GeoJournal of Tourism and Geosites
ISSN 2065-1198, E-ISSN 2065-0817

Year XVI, vol. 51, no. 4spl, 2023, p.1812-1822
DOI 10.30892/gtg.514 spl22-1177

SOIL EROSION AND IMPACT ON RECREATIONAL RESOURCES IN THE SHYNGYRLAU BASIN, WESTERN KAZAKHSTAN: A MULTI-ANALYTICAL ASSESSMENT

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Citation: Ramazanova, N., Turyspekova, E., Assylbekov, K., Ozgeldinova, Z., Ahmedova, A., Ayapbekova, A., Samarkhanov, T., & Khamzaeva, J. (2023). SOIL EROSION IN THE SHYNGYRLAU BASIN, WESTERN KAZAKHSTAN: A MULTI-ANALYTICAL ASSESSMENT. *GeoJournal of Tourism and Geosites*, 51(4spl), 1812–1822. https://doi.org/10.30892/gtg.514spl22-1177

Abstract: Over the past decades, water erosion has increased significantly in the Shyngyrlau River basin. Recreational development, haphazard construction and operation of roads have led to increased water erosion and the formation of numerous linear erosion forms. Erosion reduces the natural resource status of the region. Water erosion develops in most cases along roads laid along the thalwegs of the ravine-hollow network. The light substrate along with sparse vegetation cover (the sparseness is aggravated by intensive grazing) predetermine its rapid development. Water erosion is an acute problem arising from the present climate change, agricultural intensification and diverse forms of anthropogenic land degradation. Assessment of present and potential soil erosion is useful for landscape preservation as well as development planning. Multi-analytical modeling can provide a quantitative and consistent estimation of soil erosion and sediment yield under locally specific environmental conditions. The soil loss model, Revised Universal Soil Loss Equation (RUSLE), integrated with GIS, has been used to estimate soil loss in the Shyngyrlau Basin (a left-bank tributary of the Ural River, NW Kazakhstan). The RUSLE model is based on remote sensing and field data; erosion probabilities were determined using GIS. The percentage ratio of the soil loss in the Shyngyrlau River basin shows erosion variation of 0.001–2.47 t/ha/yr. The degree of erosion increases with the length of the slope. A new factor Chip curvature (Cu factor), defining the accuracy of the soil loss results, was defined. According to this factor, soil erosion in the study area is 0.007–2.48 t/ha/yr within the low erosion class. The lowest indicator of the K factor is 0.2 in sandy clay soils used as pasturelands. The highest K factor (0.3) relates to clayey arable soils. The research results add to implementation of new strategies in soil management and conservation practices reducing soil erosion in the Shyngyrlau Basin. Both climate and anthropogenic factors are seen behind the activated ground erosion. The development of forms of water erosion leads to a violation of the integrity of modern natural complexes of the West Kazakhstan region, which significantly reduces their stability and recreational potential.

Key words: Shyngyrlau Basin; RUSLE; GIS; Soil; Erosion; Climate; Environment

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INTRODUCTION

Present soil erosion is a global phenomenon that degrades agricultural lands worldwide by removing the top, nutrient-rich surface layer. This process generates an increasing surficial runoff ona more impermeable subsoil, and reduces the amount of water available to plants. The effectiveness of a soil conservation program depends on the calculation of soil loss and the identification of crucial areas for implementation of soil preservation management practices. The soil erosion results in a depletion of soil elements due to natural mechanical factors such as wind, water, and gravity, frequently with co-acting human factors (Gunawan et al., 2013).

The biophysical environment, which includes soil, climate, terrain, bedrock, top ground cover, and interactions between these, affects the locally specific soil erosional processes. Erosion is a natural geological occurrence that occurs when soil particles are removed by water or wind and carried to new locations. Slope, length, local geology and geomorphology are the principal topographical features that affect the mechanism of soil erosion and the top surface runoff. The runoff intensity and reduction in water infiltration into ground increase with slope (Nearing et al., 2005) As the runoff's velocity rises, the runoff generated by the gravity slope processes will cause soil erosion. Some anthropogenic actions, such as agricultural practices and deforestrationpromoting expansion of farmland, would exacerbate erosion rates. Steep slopes, climate, torrential rains, improper land use, and vegetation patterns of the local land cover are some of the variables that contribute to erosion (Renschler et al., 1999). Additionally, some loose (sandy) soilsare more susceptible to erosion (Mekonnen et al., 2015). Insightful modeling may provide closed information regarding the current state of ground stability and erosion predispositions/tendencies, and mitigation of risks. The effects of soil erosion and deposition need to be taken into account in terms of present climate change (Lal, 2003; Liu et al., 2003; Berhe et al., 2007; Doetterl et al., 2012). Soil erosion and deposition are crucial for maintaining the equilibrium of the atmospheric carbon budget (Alexakis et al., 2013).

Human alterations of the landscape, such as reduction of native vegetation for crop agriculture and grazing, channelization of streams, and tile and ditch drainage, among other activities, have led to deeply incised channels with accelerated stream bank erosion (Zaimes et al., 2006). In Western Kazakhstan, some former modeling the process of soil erosion in the basin of small rivers of Western Kazakhstan was performed resulting in locally specific erosion actions (Chashina et al., 2020). The problem of soil erosion is a key problem for agriculture in the country, and also has an impact on the recreational sector, since recreational land use is directly related to agriculture, and agriculture depends on soil fertility and the erosion component (Ramazanova et al., 2022).

It is expensive and time-consuming to evaluate the soil erosion risks using the standard approaches (Bonilla et al., 2010). Geographic information systems (GIS) are useful for integrating field data, data from remote sensing technologies, and data from currently used soil erosion models (Moore et al., 1991; Imamoglu and Dengiz, 2017; Fernandez et al., 2003; Gitas et al., 2003).The Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) are the most frequently used erosion assessment tools (Xu et al.,2009; Udayakumara et al., 2010; Das et al., 2018).

RUSLE employs an empirical methodology based on how erosion processes work in combination with GIS landscape models (Prasannakumar et al., 2012; Ranzi et al., 2012; Renard et al., 1997; Sharma, 2010; Wijesundara et al., 2018; Ranzi et al., 2012; Wijesundara et al., 2018).The RUSLE model can predictan erosion potential on a cell-by-cell basis (Shinde et al., 2010) demarcating the spatial distribution of soil loss across a wide area. Various factors assessing the erosion potential value may be determined using the GIS tools and programs. This paper presents a multi-analytic approach using the empirical soil erosion RUSLE models integrated with GIS to estimate the soil erosion risks in the Shyngyrlau Basin, and discuss the impact of change in the land use-land cover with respect to the soil erosion ratio. The study combines the regional remote sensing data, GIS, and RUSLE data in order to detect the most accurate spatial distribution of soil erosion and analyze the effects of changes in land use and the land cover exposed to erosion. The regional soil erosion probability zones within the belt of the Central Asian parkland steppes are defined (Mhangara et al., 2012).

STUDY AREA

The study area is located in NW Kazakhstan within the Shyngyrlau River valley (Figure 1). The length of the river that is a left-bank tributary of the Ural River is 290 km^2, with a hydrological catchment area of 6940 km^2. The sources of Shyngyrlau are located on the Poduralsky Plateau at an altitude of 250 m. A meandering river channel with ox-bow lakes characterizes the lower reaches. Since November until mid-April the river is frozen. The waters of the river are used for irrigation and rural water supply. On the right river bank there is the city of Aksai. The water temperature is 17–26.9°C, pH 7.74–7.83.

The regional climate is continental, semi-humid, with moderately harsh winters with little snow. The average monthly temperature in January is –14.5°C, in July +22.6°C, the average annual temperature is +4.2°C. The mean annual precipitation is 268 mm, the highest average monthly precipitation is in June (39 mm) and October (32 mm), and lowest average annual precipitation is in January (8 mm). The main part of the region is occupied by steppe landscapes of elevated plains of the Poduralsky Plateau. Alluvial terraces are developed along the rivers. The area is drained towards north by the Ilek River which is a principal tributary of the Ural River) with small perennial tributary streams that dry up in summer, and the Shyngyrlau River flows in the central part of the region. Along the valley of the Utva River and the territory adjacent to the Ilek River in the north there are open grasslands of the Pre-Syrtovy Lowlands.

The regional bedrock is built by sedimentary rocks—Cretaceous chalk and limestone (the Poduralsky Plateau), overlain by marine sediments/clays of the Oligocene Akchagyl Sea, loams and sands (the Pre-Syrtovy Highlands).Within the PoduralskyPlateau, the plain is intensively dissected by an ancient, presently inactive river network into syrts, ridges and cuesta ridges, on the slopes of which erosion forms gullies and ravines. In the leveled areas, a mosaic micro-relief is developed. On the Pre-Syrtovy Lowlands there is the Ural River valley plain geologically structured by of alluvial deposits of the Ilek and Shyngyrlau Rivers. Between the Poduralsky Plateau and the Ilek River, small sand massifs and large wavy elevations—ashiks—are developed. The influence of halokinesis (movement of large masses of salts to the surface) is manifested over the landscape. In the south there are two gravity slope sand massifs with large differences in the aeolian deposit elevation over relatively short distances—Zhar-Shagal Ridge (with the adjacent forest dacha Kara-Agash at the bottom of the slope) and the Ak-Kumy Ridge (Petrenko et al., 1998). The Shyngyrlau-Ilek *soil-geobotanical* region enters the territory of the Shyngyrlau basin in the northeast. The previously widespread colorful feather grass steppes on dark chestnut soils were largely plowed. Only some pristine areas with feather grass steppes have been preserved. Fescue, Becker fescue and white wormwood grow in these places on sandy soils. The Dzhambeity - soil and plant cover region, covering the slopes of the Poduralsky Plateau, enters the southern part of the basin. The broken geomorphic relief is represented by river valleys, gullies, and outcrops. The modern pedological variety includes chernozems, chestnut soils and solonetz. Sagebrush and secondary steppes with feather grass (tyrsa) and fescue are widespread.

Finally, in the extreme southeast, along the Pre-Syrtovy Ridge of the Poduralsky Plateau, flat-undulating spaces of Erkekov-feather grass steppes with sandy and sandy loam light chestnut soils dominate (Janaleyeva, 2010).

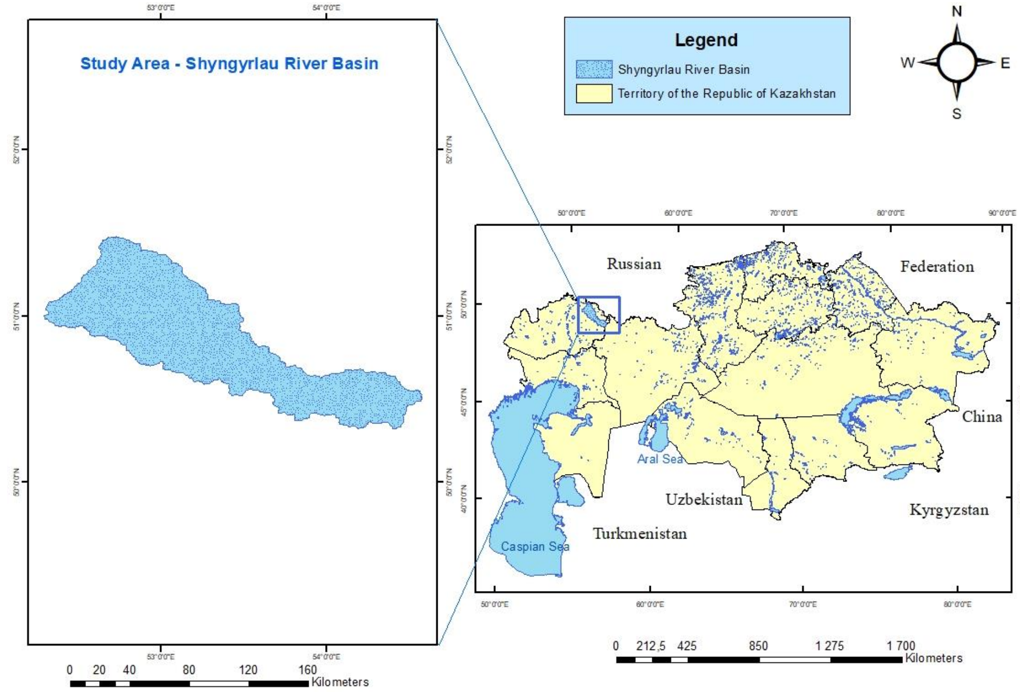


Figure 1. Map of the Research Area (Source: compiled by Ramazanova and Turyspekova in the ArcGIS program)

MATERIALS AND METHODS

Methods

The goal of the present study was to assess a spatial distribution of soil erosion in the study area using multi-analytical approach combining remote sensing, GIS, and the Revised Universal Soil Loss Equation (RUSLE). The research rational was to define the soil erosion probability and the effects of ongoing erosion in the Shyngyrlau Basin, and document the changes in land cover due to natural and anthropogenic factors.

In order to quantify soil erosion risk at various levels, including single slope, river/wadi catchment, regional, as well as global scales, several precise soil erosion models have been created during the last decades (Prasannakumar et al., 2012). Among these, there is the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965; Wischmeier and Smith, 1978), the European Soil Erosion Model (EUROSEM) (Morgan. et al., 1998), Soil Erosion Model for the Mediterranean Region (SEMMED) (De Jong et al., 1998), Water Erosion Prediction Model (WEPP) (Flanagan et al., 1998; Ascough et al.,1998,), the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998), and Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) (Rudra et al., 1985). The USLE model has been widely usedworldwide to assess soil erosion risks. The less cost-demanding data-processing alternative is the Revised Universal Soil Loss Equation (RUSLE).

The revised model accommodates more accurate methods to estimate rainfall erosion (R), soil erodibility (K), slope length and steepness (LS), land cover management (C), and conservation practice (P) factors. Information on factors leading to soil erosion can be used as a guide for formulating appropriate soil conservation and land management plans. The RUSLE model is used to estimate the magnitude of soil erosion loss from watershed areas, the spatial distribution of soil erosion and its severity, delimiting sites vulnerable to soil erosion for both agricultural and partly forested sites. The model has several advantages: it is 1) easy to implement and understand from a functional perspective, 2) less demanding in terms of data requirements, 3) compatible with the Geographic Information System (GIS). Overall, USLE and RUSLE models are two of the most popular and widely used soil erosion models for agricultural areas throughout the world (Ramazanova et al., 2023).

The RUSLE model was estimated from remote sensing and field data, and erosion probabilities determined using GIS. Within the present study area, the RUSLE model demonstrates effectiveness compared to the USLE model (Wischmeier and Smith, 1978). In addition, RUSLE turns to be more flexible in modeling soil erosion in terms of its ability to change conditions and parameters, and is easy to integrate with a GIS for spatial analysis (Wischmeier and Smith, 1965).

The RUSLE (Renard et al., 1997) model is expressed as Eq. (1): $A * R * K * LS * C * P$ (1)

Where: A Computed soil loss per unit area per year (t/ha per year)
R The rainfall erosivity factor (MJ mm ha^{-1} h^{-1} $year^{-1}$)
K The soil erodibility factor (t ha MJ^{-1} mm^{-1})
LS The slope length and steepness factor (dimensionless)
C The cover and management factor (dimensionless)
P The support practice factor (dimensionless)

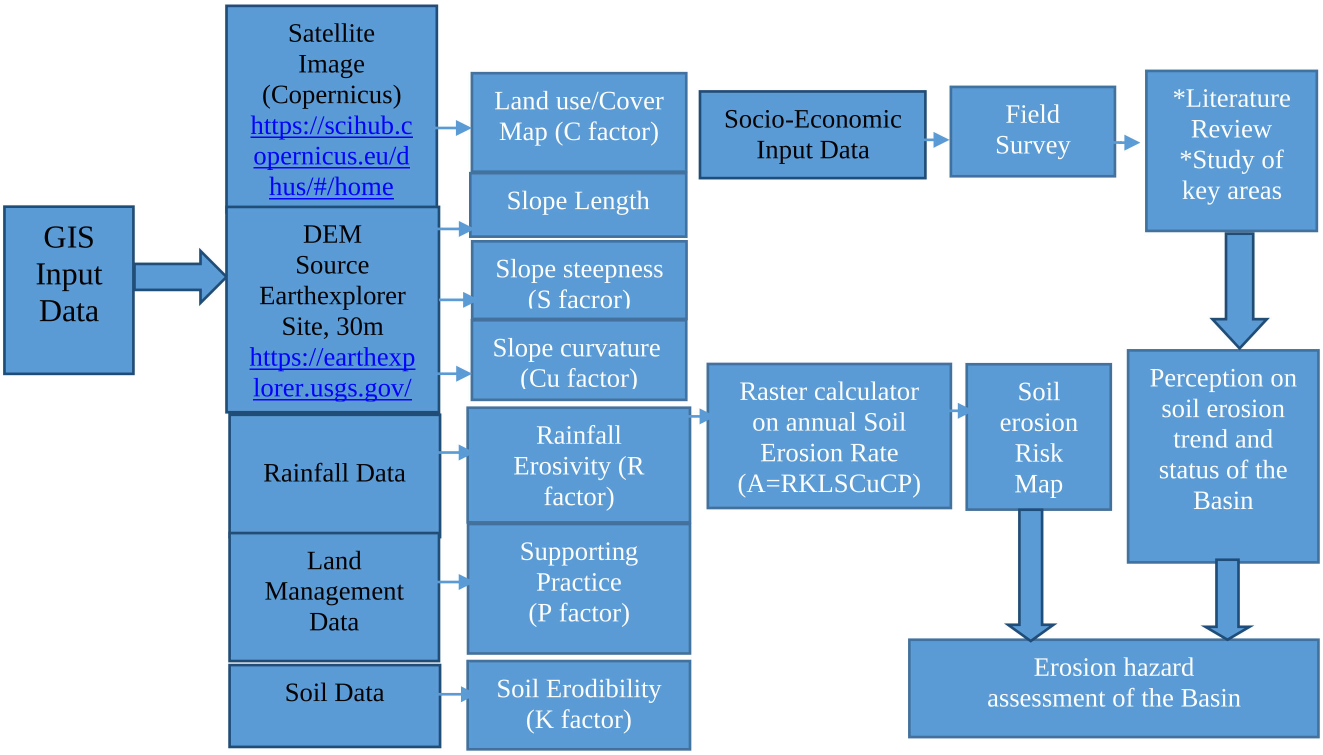


Figure 2. A diagram illustrating the application of the RUSLE model for estimating soil loss within the research area

Calculation of the RUSLE Factors:

Rainfall Erosion Factor (R)

The initial data for the implementation of the precipitation map of the study region were the statistical series of precipitation for the warm and cold periods of 2010–2021 according to Kazhydromet (Official Internet resource - RSE “KAZHYDROMET” https://www.kazhydromet.kz , 11/01/2021). Precipitation indicators were taken for each observation period per month for each meteorological station in the study region, after which the data were averaged and processed in Microsoft Office Excel. The entire region is characterized by scarcity of precipitation and high dryness of air and soil. Precipitation is unevenly distributed over the territory of the West Kazakhstan region, the average annual precipitation varies from 300 mm in the north to 170 mm in the south of the region (Janaleyeva, 2010).

For the precipitation mapping, various interpolation methods were used including the Spatial Analyst module of ArcGIS 10.1 software "Spline". This method calculates the point values based on a mathematical function that corrects the conditions of the given geographic area, resulting in a smooth surface that passes through all measurement points.

The Geostatistical Analyst module was used to interpolate the values by studying the relationships between all control (control) points and building a continuous precipitation distribution surface. This module allowed to build an interpolation model and to evaluate statistically the quality of the final results.

Factor-R, Factor erosion of sediments R connects the intensity of precipitation with the kinetic energy available for the erosion of soil particles (Wischmeier and Smith, 1978; Panagos et al., 2015). The erosion coefficient of precipitation is calculated based on the amount of atmospheric precipitation according to the following formula:

$$R=0.548257*P-59.9 \quad (2)$$

Where, P is the average annual amount of precipitation.

Soil Erosion Factor (K)

The K-factor is a coefficient of soil erosion that reflects both the soil's susceptibility to erosion and the rate of runoff, measured under the conditions of a standard single plot. Data for defining the mechanical composition of the soil were taken from the website *Open Land Map,* presenting a raster mosaic of the surficial land mass structure. Each value of soil texture was given its erosion resistance coefficient at the average content of organic matter in the soil. During the fieldwork in the study areas along eight key study sections, the mechanical composition of the soil was determined in addition to the type of land use and crop arable land,. The analysis of the mechanical pedological qualities (2021) completed the cartographic data (Table 2). Soils with high clay contents have low K values, around 0.05 to 0.15, because they are resistant to separation. Roughly structured, loose soils, such as sandy soils in the study area, have low K values, around 0.05 to 0.2, due to low runoff, although these soils are easily separated. Medium grain size soils, such as silty loamy soils, have moderate K values, around 0.25 to 0.4 and produce moderate runoff. Soils with high silt content are the most susceptible to erosion of all soils. They separate easily, are prone to crusting, and give high flow rates. The K values for these soils are generally greater than 0.4. Organic matter reduces erosion because it reduces the soil's susceptibility to sloughing and increases infiltration, which reduces runoff and thus erosion. The addition or accumulation of increased organic matter due to management such as manure application is represented by the C factor and not by the K factor. Soil structure influences both susceptibility to detachment and infiltration. Soil profile permeability affects K because it affects runoff.

Although the K factor was chosen to represent the soil in its natural state, past management or misuse of the soil as a result of intensive farming in the Shyngyrlau River basin can increase its erosive capacity.

Slope Length and Steepness Factor (LS)

The LS coefficient was derived from the Stone and Hilborn equation (Stone and Hilborn, 2000). The calculations and coefficients of the spatial distribution L, S is carried out in the GIS environment using the following equation:

LS=power [(Flow Accumulation)*cell size/22.13]0,4*power[sin(slope*0,01745/0,0896].

The value of the terrain steepness is expressed in degrees. Most of the space images were obtained from the US Geological Survey mapping portal https://earthexplorer.usgs.gov.The value of the terrain steepness is obtained in degrees.

Slope Curvature Factor (Cu)

The idea of this article is that the improved universal soil loss equation (RUSLE) is used along with the GIS spatial analytic techniques and satellite data, giving an assessment of the current distribution of water erosion processes and development conditions in the Shyngyrlau River basin. For the first time, the coefficient Cu (the curvature of the soil loss slope) is used based on the improved universal soil loss equation. In the study, a new factor called curvature (Cu factor) was introduced to augment accuracy of the soil loss results. Application of the above coefficient in the Shyngyrlau River basin will allow for a more accurate assessment of soil erosion.

Calculations and spatial distribution coefficients L, S, and Cu are applied in the GIS using the following equation:

$$\text{LSCu} = \left[\frac{Q_a M}{22.13}\right]^y \times \left(0.065 + 0.045 \times S_g + 0.0065 \times S_g^2\right) \quad (3)$$

where LSCu - Topographic factor; Qa - Flow Accumulation grid; Sg - Grid slope in percent; M - grid size (x × y), y or NN common value – dimensionless exponent, taking slope and curvature values between 0.2–0.5. The total curvature based on the Zevenbergen-Thorne algorithm can be calculated as (Zevenbergen and Thorne, 1987):

$$\text{Curvature} = -2(D + E) * 100 \quad (4)$$

$$D = [\frac{(z^4+z^6)}{l^2} - z_5] \qquad E = [\frac{z_2 + z_8)}{l^2} - z_5]$$

where z^4 – height points in cells; l – distance between elements of the DEM (spatial resolution of the raster), units of measurement (meters). Curvature is measured in 1/m, after which it is multiplied by 100, i.e. the profile (vertical) curvature characterizes the change in the slope of the surface by 100 m along its main direction. The convex part is characterized by positive values, and the concave part is characterized by negative values, zero values are respectively characterized by a flat surface in the profile.

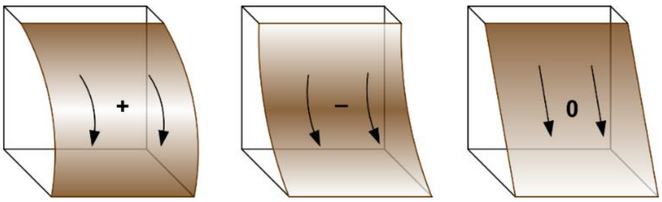


Figure 3.The profile curvature is parallel to the direction of maximum slope, characterizes the curvature of the streamline in the vertical plane (Buckley, 2010)

The range of possible values for all three curvatures ranges from –0.5 to +0.5 for areas with flat terrain and from –4 to +4 for mountainous areas [49]. Elevation of the study region ranges up to 277 m NN curvature is calculated + 0.5.

In our calculations, we used the profile curvature, which affects the acceleration or deceleration of the flow, and, therefore, affects erosion and sediment deposition, which is calculated using the ArcGIS Spatial Analyst software module.

Crop Management Factor (C)

Factor-C takes into account the type of crop and the method of tillage. It is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. Factor C is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. In the study region in the north during the period of vegetative activity (from May to August) with average cloudiness, the monthly amount of photosynthetic active radiation is 284–336 MJ/(m^2 •month), in the south this figure increases to 293–348 MJ/(m^2 •month). During the period of vegetative activity during the month, the average sun shines 9.5–10.5 hours a day. By natural conditions, the study area is favorable for growing long-day plants, solar radiation indicators are sufficient to provide optimal conditions for the growth of crops. For early spring crops, the duration of the growing season is 191–212 days; for late spring crops, this figure increases from north to south by 156–180 days.

In the study area, during the growing season, at an air temperature >5°C, 3100–3800°C of heat accumulates; at an air temperature above 10°C, 2900–3600°C of heat accumulates During the warm period, on average, 112–228 mm of precipitation falls, of which 62–137 mm of precipitation falls during the period of active vegetation of crops. In the northern regions of the region for this period, about 72 mm of precipitation is provided by 90%, in the southern regions of the region; this amount drops to 44 mm, which is insufficient for the normal development of crops. On the territory of the region, the moisture coefficient is 0.33–0.74. In the northern part of the study region, the biochemical oxygen demand under natural moistening conditions exceeds 30-35 q/ha, in the central part the value of biochemical oxygen demand is from 20 to 30 q/ha, and in the southern part of the region is less than 20 q/ha.

Conservation Practice Factor (P)

One of the main land management measures aimed at the efficient use of land resources and preservation of soil fertility is anti-erosion measures. In this case, the main task is the implementation of anti-erosion measures. The development of design schemes for the use of erosion-hazardous lands determines economic technical measures for the implementation of anti-erosion actions for a certain period of time, as well as long-term goals for protecting land resources from erosion processes and ways to achieve them. In the region under study, the following types of anti-erosion measures are used (Darbayeva et al., 2020; Ramazanova et al., 2019):

- anti-erosion crop rotations,
- flat-cut processing methods,
- plowing across the slope,
- dumpless plowing,
- socketing

Table 1. Values of anti-erosion measures according to the universal RUSLE formula (P factor data) [35]

Support practice	P factor
Up and down slope	1.0
Cross slope	0.75
Contour farming	0.50
Strip cropping, cross slope	0.37
Strip cropping, contour	0.25

Factor P expresses complex anti-erosion measures aimed at protecting the upper layer of the soil cover from erosion. This factor characterizes intentional initiative forms of soil cover cultivation by land users.

The values of this factor vary from 0.01 to 1; an increase in the value characterizes the absence of coverage, a decrease in the set. For example, contour farming can reduce the value of this factor to 0.50. Since the territory of the Shyngyrlau River basin is represented predominantly by slightly undulating and slightly sloping plains, soil cultivation is mainly carried out by transverse plowing. Cross plowing technology is used on inclined surfaces up to 3°. Transverse plowing is characterized by a value of “0.75” (Table 1). The main objective of organizing anti-erosion measures is to counter erosion processes and restore the fertility of eroded soils, as well as to prevent the formation of erosion in areas with a potentially high risk of erosion processes, that is, the elimination of factors that can cause erosion processes. But planned activities can be implemented if these activities are cost-effective. In this regard, it is necessary to determine the economic feasibility of the planned anti-erosion measures. When assessing economic calculations for the implementation of anti-erosion measures, it is first of all necessary to take into account their environmental feasibility, which primarily takes into account the preservation of landscape diversity and the prevention of erosion processes.

RESULTS

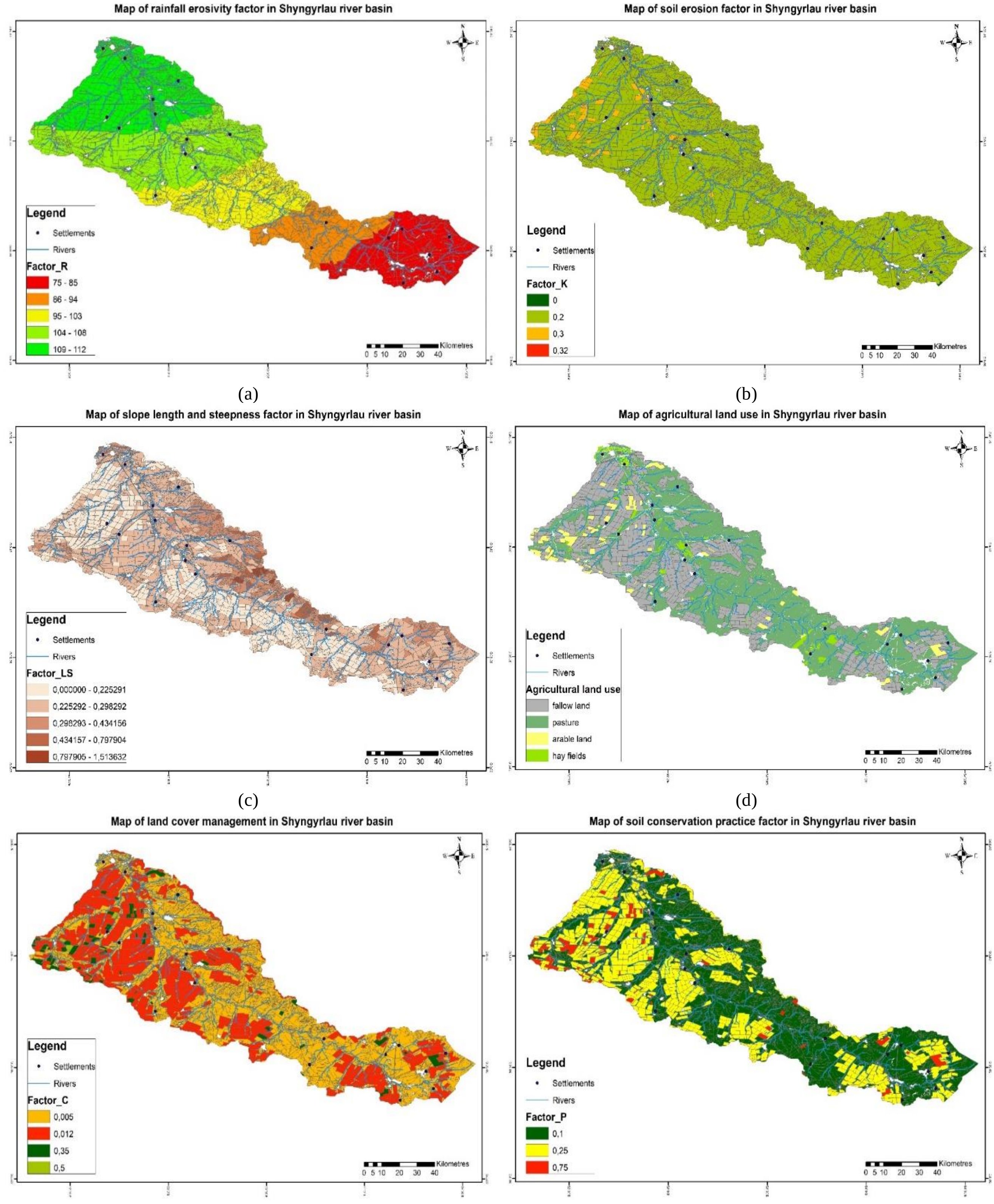
The produced rainfall (R factor) maps Figure 4 (a) showed a temporally and spatially differential precipitation distribution. These variations follow the annual rainfall Figure 4 (a that has been recorded at the rain monitoring four stations in the Shyngyrlau Basin. As a rule, the data used in the calculation of the R factor, except precipitation, remain unchanged. This regularity is also characteristic of the spatial distribution of precipitation. The precipitation factor displays a value variation range from 75 to 112.6 with an increasing and decreasing trends in the north and the southwest, resp,. Figure 4 a. In general, the northern part of the studied territory has the maximum predisposition for initiation of erosion processes because of the higher rainfall and topographic gradient. The degree of erosion increases with the length of the slope.

Table 2. Key study areas West Kazakhstan region

	Key area	Coordinates	Soil structure
1	Zelenovsky	N 51°60’712“ E 052°10’570“	Clayey
2	Shyngyrlausky	N 51°41’880“ E 051°93’748“	Loam
3	Syrymsky	N 51°27’457“ E 051°92’629“	Loess
4	Karatobynsky	N 51°18’658“ E 051°10’022“	Loess
5	Burlinsky	51°43’964“ 050°85’882“	Loess
6	Terektinsky	51°42’762“ 050°78’121“	Diversesediments
7	Akzhaiyksky	N 51°33’221“ E 050°61’142“	Diversesediments
8	Baiterekský	N 51°35’331“ E 050°54’535“	Clayey

The soil erosion map Figure 4 b displays the areas where solid crystalline rocks forming the present surface are widespread with a coefficient of 0.2 which are less prone to erosion.

According to the mechanical composition of the soils in the Shyngyrlau Basin of the West Kazakhstan region, they are mainly clayey, loamy, sandy, and loess-like soils with low K values. At places, where the level of silt is high in loams the soil cover is more susceptible to erosion, there the K factor reaches a level of up to 0.32.



(e) (f)

Figure 4. The RUSLE soil cover erosion parameters in the Shyngyrlau Basin: (a) Rainfall erodibility factor (R factor) for the year 2021; (b) erodibility factor (K factor); (c) slope length and steepness factor (LS factor); (d) agricultural land use; (e) cover management factor (C factor); (f) erosion control practice factor (P factor)

The steepness map was generated for the entire river basin Figure 4c. The slope rate was calculated in the GIS environment with a LS-factor of 0.0001. The value of the relief steepness of the Shyngyrlau River basin varies from 0 to 1.513 degrees. The climatic conditions of the area allow the cultivation of corn and sorghum.

The low yield of crops in the investigated river basin is due to traditional agricultural practices, and the low productivity of the irrigated lands. Other factors include frequent droughts, a low level of application of modern technologies, and an extremely low production efficiency of the irrigated land.

DISCUSSION

The conducted field investigations and analytical research provided a close assessment of the potential soil erosion dynamics in the Shyngyrlau Basin using the diagnostic multi-criteria of the RUSLE model processed by the ArcGIS software. The RUSLE approach for the regional risk erosional assessment on the territory of Western Kazakhstan was applied for the first time in spite of certain methodology limitations. The applied empirically based approach provides prediction of the long-term average annual rate of slope soil erosion using six specific factors. It estimates soil loss in similar landscape terrains and under analogous meteorological conditions. The integrated factors (R, LS, K, P, C, Cu) minimize the overall uncertainties. The newly introduced Cu-factor increased accuracy of the soil loss results.

The MAP is the key factor, along with the slope structure, inclination and the land use, affecting soil erosion. In the northern part of the study area (Taskala, Aksai, Uralsk, Yanvartsevo), >300 mm of MAP is recorded contrasting to <200 mm of precipitation in the south of the region (Taipak, Zhanakazan) (Figure 5). In general, during the warm season of the year, precipitation falls 2 times more frequently than during the cold season. In the course of a year, two precipitation maxima are observed; the first in July in the north gradually shifting southward, and the second in October.

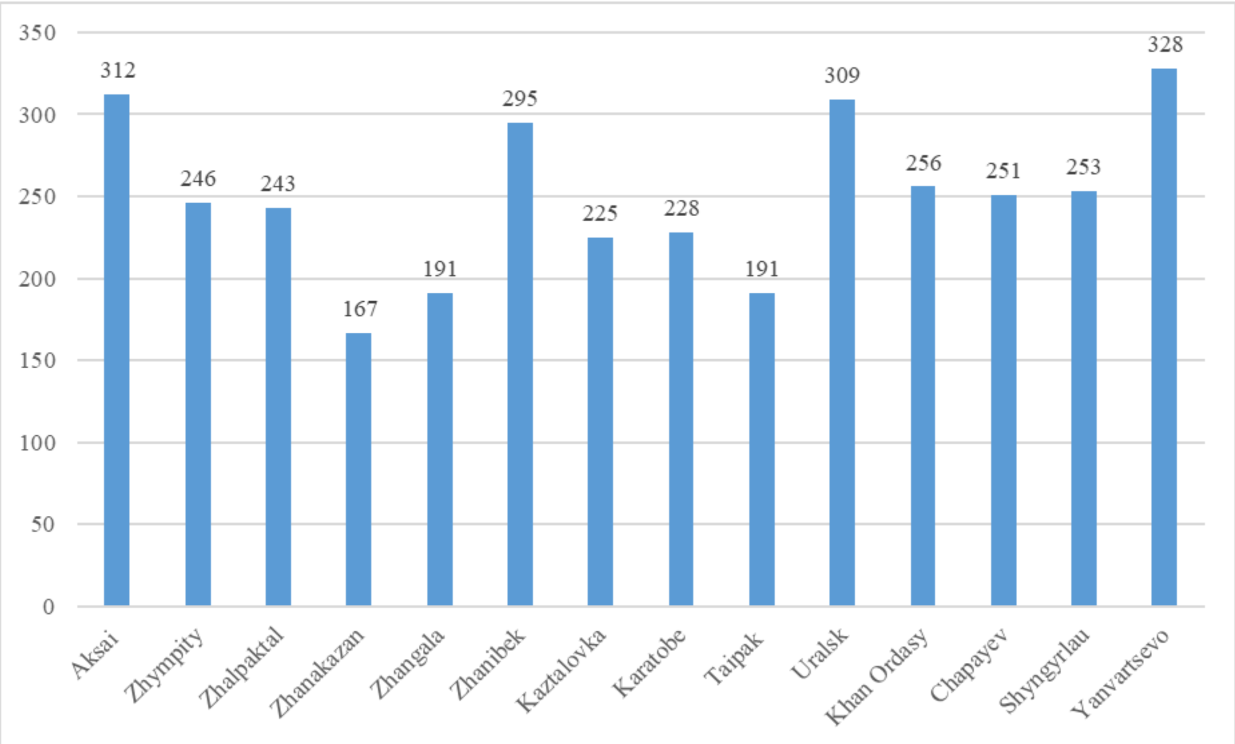


Figure 5. Average annual precipitation records of the West Kazakhstan region

According to the precipitation variation records from the weather stations, the long-term precipitation data for the warm (April–October) and cold (December–March) seasons are uniform and amount 22–23% of MAP (Table 1). The results (Figure 4 (a)) show that the precipitation regime, both warm and cold, remains moderate from year to year, and is long-term relatively stable. The frequency from 2011 to 2021 of a high rainy warm period is 21% with a probability of 2 times per decade. The repeatability of a low rainy warm period is 18% with a probability of 2 times per decade.

The K-factor is a major variation to the USLE procedure. Its values for the study area (0–0.32) asses soil erodibility with zero values least susceptible to erosion. The analytical data show that K is not constant, but varies with the season, starting from the early spring and ending in mid-autumn during the first ground freeze. Practically at all key sites (Table 2), there was a high content of clay in soils. These are the places with the low erosive risks and more consolidated top grounds. The relief model (DEM) of the Shyngyrlau River basin shows a dominantly low topography gradually decreasing from the NE to the SW. The anti-erosion measures are aimed to counteract the activated erosion processes and restore the fertility of the eroded soils, as well as to prevent erosion in the areas with potentially high ground instability. It is necessary to determine the economic feasibility of the planned anti-erosion measures because of high costs. Also environmental feasibility must take into account the preservation of the pristine landscape diversity and the prevention of erosion processes.

The climatic, geomorphic and pedological conditions predetermine the agricultural yields. The cooler years do not offer optimal predispositions for growing winter barley opposite to winter rye and wheat. This is partly due to a small snow cover and the soils' minor retention potential during early winter. The latter plants can be cultivated in the Zelenovsky, Taskalinsky, Uralsk, Terektinsky, Shyngyrlau and Borilinsky districts, as well as in the north of the Kaztalovsky, Zhanibeksky, Syrymsky, Akzhaiyksky and Karatobinsky districts. Nevertheless, during cold winters, winter wheat and rye are more likely to freeze. In the northern part of the study area, during the period of vegetative activity (from May to August) with average cloudiness, the monthly amount of photosynthetic active solar radiation is 284–336 MJ / (m^2 •month), in the south this figure increases to 293–348 MJ / (m^2 •month), with average sunshine 9.5–10.5 hours a day. The regional natural conditions provide optimal predispositions for vegetation growth and crop agriculture.

In the areas of cultivation of crops in the study area, the minimum air t ranges from –37.6° C to –41.1 ° C. Under such temperature conditions, the optimal height of snow cover that protects winter crops should exceed 23 cm. The average snow cover height throughout the region is < 23 cm along with a strong drop in air temperature. The indicator of the severity of winter according to A.M. Shulgin from 1 to 2.9 (severe) for 4 weather station according to A.M. Shulgin (Baisholanov, 2017), >3 (very severe) for 9 weather station. Such indicators do not create optimal conditions for growing winter crops, where the main reason is the low snow depth. The results conclude that the annual average soil loss estimated using the RUSLE model is about 142,419 t/ha/yr in the Shyngyrlau Basin. It is also observed that the overall erosion varies with respect to the relief, vegetation cover and the character and intensity of land use. In the most threatened places, suitable soil conservation practices are to be implemented (Figure 6).

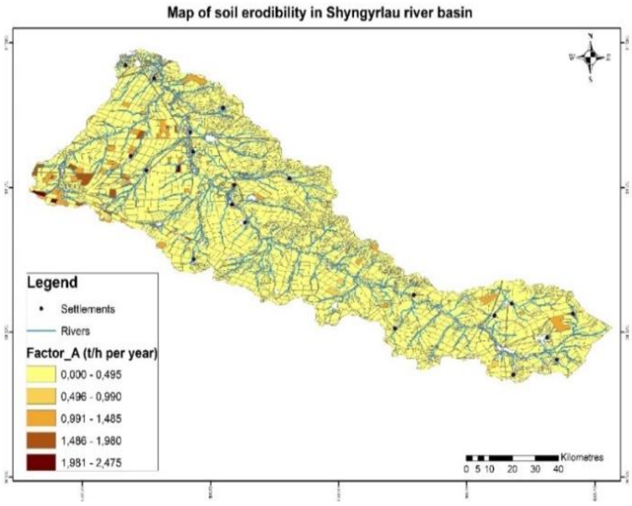


Figure 6. Soil erodibility (the Shyngyrlau river basin)

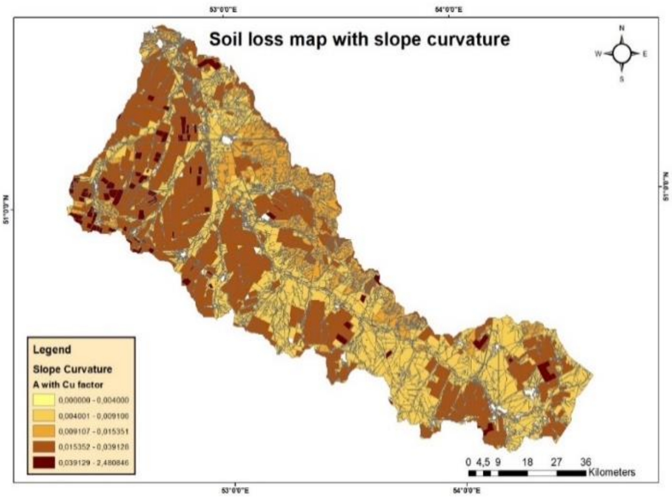


Figure 7. Soil loss map with slope curvature (the Shyngyrlau river basin)

CONCLUSION

Active recreational development, haphazard construction and operation of roads have led to a strong increase in water erosion and the formation of numerous linear erosion forms. Water erosion develops in most cases along roads laid along the thalwegs of the ancient ravine-hollow network. Light substrate and sparse vegetation cover predetermine its rapid development. The situation is aggravated by intensive grazing. Thus, in most cases, the expansion of the erosion network is caused by anthropogenic factors. The development of forms of water erosion leads to a violation of the integrity of modern natural complexes of Western Kazakhstan, which significantly reduces their stability.

The multi-proxy, satellite and GIS-based RUSLE analysis detailed more accurately the spatial distribution of places in the Shyngyrlau Basin prone to erosion. The data layers (raster maps) extracted for the K, LS, Cu, R, C, and P factors of the RUSLE model were integrated within the Arc GIS spatial analyst to quantify, evaluate, and generate the maps of soil erosion risks and its severity within the study area of Western Kazakhstan**.** The soil erosion risks show their increase in the agrarian areas due intensification of agricultural practices. The lowest Soil Erosion Factor (K) value (0.2) defines the sandy clayey soils, predominantly of a pastoral land use; the highest value (0.3) associated with clayey soils characterize the arable agriculture. According to the newly defined Cu Factor, the soil erosion in the investigated area is estimated 0.007–2.48 t/ha/yr.

Empirical soil erosion models are easy to interpret, require minimal resources, and can be worked out with readily available inputs to the areas of high erosion risk. The results define the spatial places exposed to erosion and outlined control measures in the most severely affected places. The RULSE model helps in mapping vulnerable zones susceptible to soil erosion and sediment re-deposition. Application of the model has a major significance in determination and identification of most effective management strategies aimed at the surficial erosion control. A comparison of the potential and actual soil loss helps in assessing the erosion impact of various cropping systems as well as to the choice of the proper land conservation practices. The results in of the pilot research facilitate implementation of new approaches in conservation practices of the non-cultivated (pristine) and cultivated lands, reducing soil erosion in Western Kazakhstan. They also contribute to the regional development management and provide options to policymakers for control of the present/future soil erosion risks, mitigation of degraded lands, and soil loss.

Author Contributions: Conceptualization, N.R., Zh.O., and J.C.; methodology, K.A. and A.A.; software, E.T.; writing – original draft preparation, N.R. and E.T.; writing – review and editing, J.C., analysis tools and technical assistance S.T.; A.A. and J.Kh.; supervision N.R.;. All authors have read and agreed to the published version of the manuscript.

Funding: This study was conducted within the framework of grant funding of scientists for scientific and (or) scientific and technical projects for 2021-2023 by the Ministry of Science and Higher Education of the Republic of Kazakhstan (IRN No. AP09260232).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data are available on request to the corresponding author..

Acknowledgments: The research undertaken was made possible by the equal scientific involvement of all the authors concerned.

Conflicts of Interest: The authors declare no conflict of interest.

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Article history: Received: 25.09.2023 Revised: 24.11.2023 Accepted: 20.12.2023 Available online: 29.12.2023