

ESTIMATION OF SURFACE SOIL EROSION IN GRASSLANDS OF THE POIANA RUSCĂ MOUNTAINS. A CASE STUDY

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Abstract. Soil erosion, a natural phenomenon intensified by human activities, represents a significant threat to the environment, agriculture and economic sustainability, affecting the fertility and stability of land, including grasslands, in different regions of the globe and in Romania. To analyze this phenomenon, the study applies the USLE model integrated into GIS environments, using geospatial and remote sensing data to estimate the average erosion rate in the Poiana Rusca Mountains area, with a focus on grassland areas. Factors analysed include rainfall erosion, soil erodibility, topography, land use and the impact of erosion control measures. The results show that most grassland areas have a low average erosion rate (0-3 t/ha/year), due to the protection offered by the vegetation cover, but areas with steep slopes and sparse vegetation record moderate or severe losses (over 21 t/ha/year). The conclusions of the research emphasize the importance of implementing conservation measures, such as the restoration of the vegetation carpet in degraded grasslands and the sustainable management of grasslands, along with the use of geomatic technologies to monitor erosion phenomena, to reduce risks, contributing to the protection of these valuable ecosystems from an economic and biodiversity point of view.

Keywords: grasslands, surface erosion, assessment, geospatial data, USLE, GIS

INTRODUCTION

The degradation of agricultural land and implicitly of grasslands, through soil erosion, is a major problem in many regions of the world (Kim et al., 2005; Vilceanu et al., 2018; Spalevic et al., 2020). This natural phenomenon, amplified by various anthropogenic actions, endangers soil and water resources (Tu et al., 2023) and has significant consequences for the economy, human society and the environment (Hermassi et al., 2023).

Globally, soil erosion is thought to be responsible for about 85% of degraded land (Balabathina et al., 2020), a phenomenon that significantly affects agricultural productivity by decreasing soil fertility (Oncia et al., 2013; Merchán et al., 2023; Patriche, 2023).

Soil degradation through erosion is also an important problem for Romania, having a significant impact on the sustainability of the environment and agriculture. It is considered that about 43% of agricultural land is exposed to a risk of erosion, a phenomenon that manifests itself in various forms, depending on the specifics of local conditions (Nistor and Nistor, 2002).

At a national level, the average erosion rate was estimated at 2.98 t/ha/year (Patriche, 2019) however, this varies considerably depending on the region. Forecasts for the coming decades (Patriche, 2023) points to an intensification of the phenomenon, stressing the importance of adopting effective soil protection measures, especially in the context of climate change.

Soil erosion is also a significant limiting factor for grassland areas, affecting their fertility and productivity. The assessment and estimation of this phenomenon is very important for identifying vulnerable areas and implementing appropriate soil conservation measures.

Currently, the literature presents a wide variety of models and models for estimating and evaluating soil erosion, under various environmental conditions and at different spatio-temporal scales (Estifanos, 2014; Golosov et al., 2017; Asnake and Amare 2019; Mengie et al., 2019; Niacsu et al., 2021; Patriche, 2023).

One of the most widespread and widely used empirical models for assessing soil erosion is the Universal Soil Loss Equation (USLE), later revised in the form of the RUSLE model (Revised Universal Soil Loss Equation), with various variants (Foster et al., 2003; Panagos et al., 2015). These empirical models are integrated and applied through Geographic Information Systems (GIS) and are applied at local, regional, national or international level (Panagos et al., 2015; Borrelli et al., 2017; Patriche, 2019; Marcinkowski et al., 2022; Räsänen et al., 2023).

Based on these theoretical premises and the versatility of the USLE and RUSLE models in the spatial analysis of soil erosion, this study aims to explore the applicability of the USLE model in estimating the average soil erosion rate for grassland areas in the central-eastern part of the Poiana Rusca Mountains, using spatial data, remote sensing data and GIS tools.

MATERIAL AND METHODS

1. Study area

The study area (Figure 1) is located in the western part of Romania, in the Poiana Rusca Mountains. The relief varies from 251 m to 1265 m, according to the Digital Elevation Model (DEM); the average altitude is 816 m, which indicates a mountainous region. The higher altitudes are concentrated in the southwestern and central part of the area, and the lower ones in the peripheral areas. Therefore, the general inclination of the relief is from southwest to northeast.

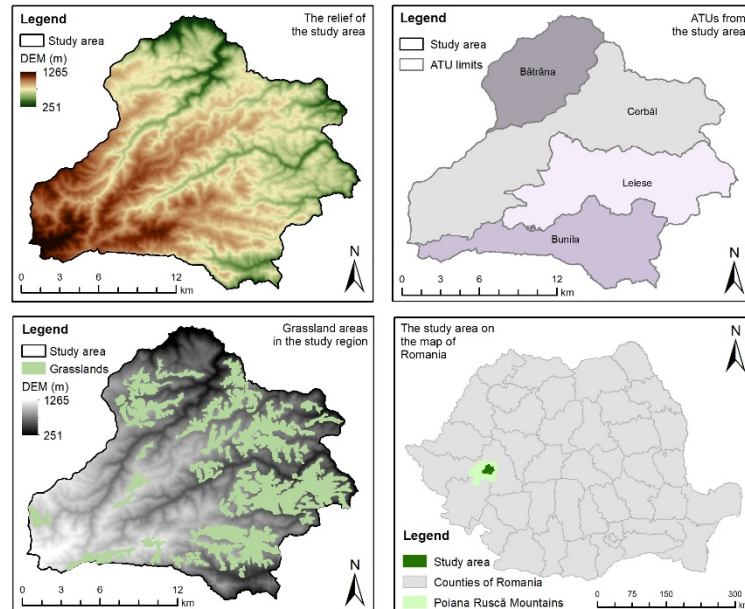


Figure 1. Location of the study area (processing after; ANCPI, 2023; EU - DEM, 2023; Geospatial, 2023)

The land use in the study area is mainly agro-pastoral, a situation characteristic of mountainous areas (Hoancea et al., 2018). The grassland areas, which total 7360 ha, are located especially in the lower areas, in the eastern half and with a greater predominance towards the peripheral areas (Figure 1).

The study area was delimited according to an administrative criterion. It includes four administrative-territorial units (ATUs): Bătrâna (in the north), Corbâl and Lelese (in the central part) and Bunila (in the south).

In general, the study area has a diversified relief, with moderate to high altitudes and is dominated by forests and meadows, indicating agro-pastoral use of the territory. It is well delimited from an administrative point of view and is located in a valuable ecological and natural context, characteristic of the Poiana Rusca Mountains.

2. Materials and software used

In order to estimate the soil surface erosion rate, for the entire study area and in the case of grassland areas, the following statistical and geospatial datasets were used: multiannual average precipitation amounts (2019 - 2023), recorded at 14 meteorological stations in the Banat area (Baze de date climatice, 2023); soil map, in vector format (Geospatial, 2022); Digital Elevation Model (DEM), with spatial resolution at 25 m (EEA, 2016); Sentinel 2A satellite images (Copernicus Open Hub, 2023).

Statistical data and geospatial data were processed with ArcGIS 10.4 for Desktop software (ArcGIS Documentation, 2023).

3. Research methodology

In order to estimate the average annual soil losses due to erosion and to create the erosion vulnerability map, for the entire territory and for the grassland areas, the Universal Soil Loss Equation (USLE) was applied (Balabathina et al., 2020; Ge et al., 2023). This involves the generation, in the form of raster maps, of five factors and then their product, in the GIS environment, according to Figure 2 and Table 1.

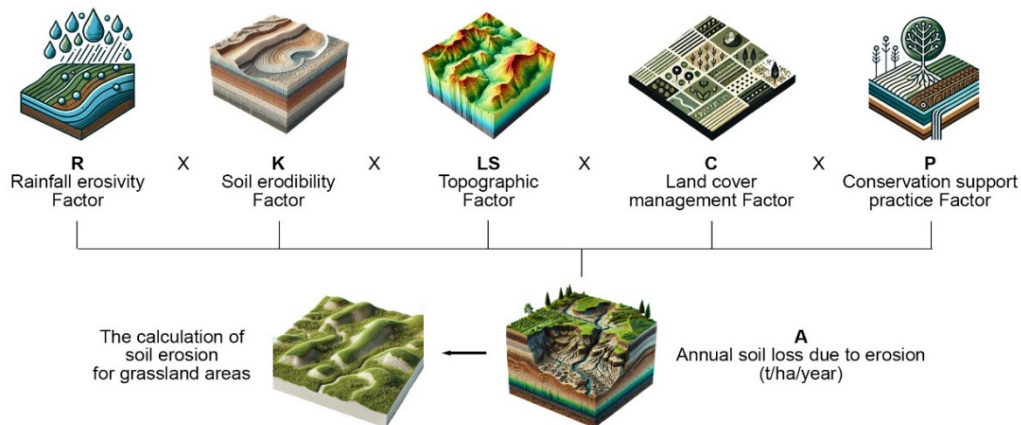


Figure 2. Research methodology

Tabel 1

Equations for the calculation of USLE factors

R - Rainfall erosivity factor¹ (MJ mm ha⁻¹ h⁻¹ year⁻¹)

$$R = 0.55 \times P - 4.7$$

(1)

P - average annual precipitation (mm)

K - Soil erodibility factor² (t ha⁻¹ MJ⁻¹ mm⁻¹)

$$100K = 2.1M^{1.14} \times 10^{-4} \times (12 - a) + 3.25 \times (b - 2) + 2.5(c - 3)$$

(2)

M - calculated as [very fine sand (%) + silt (%)] × [100 - Clay (%)]; a - soil organic matter (%); b - soil structure code; c - soil profile permeability class

LS - Topographic Factor³ (adimensional)

$$LS = \left(\frac{FA \times \text{cell size}}{22.13} \right)^m \times \left(\frac{\sin(\text{slope angle} \times 0.01745)}{0.9} \right)^n$$

(3)

FA - flow accumulation; cell size - 25 × 25 m; slope angle – map of slope, in radians; m = 0.5; n = 1.3 - the exponent values

C - Land cover management factor⁴ (adimensional)

$$C = \exp \left[-\alpha \times \frac{NDVI}{(\beta - NDVI)} \right]$$

(4)

NDVI - Near-infrared band; R - Red band; α = 2; β = 1

P - Conservation Support Practice Factor⁵ (adimensional)

$$P = 0.2 + 0.03 \times S$$

(5)

S - the slope grade (%)

Average annual soil loss (t ha⁻¹year⁻¹)⁶

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

(6)

Source: 1 – Hurni, 1985, cited by Balabathina et al., 2020; 2 - Wischmeier et al., 1971, cited by Selmy et al., 2021; 3 – Mitasova, 1996, cited by Zisu, 2014; 4 - Van der Knijff et al., 2000, cited by Balabathina et al., 2020; 5 - Wener – cited by Allafta and Opp, 2022; 6 - Balabathina et al., 2020; Selmy et al., 2021; Ge et al., 2023

By multiplying the maps of the five factors, in the GIS environment, the map of the average annual soil losses (A, expressed in t ha⁻¹year⁻¹), for the entire area taken into account, was obtained. By extracting the grassland surfaces, the soil erosion map was obtained, in their case.

RESULTS AND DISCUSSIONS

The analysis of grasslands, in general, by geospatial methods allows a detailed and integrated assessment providing precise tools for monitoring, mapping and sustainable management of these ecosystems (Cojocariu et al., 2015; Simon et al., 2022).

Grassland erosion is the process of topsoil removal caused by water, wind or human activities, influenced by factors such as vegetation density, land slope, rainfall intensity and land use, which can lead to loss of soil fertility and degradation of natural habitats (Moisuc et al., 1994; Cojocariu, 2005).

Spatial modelling of soil erosion on grassland areas is an indispensable tool for analyzing, monitoring and managing this complex phenomenon, providing a clear perspective on soil degradation processes. Among the most widely used models for estimating soil loss due to erosion is the USLE (Universal Soil Loss Equation), which allows a quantitative assessment of erosion by integrating five factors: rainfall erosivity (R), soil erodibility (K),

topographic factor (LS), vegetation and land use impact (C - Land Cover Management Factor) and the effect of erosion control measures (P - Conservation Support Practice Factor).

The R factor expresses the ability of precipitation to cause soil erosion, by detaching and mobilizing soil particles (Allafta and Opp, 2022).

At the level of the study area, the factor that quantifies precipitation erosivity (R) varies between 419.55 and 635.62 MJ mm⁻¹ha⁻¹h⁻¹year⁻¹, with an average value of 536.28 MJ mm⁻¹ha⁻¹h⁻¹year⁻¹, indicating a relatively uniform distribution of precipitation erosivity over the entire surface.

The higher values of the R factor are concentrated in the southern and southwestern part of the area, where precipitation erosion has a more intense impact (Figure 3).

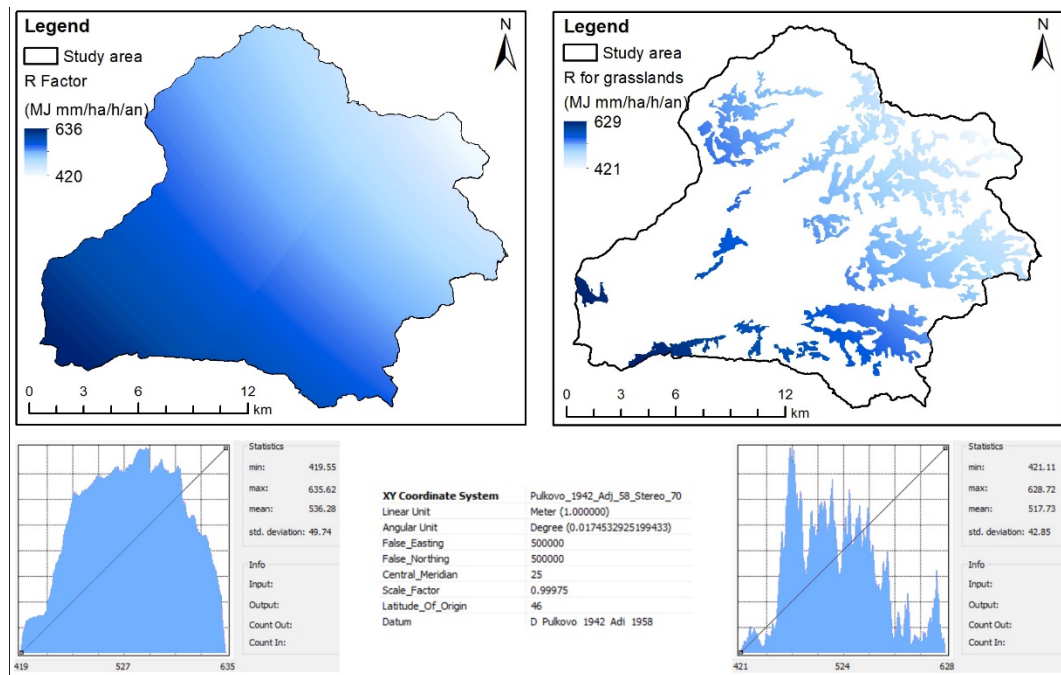


Figure 3. Distribution of the R factor in the study area and on grassland areas

The R-factor for grasslands (Figure 3) ranges from 421.11 to 628.72 MJ mm⁻¹ha⁻¹h⁻¹year⁻¹, with an average value of 517.73 MJ mm⁻¹ha⁻¹h⁻¹year⁻¹.

Compared to the entire area, the grasslands have lower values of precipitation erosivity, which indicates a higher resistance of these surfaces due to the vegetation cover, which cushions the impact of raindrops and reduces the detachment of soil particles.

The distribution of higher values of the R factor in grasslands is predominant in areas with high slopes, especially in the central-southern part of the studied area, where the combination of topography and rainfall intensity can accentuate erosion.

Grassland areas, although they have a greater capacity to protect against erosion due to vegetation, are vulnerable in regions with steep slopes and more intense rainfall, which justifies the implementation of soil conservation measures, especially in areas with higher R-factor values.

The K factor (soil erodibility) indicates the degree of predisposition of the soil to erosion by the detachment and transport of particles under the influence of rain and surface runoff (Selmy et al., 2021; Delgado et al., 2023).

In the study area, the K factor varies between 0.2 and 0.4 t ha⁻¹MJ⁻¹mm⁻¹, and the mean values are 0.22 t ha⁻¹MJ⁻¹mm⁻¹. The regions with higher erodibility values (0.3–0.4 t ha⁻¹MJ⁻¹mm⁻¹) are concentrated in the central-eastern areas of the analyzed area (Figure 4).

The K factor, in the case of grassland areas, has an average of 0.24 t ha⁻¹MJ⁻¹mm⁻¹, slightly higher than the general average, indicating a moderate susceptibility to erosion for these lands.

Grasslands with high erodibility (0.3–0.4 t ha⁻¹MJ⁻¹mm⁻¹) are concentrated in the south and southeast, where the sloping topography and soil texture can accentuate the vulnerability of these surfaces to erosion. In contrast, grasslands in the north and central areas show lower erodibility values (about 0.2 – 0.25 t ha⁻¹MJ⁻¹mm⁻¹), reflecting more stable soils, probably supported by dense vegetative cover.

Grassland areas, although they play an important role in preventing erosion due to vegetation cover, show greater erodibility in areas with more sensitive soils, especially in grasslands located on steep slopes or in regions

with clay soils. Thus, it is essential to implement management and conservation measures in these areas to reduce the risk of erosion and ensure the long-term stability of soils.

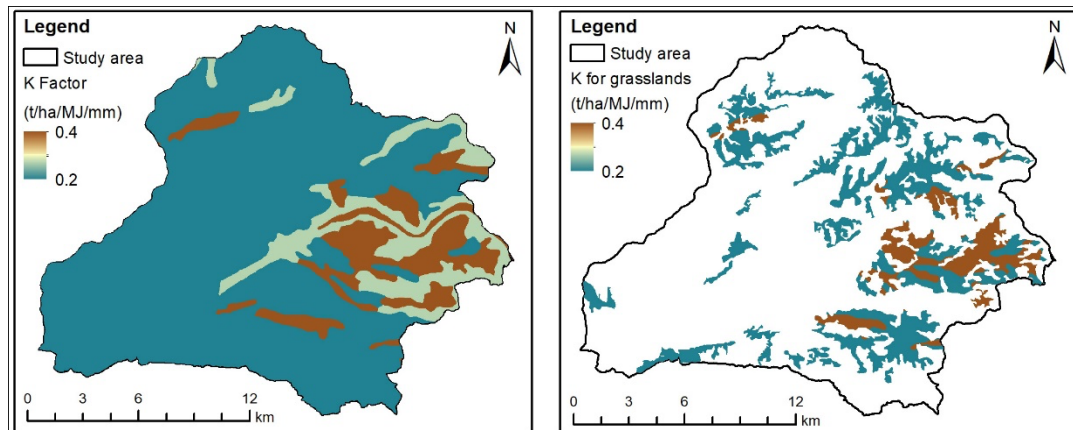


Figure 4. Distribution of K-factor in the study area and on grassland areas

The LS factor (topographic factor) shows the contribution of topography on soil erosion (Ligonja and Shrestha, 2015), taking into account both the length and the inclination of the slopes; the risk of erosion increases with the length and inclination of the slope (Lastoria et al., 2008).

The LS factor for the entire area ranges from 0 to 19.62, with an average of 0.03 (Figure 5). The highest values of the LS factor are found in regions with steep and longer slopes, concentrated in the southern and central areas of the map, where the contribution of topography to erosion is significant.

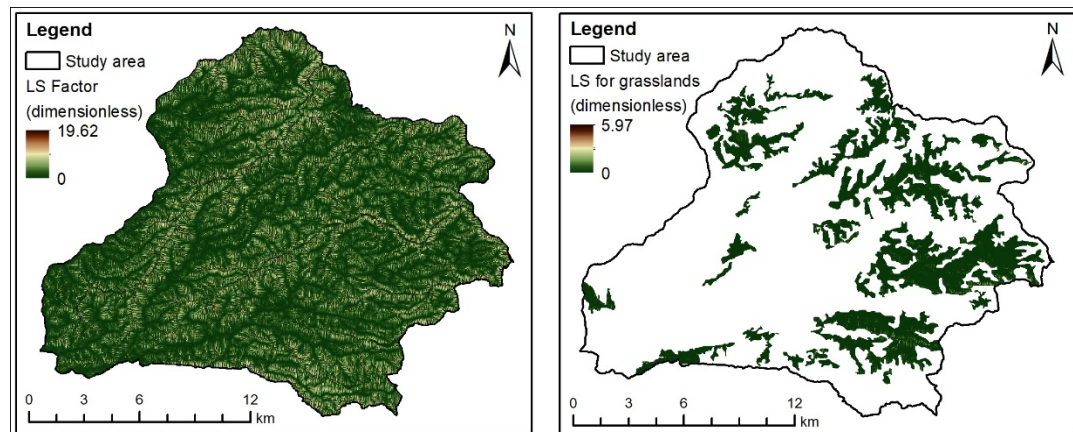


Figure 5. Distribution of LS factor in the study area and on grassland areas

The LS factor for grassland areas (Figure 5) varies between 0 and 5.97, with an average of 0.024 values, indicating a relatively low contribution of the topographic factor to erosion on these lands. Grasslands with higher LS values are located especially in hilly and mountainous areas, where steep slopes increase the risk of erosion. These regions mainly include the south-eastern areas and parts of the centre of the study area. Grassland areas with low LS values are located in lower and flatter areas, where topography-induced erosion is reduced due to minimal slopes.

Grassland areas, although generally showing lower LS factor values than the general average of the area, are vulnerable in regions with steep slopes, where the contribution of topography to erosion becomes more pronounced. Vegetative cover plays a key role in soil stabilisation on these lands, but for areas with high LS, additional conservation measures are recommended, such as terracing or the use of specific soil management practices.

Factor C (land cover management factor) is essential to measure the impact of land use and vegetation practices on soil erosion, influenced by agricultural activities, crop types, land management methods and vegetation cover (Xiong et al., 2023).

In the analyzed area, the C factor varies between 0.01 and 0.955, with an average of 0.01 values, which indicates a high degree of erosion protection in most of the region. Areas with higher values (above 0.2) are very limited and are probably associated with agricultural land or other uncovered areas, where erosion protection is lower (Figure 6).

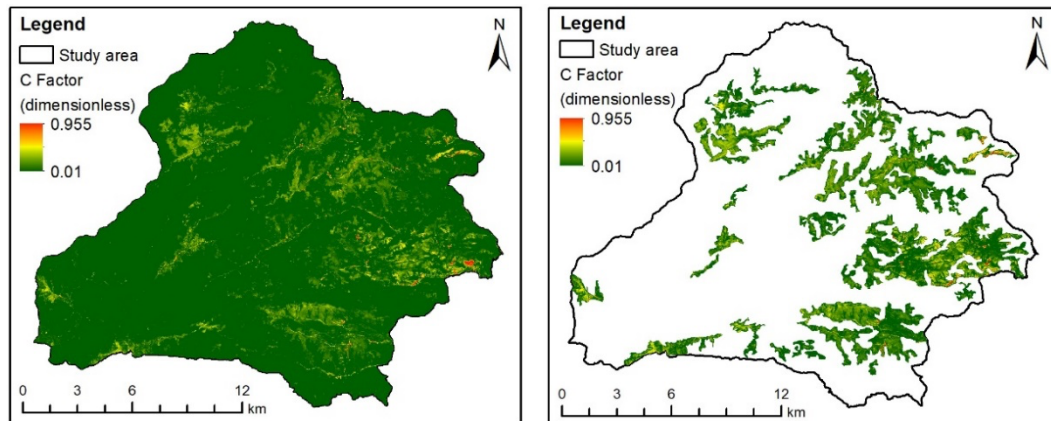


Figure 6. Distribution of factor C in the study area and on grassland areas

The C factor for grassland areas varies between 0.01 and 0.955 (Figure 6), with an average of 0.03 values, slightly higher than the general average of the area.

Grassland areas with lower C-factor values (about 0.01–0.05) are widely distributed and indicate significant protection due to well-stocked vegetation without gaps.

Regions with higher values (0.2–0.955) occur in degraded grasslands or areas with low vegetation cover, where the soil is directly exposed to erosion. They are mainly concentrated in the south-eastern and central areas of grassland areas.

Grassland areas play an important role in reducing soil erosion due to the low C-factor, which demonstrates the effectiveness of vegetation in protecting the land. However, the higher values observed in certain degraded grasslands, indicate the need for ecological restoration and sustainable management measures to maintain the functionality of these ecosystems in reducing erosion.

The P factor (which highlights the effect of erosion control measures) reflects the impact of soil conservation measures in reducing erosion on agricultural land (Al Shoumik et al., 2023).

In the analyzed area, the P factor varies between 0.20 and 4.32, with a mean value of 1.04 (Figure 7). Lower values of the P-factor (<1) are predominant in areas with dense vegetation, grasslands and forests. High values of factor P (>2) are concentrated in regions where erosion control measures are either absent or less effective, such as agricultural land or deforested areas.

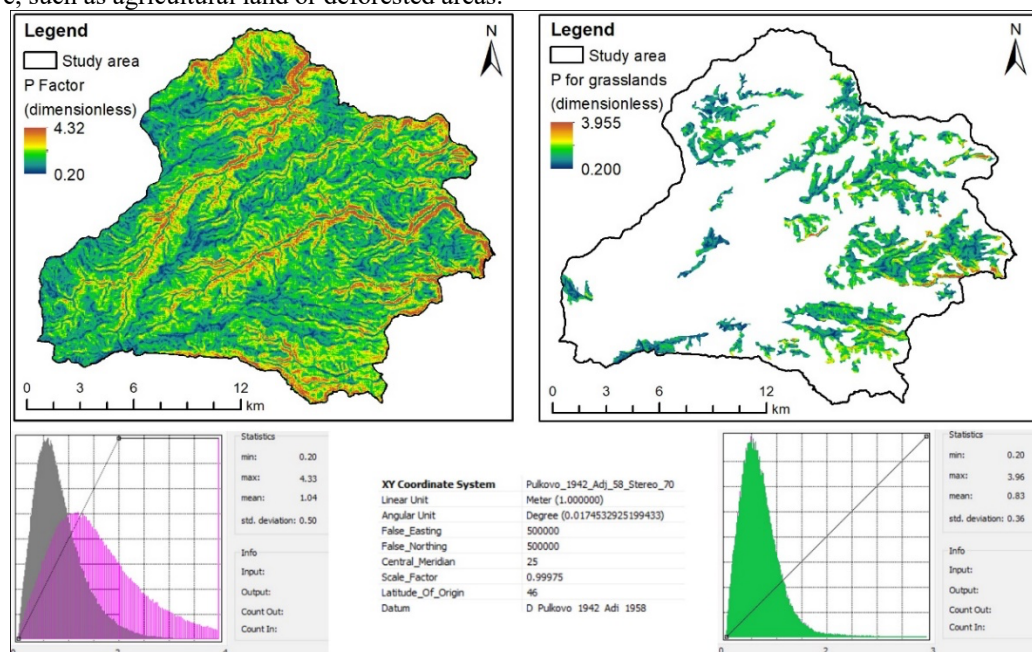


Figure 7. Distribution of P-factor in the study area and on grassland areas

The P-factor for grassland areas (Figure 7) ranges from 0.20 to 3.96, with an average value of 0.83. Grassland areas with low values of the P factor (about 0.20–0.5) are predominant and reflect the positive impact of natural vegetation in reducing the effect of erosion.

Grassland areas with high P-factor (>2) values are relatively limited and are associated with regions with poorer vegetation cover.

Grassland areas, due to vegetation cover, benefit from a high level of protection against erosion, which is demonstrated by the low values of the P factor. However, in areas with higher values, it is necessary to strengthen erosion prevention measures, such as grassland management (overseeding works, regulation of the animal load, etc.).

Based on the five factors presented, the average soil erosion rate was calculated, expressed in $\text{t ha}^{-1}\text{year}^{-1}$ (Figure 8). At the level of the entire area, surface erosion varies between 0 and $\geq 21 \text{ t ha}^{-1}\text{year}^{-1}$, with an average of $0.32 \text{ t ha}^{-1}\text{year}^{-1}$ and with predominant values below $1 \text{ t ha}^{-1}\text{year}^{-1}$. Areas with higher soil losses ($\geq 21 \text{ t ha}^{-1}\text{year}^{-1}$) are isolated and associated with steep slopes, lack of conservation measures or agricultural land exposed to erosion.

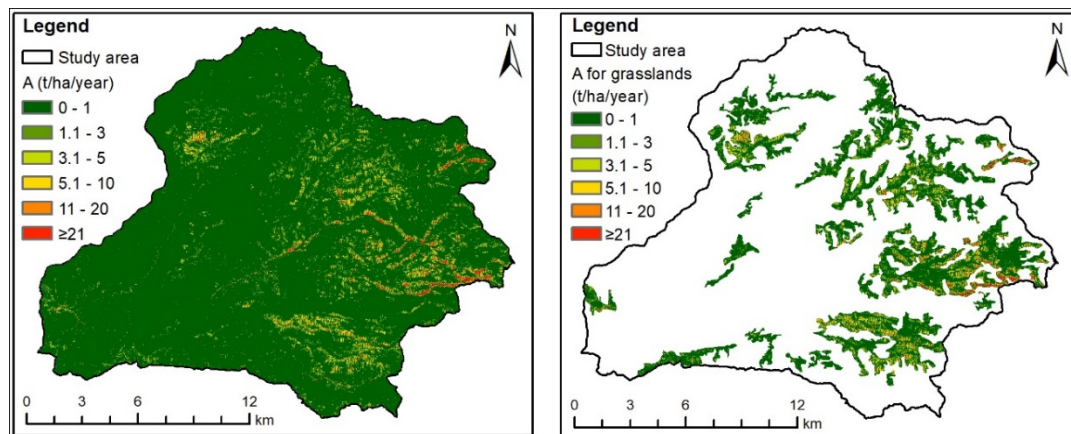


Figure 8. Map of soil surface erosion ($\text{t ha}^{-1}\text{year}^{-1}$) in the study area and on grassland areas

On grassland areas (Figure 8), surface erosion varies between 0 and $\geq 21 \text{ t ha}^{-1}\text{year}^{-1}$, but most areas record values between 0 and $3 \text{ t ha}^{-1}\text{year}^{-1}$, indicating low soil loss.

Regions with moderate soil loss ($3.1\text{--}10 \text{ t ha}^{-1}\text{year}^{-1}$) are concentrated in grassland areas located on steeper slopes or in regions where vegetation cover has been partially compromised.

The areas with a severe degree of erosion ($\geq 21 \text{ t ha}^{-1}\text{year}^{-1}$) are very limited, but they occur in the south-eastern areas and in the center of the grassland areas, where there is a combination of accentuated relief and insufficient vegetation cover.

Grassland areas, in general, play a key role in reducing surface erosion, thanks to the permanent vegetation that protects the soil. However, in areas with steep slopes or where grassland management is poor, soil loss can become significant, reaching moderate or even high values.

The implementation of erosion control measures, such as the restoration of vegetation cover and sustainable grassland management practices, is crucial to minimise these losses.

CONCLUSIONS

Grassland erosion is a natural phenomenon influenced by factors such as vegetation density, land slope, rainfall and land use.

In the study area, the R factor (precipitation erosivity) has an average value of $517.73 \text{ MJ mm}^{-1}\text{ha}^{-1}\text{h}^{-1}\text{year}^{-1}$ in grasslands, values lower than the average for the entire area, due to the protection offered by permanent vegetation. The K factor (soil erodibility) for grasslands is $0.24 \text{ t ha}^{-1}\text{MJ}^{-1}\text{mm}^{-1}$, indicating a moderate vulnerability, with high values in the south and southeast, where steep slopes increase the risk of erosion. The LS factor (topographic factor) shows a low contribution in general in grasslands (mean 0.024), but the risk increases in areas with steep slopes in the southwest and center. The C factor, with an average of 0.03, demonstrates the protection offered by grassland vegetation, although degraded grasslands show high erosion values. The P factor (erosion control measures) has an average of 0.83 in grasslands, with higher values in areas with reduced vegetation and high slopes.

The erosion rate in the analyzed grasslands is low, most areas having average annual soil losses between $0\text{--}3 \text{ t ha}^{-1}\text{year}^{-1}$, but in regions with steep slopes or compromised vegetation, losses can exceed $10 \text{ t ha}^{-1}\text{year}^{-1}$.

To reduce the risks of soil surface erosion, which is reflected in grassland fertility and productivity, measures such as vegetation restoration, sustainable grassland management and the implementation of erosion control practices such as terracing and overseeding are essential. These measures help to maintain soil stability and prevent erosion in the long term.

The application of the USLE model and geomatics techniques provides a precise and integrated framework for the evaluation and monitoring of erosion processes in grasslands, allowing the identification of vulnerable areas and the prioritization of punctual interventions, depending on the degree of risk. It also supports the optimization of anti-erosion

measures and the implementation of a sustainable management of these valuable ecosystems, both in terms of natural resources and in terms of high biodiversity.

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