UDC: 631.4:528.8:551.435

ASSESSMENT OF SOIL EROSION PROCESSES IN THE SANGZAR RIVER BASIN USING GEOINFORMATION SYSTEMS AND EMPIRICAL MODELS

Shermanov Beknazar Ortiqovich,
Assistant of the "Biology" module
e-mail: beknazarshermanov12@gmail.com

Alfraganus University

Annotation. The article presents the results of a comprehensive assessment of soil erosion processes in the Sangzar River basin using geoinformation systems and modern empirical models. The study examines relief, soil cover, climatic parameters, vegetation, and anthropogenic pressures influencing the intensity of erosion. A modified RUSLE model integrated with remote sensing data and a digital elevation model was applied for quantitative estimation. Spatial patterns of erosion development were identified, and high-risk areas were delineated. Scientifically grounded measures for stabilizing soils and reducing degradation intensity are proposed.

Key words: soil erosion, Sangzar River, GIS, RUSLE model, LS factor, land degradation, NDVI, monitoring, digital elevation model (DEM), loess soils, pasture degradation, anthropogenic pressure, remote sensing (RS), rainfall erosivity (R factor), soil erodibility (K factor), climate extremes, hydrological runoff.

Annotatsiya. Maqolada Sangzorsoy havzasida tuproq eroziya jarayonlarini geoaxborot tizimlari va zamonaviy empirik modellardan foydalangan holda kompleks baholash natijalari keltirilgan. Tadqiqotda relyef, tuproq qoplami, iqlim omillari, o'simlik qoplami va eroziya darajasiga ta'sir ko'rsatadigan antropogen bosimlar tahlil qilindi. Miqdoriy baholash uchun masofaviy zondlash ma'lumotlari va raqamli relyef modeli bilan integratsiyalangan RUSLE modelining modifikatsiyasi qo'llanildi. Eroziya jarayonlarining fazoviy qonuniyatlari aniqlanib, yuqori xavfli hududlar belgilandi. Tuproq barqarorligini oshirish va degradatsiyani kamaytirish bo'yicha ilmiy asoslangan choralar taklif etilgan.

Kalit so'zlar: tuproq eroziyasi, Sangzorsoy, GIS, RUSLE modeli, LS omili, yer degradatsiyasi, NDVI, monitoring, raqamli relyef modeli (DEM), lossimon tuproqlar, yaylov degradatsiyasi, antropogen bosim, Yerning masofaviy zondlanishi (DZZ), R omili, K omili, iqlim ekstremallari, gidrologik oqim.

Аннотация. В статье представлены результаты комплексной оценки процессов почвенной эрозии в бассейне Сангзарсая с использованием геоинформационных систем и современных эмпирических моделей. Исследованы рельеф, почвенный покров, климатические параметры, растительность и антропогенные нагрузки, влияющие на интенсивность эрозионного смыва. Для количественной оценки применена модифицированная модель RUSLE, интегрированная с данными дистанционного зондирования и цифровой моделью рельефа. Выявлены пространственные закономерности развития эрозионных процессов и определены территории повышенного риска. Предложены научно обоснованные меры по стабилизации почв и снижению интенсивности деградации.

Ключевые слова: почвенная эрозия, Сангзарсай, ГИС, модель RUSLE, фактор LS, деградация земель, NDVI, мониторинг, цифровая модель рельефа (DEM), лёссовые почвы, пастбищная деградация, антропогенная нагрузка, дистанционное зондирование Земли (ДЗЗ), фактор R, фактор K, климатические экстремумы, гидрологический сток.

INTRODUCTION

Land degradation in Central Asian countries remains one of the major environmental and socio-economic threats due to the presence of vast mountainous and foothill territories

highly sensitive to erosion processes. The Sangzar River basin, located on the northern slopes of the Turkestan Range, is among the most vulnerable areas. Its natural conditions are characterized by a highly dissected relief, pronounced vertical zonation, strong contrasts in precipitation distribution, and an extremely weak protective vegetation cover across extensive slopes.

These factors create favorable conditions for accelerated surface runoff, active slope dissection, and degradation of soil–vegetation cover, even under moderate anthropogenic pressure. Soil erosion in the Sangzar basin is driven by the following key causes:

1. Degradation of vegetation cover due to historically intensive grazing, early spring overuse of pastures, and the absence of rotational grazing systems, resulting in a steady decline in plant biomass and ground cover [1,3]

2. Irrational land use, including cultivation of slopes with medium and high steepness, improper placement of irrigation systems, and lack of contour tillage [2,11,12]

3. Reduction in humus horizon thickness, caused both by erosion and rapid mineralization of organic matter under arid climatic conditions [2]

4. Uneven spatial–temporal distribution of precipitation, with 70–80% of annual moisture falling as short-term high-intensity rainstorms [4]

5. Loess-like parent materials are characterized by low structural stability and high susceptibility to water erosion [8,11].

Climate change is further intensifying the problem; rainstorms are becoming more frequent, runoff energy increases, and bare soil surfaces expand. Hydrological changes confirm the strengthening of erosion and the formation of new gullies [2,4,6].

Modern GIS and remote sensing (RS) technologies provide new opportunities for detailed and objective analysis of erosion dynamics [5,8]. Integration of DEM data, NDVI, land-use maps, soil information, and climatic indicators allows researchers to:

· identify spatial patterns of erosion
· forecast degradation processes
· assess land resistance to external impacts
· determine zones of critical risk
· develop scientifically grounded restoration measures.

The empirical RUSLE model combined with GIS is recognized as one of the most reliable tools for regional erosion assessment. It incorporates natural and anthropogenic factors such as climate, slope characteristics, soil properties, vegetation, and land management practices [7,9,10].

Thus, the aim of this study is to conduct a comprehensive evaluation of soil erosion intensity in the Sangzar River basin based on GIS technologies and the RUSLE model, and to develop scientifically grounded recommendations for preventing further degradation of pasture landscapes and restoring their productive potential [4,5,9,10].

MATERIALS AND METHODS

A comprehensive methodological approach was used, integrating spatial d ata analysis, GIS technologies, remote sensing, and empirical models for quantitative erosion assessment. This enabled a unified analytical system for interpreting both natural and anthropogenic factors affecting erosion.

Data Sources

1. Digital Elevation Model (DEM)

ALOS PALSAR DEM (12.5 m resolution) was used to calculate slope, aspect, watershed morphology, and the LS factor. The elevated detail allowed the identification of micro-relief forms and potential runoff pathways.

2. Sentinel-2 satellite imagery (10 m)

Used for:

· NDVI calculation
· Monitoring vegetation dynamics
· Seasonal pasture degradation assessment

ISSN 2181-0826 MAXSUS SON 4/2025 y.

· Land-cover classification.

3. Soil map (1:100,000)

Used to determine soil types, texture, humus depth, and natural erodibility. These data were used for K-factor calculations.

4. Meteorological data (2010–2024)

Data from Bakhmal and Gallaorol stations were used to calculate the R-factor and analyze rainfall anomalies. The EI30 methodology was applied for storm intensity estimation.

5. Land-use map CORINE–UZ (2023)

Used to classify land categories and assign P-factor values.

6. Geological and agrochemical data

Used to calibrate K and LS factors and identify erosion-sensitive areas.

RUSLE Model

The quantitative assessment of erosion was performed using the Revised Universal Soil Loss Equation:

$$A = R \times K \times LS \times C \times P$$

Where:

- **A** — annual soil loss (t/ha/year)
- **R** — rainfall erosivity
- **K** — soil erodibility
- **LS** — slope length and steepness
- **C** — vegetation cover factor
- **P** — land-management factor

R-factor

Calculated using modified Wischmeier & Smith and EI30 methodologies.

K-factor

Based on soil texture, humus content, carbonate level, and aggregate stability (0.32–0.41 for loess soils).

LS-factor

Computed using the Desmet & Govers algorithm based on:

· D8 flow routing
· flow accumulation
· slope gradient
· slope length.

Maximum LS values reached **28–31.**

C-factor

Calculated using an NDVI-based exponential model: $$C = \exp\left(-\frac{\alpha \cdot NDVI}{\beta - NDVI}\right)$$

Values ranged from **0.12** (dense vegetation) to **0.70** (bare soil).

P-factor

Highest values (0.9–1.0) correspond to degraded ungrazed or unmanaged pastures.

Results and Discussion

The obtained results demonstrate a complex and spatially heterogeneous pattern of erosion processes in the Sangzar basin. Morphometric parameters, vegetation degradation, soil properties, and grazing pressure collectively determine erosion intensity.

Key findings:

· Slopes exceeding 1**5–20°** and lengths > **150–200 m** generate strong surface runoff

· Southern and southwestern aspects dry out rapidly and lose vegetation cover

· NDVI < **0.15**–**0.20** indicates severe pasture degradation

· Loess soils exhibit high erodibility and structural instability

· Overgrazing remains the dominant anthropogenic driver of erosion

· LS > **20**, NDVI < **0.2**, K = **0.32–0.41**, and P = **0.9–1.0** form critical degradation hotspots.

Conclusion

The Sangzar River basin is classified as a territory with high and very high erosion risk, where natural geomorphological conditions and intensive anthropogenic impacts jointly accelerate degradation processes. GIS-based RUSLE modelling revealed that approximately 43% of the basin area is subjected to severe and extremely severe soil loss, predominantly concentrated on steep loess slopes with weak structural stability. Due to the fine-silty texture, low aggregate durability and high susceptibility to dispersion, loess-derived soils demonstrate the highest erodibility, especially when the protective vegetation cover is reduced.

Seasonally variable NDVI values show a persistent decline in vegetation density during summer and early autumn, which coincides with the period of intensive livestock grazing. The

degradation of pasture biomass reduces the C-factor to critical values, amplifying the erosive effect even of moderate precipitation. In combination with steep slopes (LS > 20) and high soil erodibility (K = 0.32–0.41), the basin's geomorphic structure forms an environment extremely sensitive to hydrological fluctuations.

Climatic instability further aggravates the situation. A clear increase in the frequency and magnitude of high-intensity rainfall events, associated with regional climate change, enhances runoff energy and accelerates the formation of rills, gullies, and sheet erosion. Hydrometeorological data indicate that up to 70–80% of annual precipitation may fall during short, high-intensity storm events, which the degraded terrain is unable to buffer.

These conditions collectively create a self-reinforcing degradation cycle, where vegetation loss leads to increased runoff, which in turn intensifies erosion, further suppressing vegetation recovery. If left unaddressed, this process may result in irreversible loss of fertile topsoil, reduced pasture productivity, expansion of barren lands, and destabilization of local hydrological systems.

Given the severity of the erosion hazard, the basin requires comprehensive, integrative mitigation strategies aimed at landscape stabilization, pasture rehabilitation, slope protection, and sustainable land-use transformation. Key priorities include:

· Restoration of vegetation cover and reintroduction of rotational grazing systems

· Implementation of engineering measures such as micro-terracing, contour barriers, and Flow-dissipating structures;

· Application of organic and mineral amendments to improve soil structure and aggregate stability;

· Development of a continuous GIS-based monitoring system using seasonal NDVI, DEM updates, and erosion-risk mapping;

· Adoption of climate-adaptive land management policies to buffer the impact of high-intensity rainfall events.

These coordinated actions are essential to prevent further soil loss, maintain ecological resilience, and secure the long-term productivity of the Sangzar River basin.

Recommendations

1. Engineering and Agrotechnical Measures

A comprehensive set of structural and agrotechnical interventions is required to stabilize slopes, reduce runoff velocity, and prevent further expansion of erosion-affected zones.

· Construction of micro-terraces on slopes steeper than 10–12°

Micro-terraces redistribute surface runoff, reduce slope length, and promote gradual sediment deposition. Their effectiveness is particularly high on loess-derived soils susceptible to sheet and rill erosion.

· Installation of contour ridges and transverse furrows

These measures interrupt the down-slope flow of water, decrease the hydraulic energy of runoff, and enhance infiltration capacity, which is essential in arid and semi-arid landscapes.

· Establishment of vegetative filter strips on watershed divides and upper slope positions.

Such strips trap fine sediments, reduce sediment yield, and act as ecological buffers preventing slope-channel connectivity.

· Bioengineering stabilization of small channels and ephemeral streams

Use of fascines, brush layering, woven barriers, and geocellular structures reduces channel incision and bank collapse, which are common in rapidly eroding loess environments.

· Formation of surface runoff drainage and dispersion systems

Properly designed diversion channels and runoff collectors redirect excess

ISSN 2181-0826 MAXSUS SON 4/2025 y.

stormwater, decreasing the erosive force acting on fragile slopes. Together, these measures form a multi-level protection system that reduces peak runoff and minimizes slope instability.

2. Restoration and Sustainable Management of Pastures

Pasture rehabilitation is a central requirement to rebuild the protective vegetation cover, without which erosion control is impossible.

· Adoption of rotational grazing systems

Controlled grazing intervals stimulate vegetation regeneration, improve root development, and reduce trampling pressure.

· Reduction of grazing intensity by 35–50%

Scientific evidence shows that moderate to low stocking density significantly increases NDVI and vegetation resilience in semi-arid rangelands.

· Temporary exclusion of severely degraded plots ("resting patches")

These zones act as nuclei for vegetation recovery, allowing natural succession to rebuild topsoil structure.

· Sowing drought- and erosion-resistant forage species

Such plants as Agropyron desertorum, Festuca valesiaca, Bromus inermis, and Onobrychis arenaria establish deep root systems and enhance soil cohesion.

· Implementation of pasture-load regulators and controlled herd movement

This prevents concentration of grazing pressure near water sources and slopes, promoting more uniform utilization of pastures.

Effective pasture restoration improves the C-factor of the RUSLE model, lowering erosion risk by 30–40% over several years.

3. Agrochemical Rehabilitation of Degraded Soils

Rebuilding soil fertility and aggregate stability is essential for restoring erosion resistance.

· Application of 8–12 t/ha of organic matter (manure, compost, biocarbon)

Organic amendments increase aggregate stability, enhance humus content, improve water retention, and reduce soil detachability.

· Phosphorus fertilizers (45–60 kg/ha P_2O_5)

Phosphorus stimulates root growth, helping plants anchor the soil and accelerate pasture regeneration.

· Potassium fertilizers (60–90 kg/ha K_2O)

Potassium strengthens plant tissues, increases drought tolerance, and promotes dense vegetation cover—key for erosion protection.

· Use of green manure crops (sideration)

Leguminous green manures like lupine and rapeseed accumulate biomass, improve nutrient cycling, and rebuild the humus horizon.

Combined agrochemical measures restore the structural integrity of loess soils and significantly reduce the K-factor (soil erodibility).

4. GIS Monitoring and Digital Land Management

Long-term erosion control requires continuous monitoring supported by geospatial technologies.

· Annual NDVI monitoring using multi-seasonal Sentinel-2 imagery

Allows real-time detection of degradation hotspots, grazing impacts, and vegetation recovery dynamics.

· Updating the DEM (Digital Elevation Model) every 3 years

Ensures accurate modeling of slope geometry, channel development, and surface runoff pathways.

· Risk-based erosion zoning maps

These maps classify the basin into categories of erosion hazard, enabling targeted interventions and resource prioritization.

· Development of an integrated GIS platform for pasture management

Such a system supports decision-making by combining data on grazing

pressure, vegetation biomass, soil condition, and hydrological risks.

· Mobile applications for field diagnostics and geo-tagged monitoring

Field users can instantly record new erosion forms, track pasture degradation, and feed information into the main GIS database.

This digital management framework allows authorities to transition from reactive to proactive erosion prevention strategies.

References

1. Avvakumova, A. O. Mathematical modeling of soil erosion factors on arable lands (a case study of the Republic of Tatarstan). Regional Geosystems, 2020, Vol. 44, No. 1, pp. 5–15.

2. Buryak, Zh. A. Improvement of approaches to assessing erosion hazard of agro-landscapes using GIS technologies. Regional Geosystems, 2014, Vol. 29, No. 23 (194), pp. 140–146.

3. Buryak, Zh. A., Narozhnaya, A. G., & Marinina, O. A. Erosion hazard of arable lands in the Belgorod region. Regional Geosystems, 2023, Vol. 47, No. 1, pp. 101–115.

4. Buryak, Zh. A., & Terekhin, E. A. Anti-erosion arrangement of agrolandscapes based on the assessment of potential soil erosion losses using GIS technologies. In: Earth Sciences: Yesterday, Today, Tomorrow, 2015, pp. 1–7.

5. Vlasenko, V. P. Actualization of agro-ecological soil assessment of the Azov-Kuban lowland using GIS technologies. (Publication details not provided in the original source).

6. Gafurov, A. M. Use of unmanned aerial vehicles to assess soil erosion. Regional Geosystems, 2019, Vol. 43, No. 2, pp. 182–190.

7. Glazunov, G. P. Theory of Wind Soil Erosion. Dissertation. Moscow: Lomonosov Moscow State University, 2005.

8. Golubev, I. A. The problem of determining the intensity of water erosion of soils in Siberia. Bulletin of Krasnoyarsk State Agrarian University, 2009, No. 1, pp. 80–83.

9. Gorbacheva, E. N. Application of the Revised Universal Soil Loss Equation (RUSLE) to assess the intensity of water-erosion processes using GIS. Soil Science and Agrochemistry, 2011, No. 2, pp. 42–51.

10. Gorbunov, R. V. et al. (Title incomplete in the original source; likely related to erosion processes in low-mountain regions.) Recommendation: If you provide the full title, I will translate and format it precisely.

11. Demidov, V. V., & Makarov, O. A. Physical Fundamentals of Soil Erosion: Mechanisms, Regularities, and Forecasting. 2021.

12 .Dubrovina, I. A. Chapter II/11. Agro-ecological assessment of soils of typical agro-landscapes of Karelia. In: New Methods and Research Results of Landscapes in Europe, Central Asia and China, 2018, p. 56.