated by extracting and reprojecting the content of organic carbon, sand, silk, and clay along the study area boundary using the following equation:

$$\mathrm{K} = F_{\mathrm{csand}} \times F_{cl-si} \times F_{orgc} \times F_{hisand}\mathrm{K} = F_{\mathrm{csand}} \times F_{cl-si} \times F_{orgc} \times F_{hisand} \quad (3),$$

Where:

F_{csand} = coarse sand content coefficient:

$$F_{csand} = \left(0.2 + 0.3 \times \exp\left[-0.256 \times m_s \times \left(1 - \frac{m_{silt}}{100}\right)\right]\right) \quad (4),$$

$F_{cl\text{-}silt}$ = clay and silt ratio coefficient:

$$F_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3} F_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3} \quad (5),$$

$F_{organic}$ = organic carbon content coefficient:

$$F_{orgc} = \left(1 - \frac{0.25oegC}{orcC + [3.72 - 2.95 \times orcC]}\right) \quad (6),$$

F_{hisand} = sand content coefficient:

$$F_{hisand} = \left(1 - \frac{0.7 \times \left(1 - \frac{m_S}{100}\right)}{1 - \frac{m_S}{100} + \exp\left[-5.51 + 22.9\left(1 - \frac{m_S}{100}\right)\right]}\right. \quad (7),$$

Digital Elevation Model Data

This study utilized data from the ASTER GDEM digital elevation model, which has a spatial resolution of

30 m. The initial datasets were combined, reprojected, and masked to calculate the slope and topographic factor. Then, the combined topographic coefficient was calculated using the equation developed by Moore & Burch [25]:

$$LS = (flow\ accumulation \times \frac{Cell\ size}{22.13})^{0.4} \times (\frac{sinSlope}{0.0896})^{1.3} \quad (8)$$

Vegetation Cover and Management Factor (C)

The cover management coefficient (C) is commonly employed to evaluate the effectiveness of soil and vegetation management systems in mitigating soil erosion. The value of parameter C is contingent upon factors such as vegetation type, growth stage, and coverage percentage [26, 27]. C values range from 0 for forest plots with 100% ground cover to 1 for bare soil plots [28]. Thus, Sentinel -2 images with the following indicators were used to calculate this coefficient:

LULC	C factor value
Water	0
Trees	0.03
Rangeland	0.01
Flooded vegetation	0.21
Crops	0.21
Built Area	0
Bare ground	0.45
Snow/Ice	0
Clouds	0

Practical Conservation Support Factor (P)

The conservation practice factor, also known as the support practice factor P in use, refers to the ratio of soil loss resulting from a specific control practice compared to the soil loss observed in treatments applied both upslope and downslope. Essential erosion control practices include delineation, contour strip cropping, and terracing [29]. The P coefficient ranges from 0 to 1, with 0 indicating high conservation and 1 indicating poor conservation [30]. In this study, a P factor of 1 was universally applied due to a lack of support or management practices throughout the region.

Results And Discussion

The Rainfall Erosivity Factor (R)

The map based on the precipitation erosion coefficient indicates that the coefficient in the region varies from 46.7 to 425 MJ mm ha/h/year. The southeastern and southern parts of the region, specifically the Kegen, Raiymbek, and Talgar districts, exhibit the highest values. Conversely, the Balkhash district demonstrates lower values (Fig. 2). The erosive force is prominently evident in the higher regions characterized by hills. There is a direct correlation between precipitation distribution and erosion. As precipitation decreases, the erosive force decreases [31]. A higher R-value indicates a greater susceptibility to soil erosion caused by rainwater runoff [32].

Fig. 2. Map of precipitation erosion coefficient (MJ mm ha/h/year).

Soil Erodibility Factor (K)

The K factor in the Revised Universal Soil Loss Equation (RUSLE) considers the impact of soil characteristics on soil erosion in high-elevation regions under intense rainfall events (Renard et al., 1997). The assessment of the K-factor is influenced by various factors, including soil texture, geological formation, permeability, organic matter, and soil structure [33].

The proportion of silt in the subsoil is the primary factor influencing soil erodibility. Due to its tendency to separate easily and form a crust, silt exhibits high runoff rates. Soils with high silt content are highly prone to erosion. Organic carbon content significantly influences soil erosion. It lowers the erodibility coefficient, decreases susceptibility to soil erosion, and enhances water infiltration into the soil layers. The high infiltration rate reduces discharge and erosion [34]. Estimates are based primarily on percentages of silt, sand, and organic matter, as well as soil structure and permeability [35]. The K value of soil erodibility signifies the susceptibility of specific soil types to erosion-induced stratification [36].

The soil types of the area must be determined to calculate the K factor. Fig. 4 shows soil types and their mechanical composition. According to this data, the erosion coefficient is calculated. The K value ranges from 0 to 1; the higher the value, the more susceptible

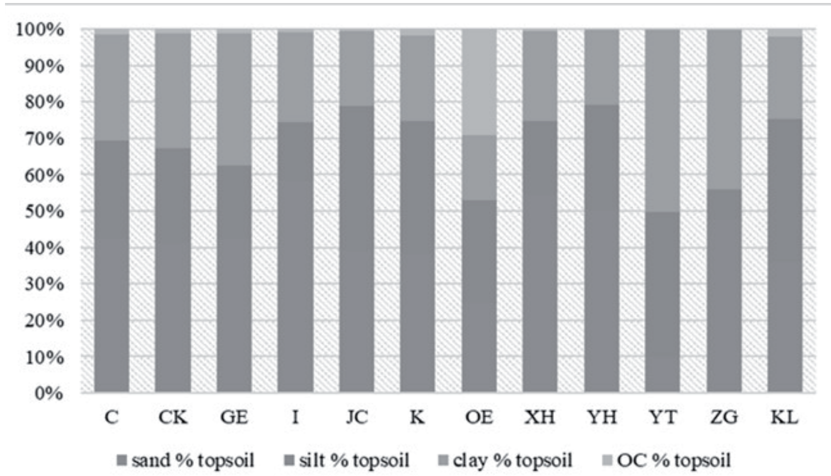

Fig. 3. Mechanical composition of soils in the region. The abbreviations stand for C - Chernozems, Ck- Calcic Chernozems, Ge - Gleyic Luvisols, I - Lithosols, Jc – Calcaric Fluvisols, K - Kastanozems, Oe – Eutric Histosols, Xh – Haplic Xerosols, Yh – Haplic Yermosols, Yt – Takyric Yermosols, Zg – Gleyic Solonchaks, and Kl – Luvic Kastanozems.

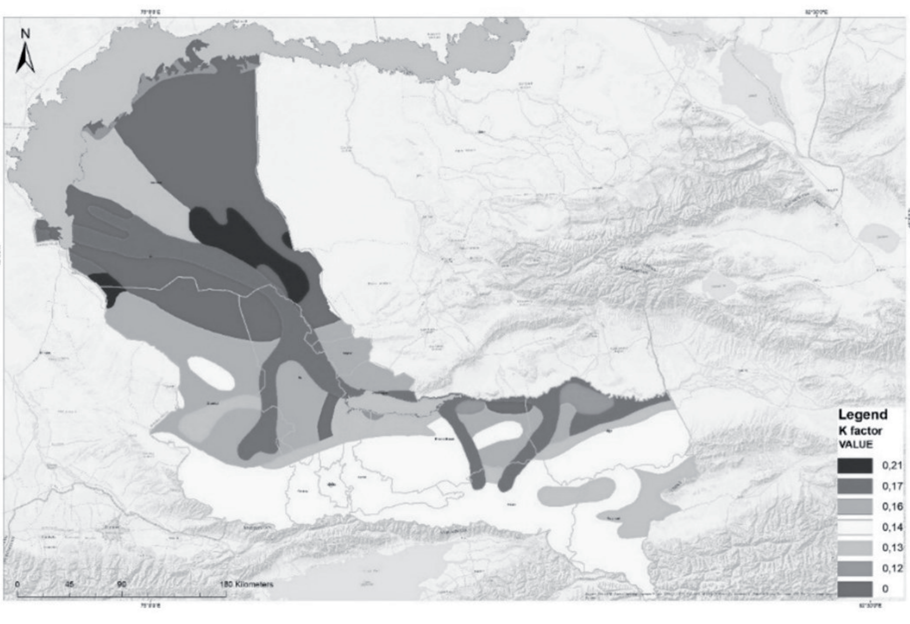

Fig. 4. Soil erodibility (K Factor) map.

the soil is to erosion. According to the extracted DSM boundary data, the following soil types are common in the region (Fig. 3).

Generally, clay and sand-dominated soils have low K values due to resistance to stratification and high infiltration rates, respectively [37]. Silt soil has the highest K value because it is highly crusted and generates high runoff rates and amounts [38]. As shown on the map above (Fig. 4), the values vary from 0 to 0.21. The highest value is in the central part of the Balkhash district, where Takyric and Haplic Yermosols are widespread.

The surface of a typical takyr is bare or almost bare, light gray, and mottled with small cracks; they are filled with earthy material so that, in general, they resemble parquet. Indeed, takyr resembles a sidewalk made of wooden blocks; it is very compact and impermeable to water [39]. Typically, these soil types develop in shallow depressions characterized by a high clay content, facilitating water accumulation and subsequent formation of salt crusts upon evaporation [40].

Slope Length and Steepness Factor (LS)

The degree of soil erosion is also influenced by topographical factors, including slope length (L) and steepness coefficients (S) [41]. Increasing slope length L is caused by increased erosion due to the gradual accumulation of runoff towards the lower slope. As the slope steepness coefficient S increases, soil erosion increases, increasing velocity [34, 42]. Areas with pronounced relief, such as mountain ranges, are characterized by the highest values of the LS coefficient. Conversely, areas with soft relief exhibit the lowest values of this coefficient [43]. The results indicate that the southern and southeastern parts of the region have a steeper slope. This topographic relationship matches the erosion factor quite well (Fig. 5).

The relief of the Almaty region consists of foothills and lowered peripheral areas of mountain systems and ridges, which exhibit hilly or mountainous characteristics, as mentioned above. Slopes ranging from 1-3° are susceptible to erosion phenomena [44]. The intensity of erosion processes is influenced by both the sweetness of the slope and the slope length index. Slopes up to 500 m long exhibit a weak intensity of flushing, while slopes of 1000 m or more exhibit the maximum possible intensity of flushing.

Vegetation Cover and Management Factor (C)

A negative correlation exists between higher vegetation levels and the probability of soil erosion. The coefficient C ranges from 0 to 1, where higher values signify increased soil erosion due to the absence of protective vegetation, while lower values indicate greater soil particle compactness [41, 45]. According to the data presented in Fig. 6, the C-factor value is between 0 and 0.45. Thus, areas with vegetation in the central part of the region have low values. Barren, open, bare land without vegetation cover showed higher values.

Estimation of Annual Soil Loss

The annual soil loss was calculated using a raster calculator in a GIS framework. This involved multiplying the R, K, LS, C, and P coefficients. The study's empirical analysis found that the average annual soil loss in the area ranged up to 26279 t/ha/year (Fig. 7). The results suggest that the southern and southeastern parts of the area exhibit greater vulnerability to soil erosion than the rest of the area.

The results of the study establish that the intensity of soil washout is determined by a set of natural conditions, among which the relief is fundamental.

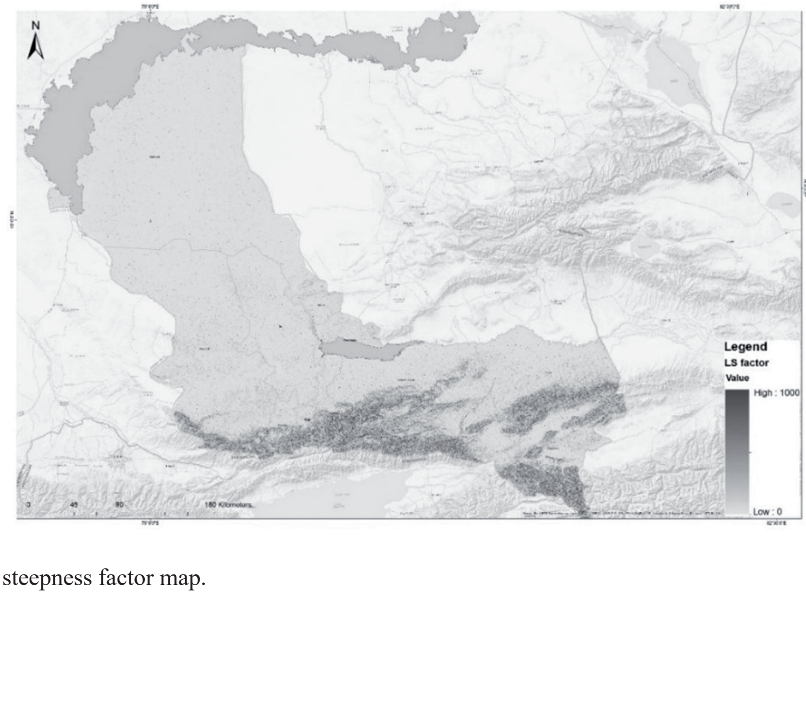

Fig. 5. Slope length and steepness factor map.

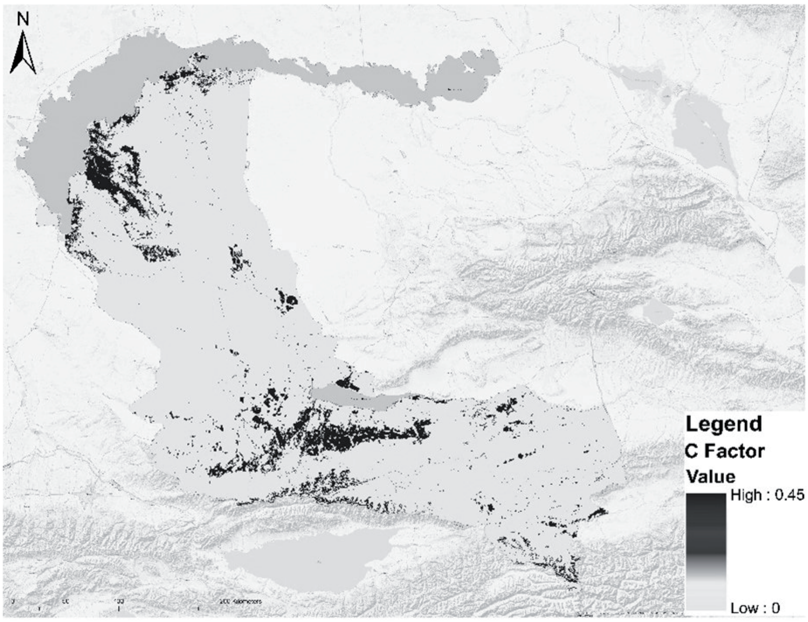

Fig. 6. Cover management factor map.

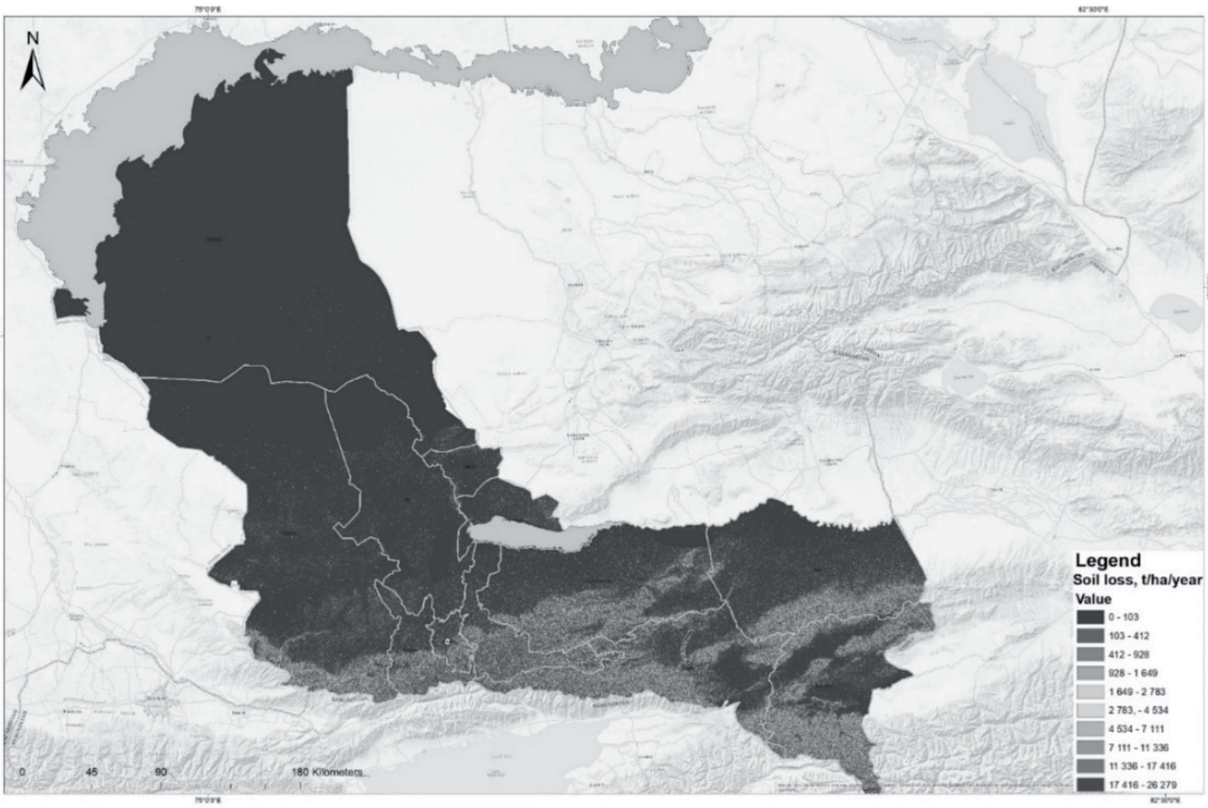

Fig. 7. Soil loss distribution, t/ha/year.

An area of 93359 ha, accounting for 88% of the region's land, experiences an annual soil loss of up to 103 t/ha. On 9% of the region's territory, soil losses range from 103 to 412 t/ha, while 2% has double the amount of soil loss.

The figure indicates that less than 1 % of the region's total area is classified as high and very high risk of soil erosion, as depicted by the red color on the map. The conservation of this region, which is highly prone to soil erosion, should be considered a top priority.

Pasture degradation stands as the primary determinant of soil and vegetation cover deterioration in mountainous regions. Overgrazing is manifested in the disturbance of vegetation cover in some places up

Table 1. Indicators of soil loss under different land use land cover.

Soil loss, t/ha/y	Area of soil loss levels, sq.km	LULC 2022 (MODIS)	%
0-103	93,359.62	Dense Herbaceous	56.51
		Sparse Herbaceous	32.78
		Other	10.71
103-412	8,671.37	Barren	47.03
		Dense Herbaceous	22.6
		Sparse Herbaceous	23.27
		Other	7.09
412-928	2,431.16	Barren	62.61
		Dense Herbaceous	9.33
		Sparse Herbaceous	22.85
		Other	5.21
928-1649	439.31	Barren	70.24
		Dense Herbaceous	7.05
		Sparse Herbaceous	17.91
		Other	4.8
1649-2783	107	Barren	67.26
		Dense Herbaceous	10.32
		Sparse Herbaceous	18.38
		Other	4.05
2783-4534	31.52	Barren	57.15
		Dense Herbaceous	18.16
		Sparse Herbaceous	21.18
		Other	3.51
4534-7111	9.78	Barren	46.58
		Dense Herbaceous	23.7
		Sparse Herbaceous	27.27
		Other	2.45
7111-11336	3.24	Barren	34.64
		Dense Herbaceous	30.31
		Sparse Herbaceous	30.98
		Other	4.07
11336-17416	0.98	Barren	27.48
		Dense Herbaceous	45.3
		Sparse Herbaceous	21.51
		Other	5.71
17416-26279	0.36	Barren	84.56
		Dense Herbaceous	15.44

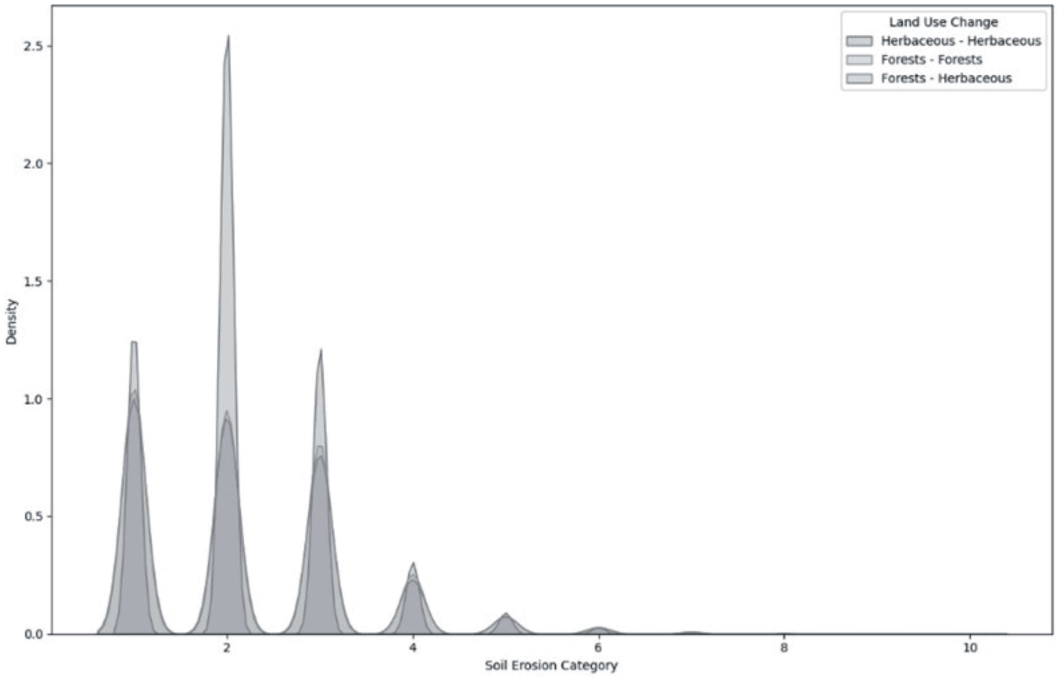

Fig. 8. Kernel Density Estimate of soil erosion categories for top 3 land use changes (2001-2022).

to its destruction, accompanied by over-consolidation and destruction of surface soil horizons [46, 47]. There is a significant correlation between soil degradation and land use. The study examined the impact of changes in land use and land cover on erosion rates [48]. In addition to the model output, we analyzed the region's land cover data from 2001 to 2022 and integrated 27 land use change scenarios into a soil loss map. The results indicate that 80% of the regional landscape is pastureland, with 93% of this land being more susceptible to soil erosion than other land types (Table 1, Fig. 8).

According to recent data, a significant proportion of the agricultural lands in the region, precisely 84%, are designated as pasture lands [16]. The remote sensing results indicate that about 34.9% of the pastureland in the region, *i.e*., 1,229,221 ha, is not being used for its intended purpose, specifically livestock grazing. Many factors contribute to this phenomenon, including problems related to water supply, lack of infrastructure on remote pasture lands, and financial constraints faced by small farmers, which limits their ability to graze livestock in remote areas.

This situation is compounded by the fact that there is a growing demand for these lands in certain areas of the region due to their transfer to private ownership and non-utilization for their intended purpose. The result is decreased livestock numbers and increased social unrest among rural communities.

Conclusions

Assessing the rate of soil erosion in the Almaty region, this study used the RUSLE model within a GIS framework and incorporated various datasets, including precipitation, vegetation cover, soil composition, and topographic features, to estimate the extent of soil erosion. The region is facing a significant issue of soil erosion, primarily caused by intensive agricultural practices such as land use, underutilization of irrigated land, degradation of arable land due to the deterioration and failure of irrigation and drainage systems, as well as the negative impacts of deforestation and improper land management.

The RUSLE model is a significant tool for evaluating the potential risks of soil erosion and implementing efficient soil conservation strategies in the Almaty region. It considers crucial factors such as rainfall erosivity, soil erodibility, slope length and steepness, crop management, and conservation practices. Its application provides essential information on erosion risks and assists in developing sustainable land management practices to mitigate soil erosion and conserve the region's soil resources.

This study reveals that Talgar, Kegen Karasay, and the southern part of Zhambyl and Enbekshikazak districts exhibit a greater susceptibility to soil erosion, thereby presenting a heightened level of risk in comparison to other geographical areas in the region. Approximately 88% of the region experiences erosion at up to 103 t/ha/year. The region has an estimated annual soil loss of up to 26,279 t/ha. Therefore, integrating remote sensing and GIS and utilizing the RUSLE model holds significant importance in determining input parameters for soil erosion modeling and resource management.

Acknowledgments

This research was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant Number BR18574227).

Conflict of Interest

The authors declare no conflict of interest regarding the publication of this article.

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