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Research Article

Soil surface erosion susceptibility analysis using the USLE model. Case study: Bran - Dragoslavele Corridor, Romania

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Abstract

The present study falls within the scope of the analysis of the morphodynamic potential of the Bran - Dragoslavele Corridor (Romania), a low mountain area, favorable to erosion processes due to the high energy of the relief, diversified lithology, tectonic complexity, and due to the variation in the energy of atmospheric risk phenomena. For the expansion of pastoral agricultural areas and those intended for human settlements, the deforestation of the last 3-4 centuries deprived the slopes and the soil of the protective forest cover on an area of 55.44%, favoring the amplification of the action of natural morphodynamic agents. In this context, the quantitative and spatial assessment of sheet erosion, expressed as the average annual rate of surface soil erosion (measured in tons hectare^{-1}) was approached by applying the calculation model implemented in the GIS environment by using the universal soil loss equation (USLE). Implementation of the model was realized through the spatial delimitation of the potential erosion and the rendering by susceptibility classes of the quantitative results which reveal the fact that the largest surface of the studied mountain unit (91.68%) presents tolerable values, of 0-1.5 t ha^{-1} year^{-1}. The highest values, over 4 t ha^{-1} year^{-1} (1.24%), are characteristic of the calcareous areas belonging to the many sectors of the gorges with discontinuous vegetation, as well as the limestone exploitation area from Mateiaș mountain. The quantitative knowledge and spatial distribution of surface erosion becomes important for communities and local authorities, interested in the planning and management of the implementation of some agrotechnical measures to improve the quality and productivity of soils or to prevent and restrict erosion processes with a tendency to expand areally and in depth.

Keywords: GIS analysis; USLE; surface soil erosion; susceptibility; Romania

Introduction

The continued attraction of European structural funds for the development of agriculture in the Romanian Carpathian space requires, among other things, the creation of an inventory of the land, especially those exposed to anthropogenic activities such as intensive grazing, deforestation, clear-cutting, as well as those related to infrastructural constructions that inevitably lead to the subsidence and destructuring of pedogenetic horizons. The identification of the underlying and triggering causes responsible for physical land degradation (due to surface erosion, erosion by erosion, gullying, landslides or significant land masses etc.) is of major

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practical importance in order to make appropriate decisions on how to prevent losses due to soil degradation and to implement the most effective measures to improve the quality of this valuable resource.

Of the many land degradation processes, surface soil erosion is directly dependent on the intensive, sometimes inappropriate, exploitation of the natural resources of the geographical environment (especially natural vegetation and soil), a phenomenon which has increased with the growth of technological progress linked to land use (Săvulescu *et al.*, 2019), induced by the ever-increasing anthropic pressure on the natural environment due to the expansion of the habitat and the interests of society in order to meet increasingly diversified needs.

Current research, related to surface erosion (areal = in/surface = in the web = pluviodenudation) of soil, is based on GIS techniques, using information and methodologies successfully applied by Moore and Wilson (1992), Mitasova *et al.* (1996 and 1998), Bilașco *et al.* (2009) and others.

The best known and most widely used model for calculating soil surface erosion is the Universal Soil Loss Equation (USLE). In Romania, a significant contribution to the development of empirical soil erosion models was made by academician Mircea Moțoc, starting in 1975, the last model (ROMSEM of the USLE type) being published in 2002 (Moțoc and Sevastel, 2002). Recent research is especially devoted to the improvement of classical computational models of soil erosion. Thus, some models can calculate the intensity of erosion and runoff by estimating the yield of sediments from hydrographic basins (Sestras *et al.*, 2023b), and other models allow the evaluation of the financial risk induced by surface soil erosion on land use (Costea *et al.*, 2022).

The well-known universal soil loss equation, inspired by the research carried out and published by Wischmeier and Smith (1965), was adapted to the soil and climatic conditions of our country by Moțoc *et al.* (1975).

Correction coefficient (K) according to climatic (rainfall) aggressiveness is the rainfall-induced erosivity index, calculated according to the formula K = H*I15, where H represents the amount of rainfall and I15 represents the intensity of the torrential core of a 15-minute rainfall, equivalent to the time of water concentration within the runoff plots for gully formation (Stănescu *et al.*, 1969). At the level of the Bran - Dragoslavele Corridor, K has a value of 0.16 in the northern sector and 0.14 in the mountainous sector of the Dâmboviței Valley south of the town of Rucăr, taken from the map of the regionalization of climatic aggressiveness coefficients in Romania (Stănescu *et al.*, 1969). The coefficient was introduced in the final equation in numerical form, the assigned value being 0.15, obtained by averaging the above-mentioned values.

The topographic coefficient (LS) is a morphometric indicator dependent on both the length of slopes on the line of greatest slope and their steepness (Kinnell, 2005). Thus, the greater the slope length and slope steepness, the greater the LS index value will increase (Desmet and Govers, 1996), in direct proportion to the increase in runoff velocity and stormwater erosion action. Open source data such as Shuttle Radar Topography Mission Digital Elevation Model can be successfully used to calculate the slope length (Sestras *et al.*, 2023a).

The present research is part of a larger study entitled "The Bran - Rucar - Dragoslavele corridor - applied geomorphology study", a PhD thesis (ST) in the process of publication, in which the potential of current landform modeling processes is also analyzed, among which surface and linear erosion play an important role. In this context, the aim of the present study is to perform a quantitative argumentation of the modeling potential offered by surface soil erosion. The final goal of the application of the USLE model is intimately linked to the choice of the best management policies to improve soil quality in order to reduce the mean annual erosion rate. At the same time, the mapping of areas with soil erodibility potential will be able to improve the knowledge about the vulnerability to rainfall and for other areas similar to the Carpathian mountain environment characterized by specific physico-geographical and economic-geographical conditions of the Bran - Dragoslavele corridor.

Materials and Methods

The mathematical formula applied in the ArcGIS/ArcMap program (Spatial Analyst Tools module, Raster Calculator tool) on the basis of which the average annual rate of surface soil erosion in the area of the Bran - Dragoslavele Corridor was calculated as:

*E = K*LS*S*C*Cs* (Moțoc *et al.*, 1975), where: E - average annual rate of surface soil erosion (amount of sediment generated by in/surface erosion) in tons hectare^{-1}; K - correction coefficient for climatic aggressiveness (rainfall); LS - topographic coefficient, dependent on slope (expressed in sexagesimal degrees) and slope length (Mitasova *et al.*, 1996); S - correction coefficient for soil erodibility, depending on characteristics of each soil type, such as structure, texture, permeability, organic matter content etc.; C - correction coefficient according to vegetation type/structure and land use; Cs - correction coefficient dependent on the influence of anti-erosion measures and works.

In the present research, the slope length was calculated based on DEM with 20 m resolution, according to the formula proposed by Mitasova *et al.* (1996).

*Power("accumulation" * 20 / 22.1, 0.6) * Power(Sin("slope" * 0.017) / 0.09, 1.3)*,

where: "accumulation" - runoff accumulation (due to water erosion); 20 - DEM cell resolution; 22.1, 0.6, 0.017 and 1.3 - experimental coefficients (Moore and Wilson, 1992); "slope" - land slope expressed in sexagesimal degrees.

Correction coefficient (S) according to soil erodibility (Indicator 186 of the "Methodology for the elaboration of pedological studies", published by I.C.P.A. Bucharest, 1987)

The database of soil types was created by digitizing maps at a scale of 1:200000 (Soil map – Brașov sheets, 1975 and Târgoviște, 1970) with the name SRCS (Romanian Soil Classification System), made by I.C.P.A. Bucharest (Research Institute for Soil and Agrochemistry) and updated (Florea and Munteanu, 2003) according to the latest FAO UNESCO SRTS 2003 (Romanian Soil Taxonomy System) designations. In conjunction with the creation of the thematic layer of soil types, soil erodibility coefficient values (Moțoc and Sevastel, 2002) were identified and introduced as an attribute according to the texture of each type. In the area of the intramontane corridor studied, this index shows values ranging from 0.8 to 1.1 (Table 1 and Figure 1).

Table 1. Value of the correction coefficient (S) according to soil erodibility according to the textural attribute of the soil types in the Bran - Dragoslavele Corridor

No.	Soil type according to FAO UNESCO SRTS 2003 (Romanian Soil Taxonomy System)	Soil texture (Puiu and Ispas, 1997)	S coefficient (Moțoc *et al.*, 1975)
1	Eutricambosols	Lutonisipoous - luteous	0.8
2	Districambosols	Lutonisipoous - luteous	0.8
3	Districambosols și eutricambosols	Lutonisipoous - luteous	0.8
4	Alosols	Lutonisipous to lutoargylous (differentiated by profile)	0.8
5	Nigrosols	Lutonisipous to lutoargylous (differentiated by profile))	0.8
6	Gleisols	Lutonisipoose to lutoargylous	0.8
7	Rendzinas and eutrichambosols	Loamy to clayey	0.9
8	Prepodzols	Sandy loam or silty loam	0.9
9	Districambosols and prepodzols	Lutonisipoous - luteous	0.9
10	Rendzinas and limestone up to date	Loamy to clayey	1
11	Carbonate rocks to day and rendzinas (in gorges)	Loamy to clayey	1.1
12	Aluviosols	Sandy to silty loamy	1.1

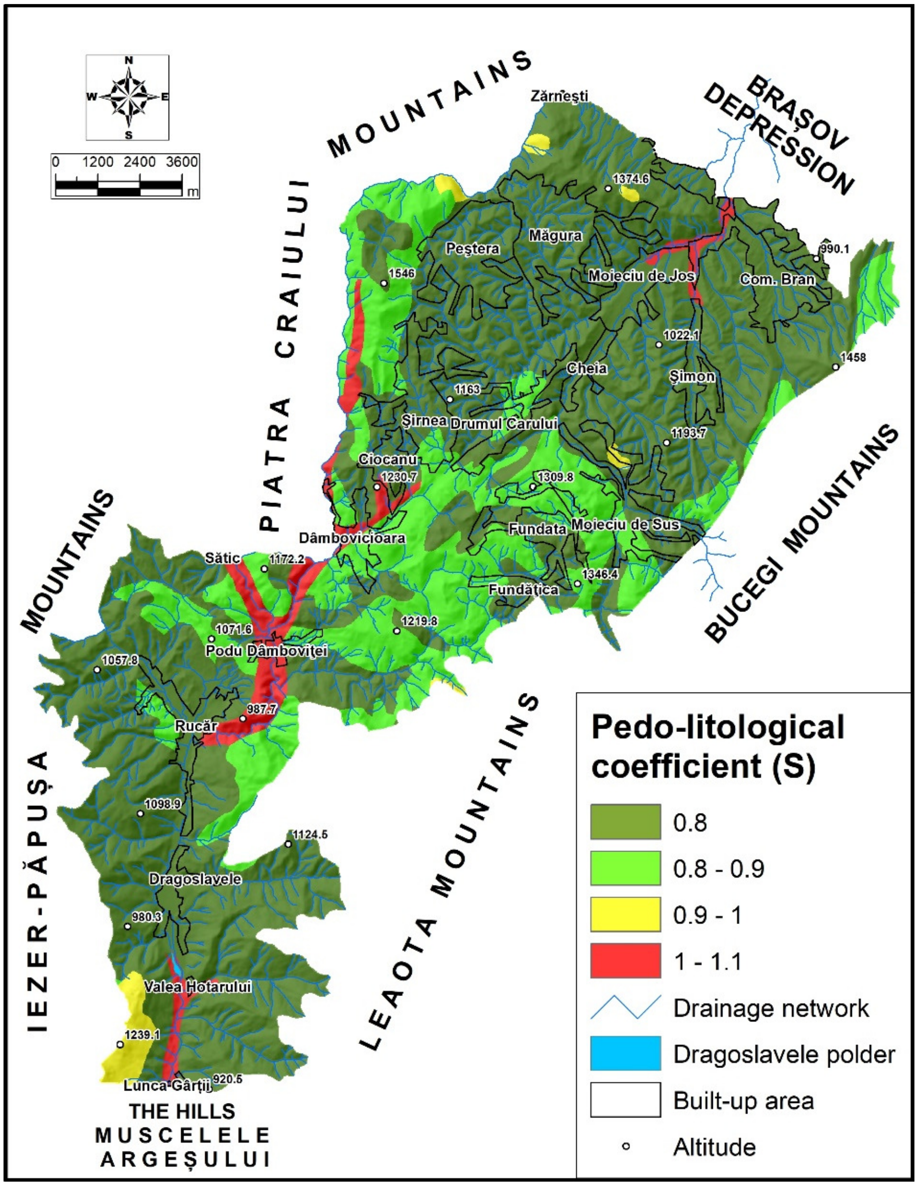

Figure 1. Correction coefficient (S) as a function of soil erodibility

In some studies, the soil properties used in the calculations were obtained from SoilGrids, a state-of-the-art digital soil mapping system developed by the International Soil Information and Reference Center (ISRIC—World Soil Information), accessible at *https://soilgrids.org/* (Hengl *et al.*, 2017; An *et al.*, 2022; Stefanidis *et al.*, 2024).

Correction coefficient (C) according to vegetation type/structure and land use

The land cover/land use map includes the CORINE Land Cover 2018 database and has been corrected/updated based on the satellite image dated 16.09.2019 provided by Google Earth Pro. The C coefficient values (Moțoc and Sevastel, 2002), attached as an attribute according to land cover (with vegetation) and land use, range from 0.005 to 1.2 (Table 2 and Figure 2).

Table 2. Value of correction coefficient according to vegetation type and land use in the Bran - Dragoslavele Corridor

No.	Cover (type of vegetation) / land use (CORINE Land Cover 2018)	C coefficient (Moţoc *et al.*, 1975)
1	Water surface (Dragoslavele Polder)	0
2	Forests (broadleaved, mixed and coniferous)	0.005
3	Meadows with areas of natural vegetation (forests)	0.2
4	Pastures, meadows and secondary mountain meadows	0.3
5	Fruit tree plantations / isolated trees and shrubs	0.5
6	Discontinuous human settlement (urban area)	0.8
7	Areas of complex crops	0.8
8	Clear felling of forest stands with recent shrub vegetation	0.8
9	Calcareous rocks with discontinuous vegetation (slopes in gorges)	1
10	Limestone quarry (rock to day)	1.2

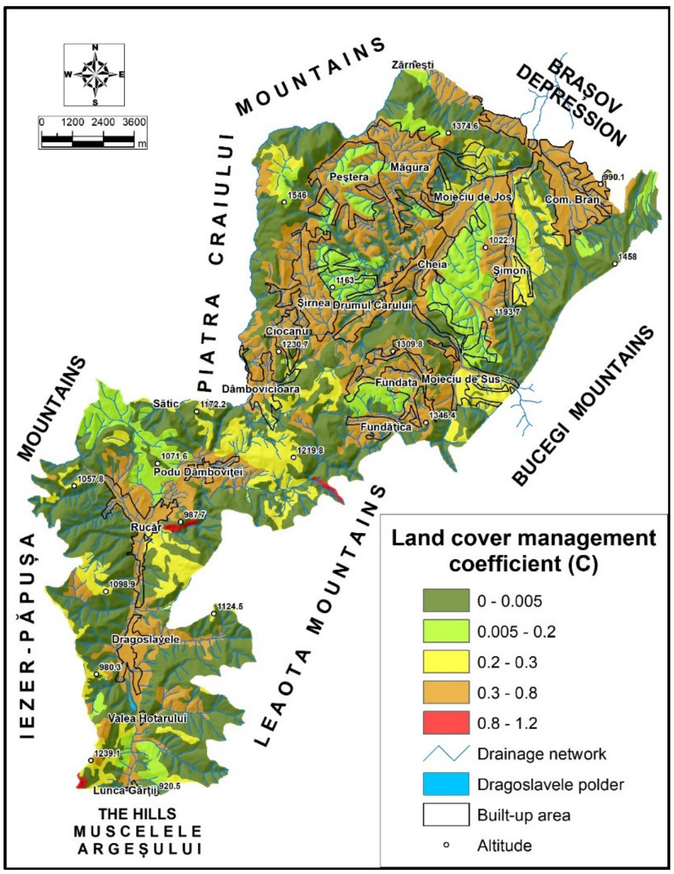

Figure 2. Correction coefficient (C) as a function of vegetation type, structure and land use

For the mountain area analysed, *the correction coefficient (Cs) dependent on the influence of anti-erosion measures and works* was assigned a value of 1, because in the area of the Bran - Dragoslavele Corridor there were not or are not in practice such measures and works. Field observations or recent satellite images have allowed to identify plots for annual or multiannual crops, mostly correctly sown, along contour lines, on slopes with slope values usually ranging between 6°-17° (in the villages of Şirnea, Ciocanu, Fundata and Fundăţica) and 0°-6° (in the villages of Bran, Moieciu de Jos, but also in the villages along the Carpathian valley of Dâmboviţa within the Bran - Dragoslavele Corridor).

Results

A first result is related to the spatial distribution of the topographic coefficient (LS). From the analysis of the resulting map (Figure 3) it was found that the lowest values of the topographic coefficient belong to the range 0-5 m and represent 28.49% of the surface of the studied mountain unit, being evidenced on extended areas in the beds of the main rivers, in the depressions of Podu Dâmboviței, Rucăr, Dragoslavele, Fundata - Fundățica, as well as in the area of the upper erosion level, Ciocanu, in the homonymous village. The highest values of this coefficient, above 50 m (6.1%), are mainly found in the numerous sectors of gorges, indicating the concentrated nature of the runoff and the increased intensity of erosion in areas with slopes whose gradient exceeds 32°.

The calculation of the average annual rate of superficial soil erosion in the Bran - Dragoslavele Corridor allowed obtaining values that vary between 0 and over 4 t ha^{-1} $year^{-1}$. The calculated average value is 0.3 t ha^{-1} $year^{-1}$.

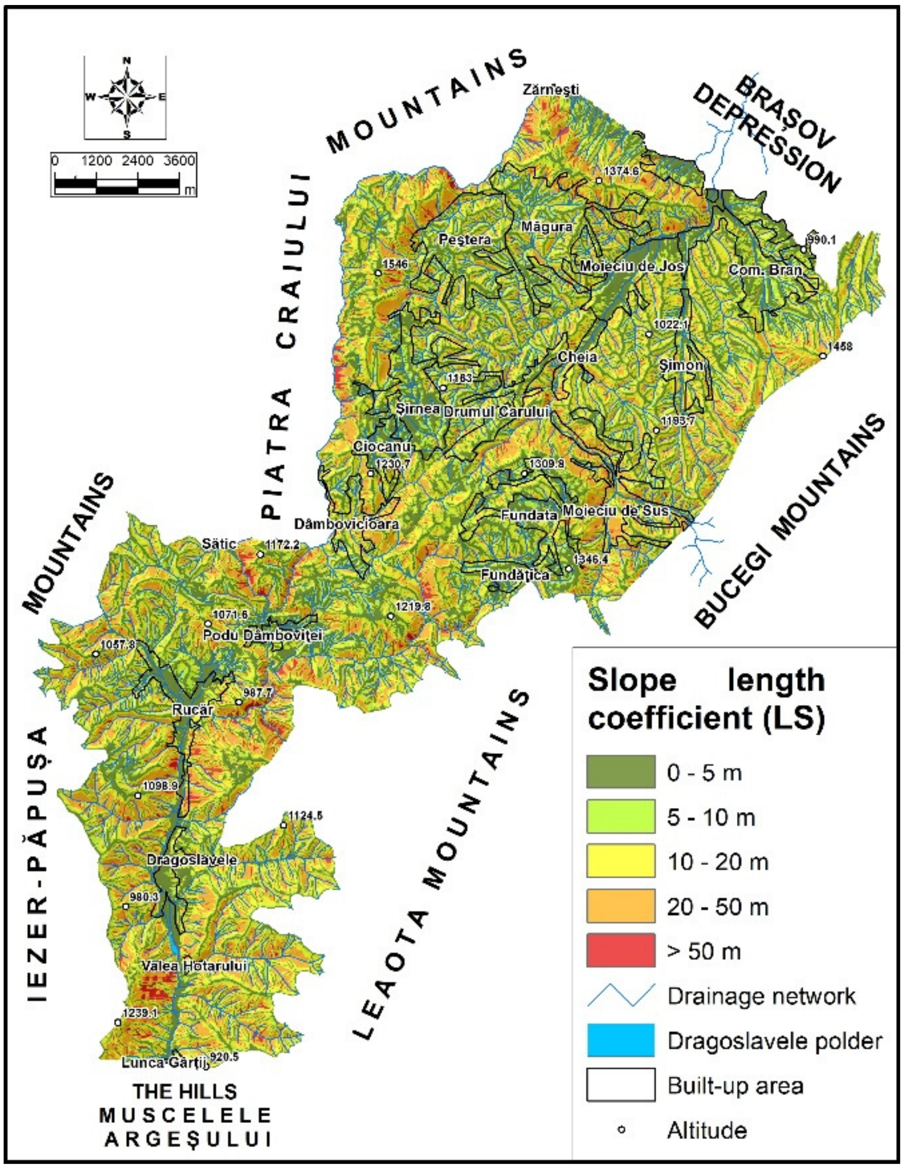

Figure 3. Slope-dependent topographic coefficient (LS) (sexagesimal degrees) and length of slopes (m)

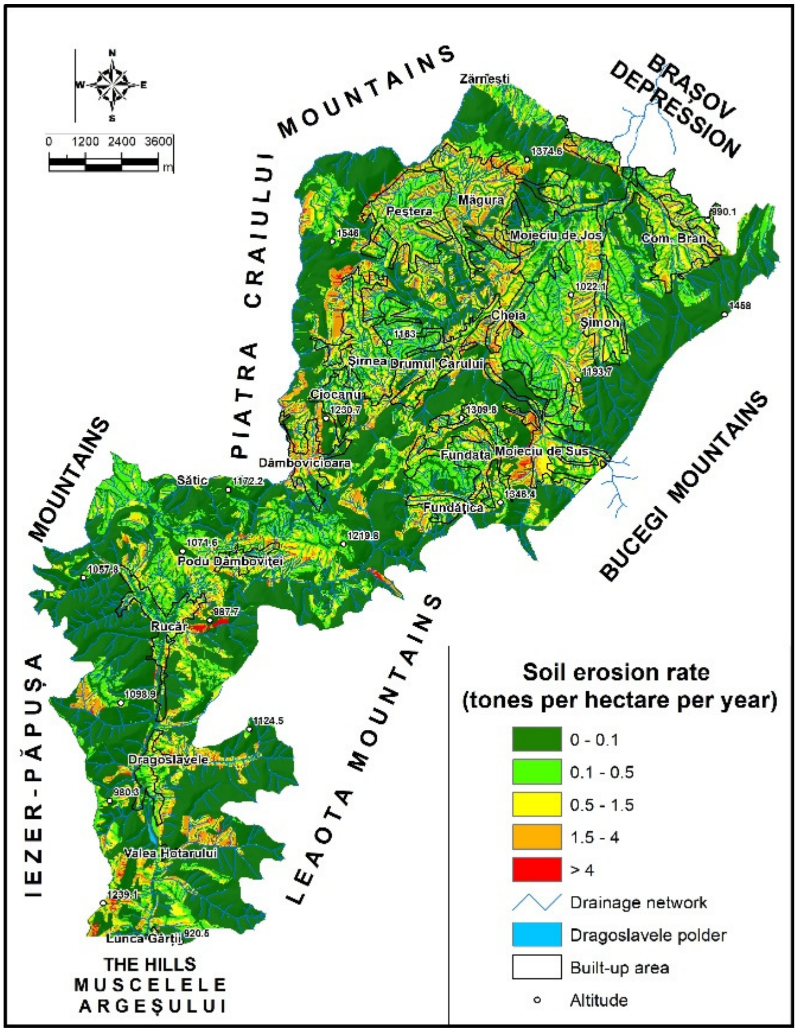

Figure 4. Spatial distribution of the average annual rate of superficial soil erosion in the Bran - Dragoslavele Corridor (USLE model)

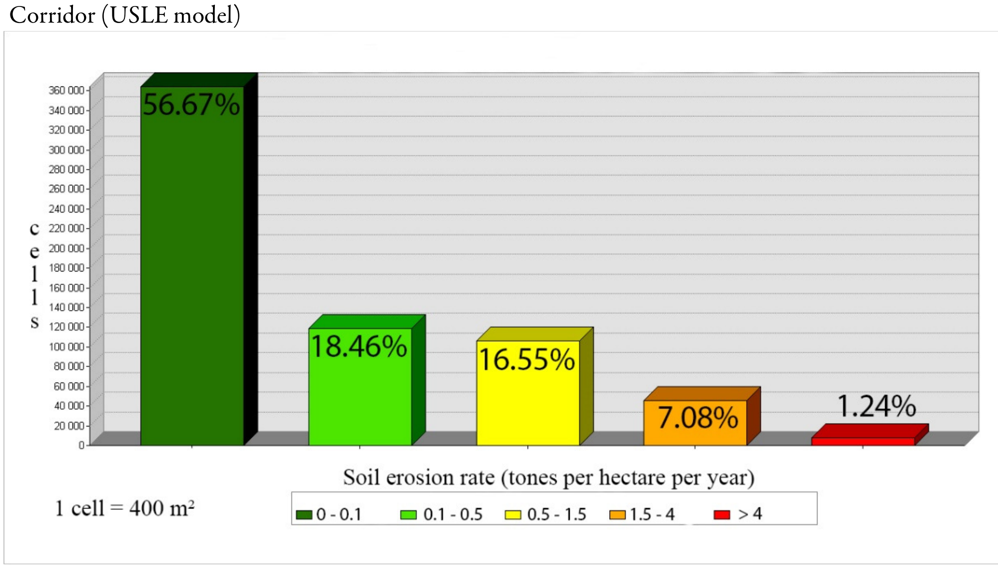

Figure 5. Histogram of Susceptibility to Surface Soil Erosion from Bran - Dragoslavele Corridor

Table 3. Susceptibility to surface (in/surface) soil erosion from Bran - Dragoslavele Corridor

Surface erosion (t ha^{-1} $year^{-1}$)	Susceptibility classes
0-0.1	Very low susceptibility (insignificant potential erosion)
0.1-0.5	
0.5-1.5	
1.5-4	Low susceptibility (low potential erosion)
> 4	Medium susceptibility (moderate potential erosion)

Analysis of the resulting thematic map (Figure 4) and the related histogram (Figure 5) allows observations on the spatial distribution of the potential amount of material (both mineral and organic) dislodged by surface erosion. The universally accepted threshold value for surface soil erosion is 3 t ha^{-1} $year^{-1}$. According to the physico-geographical characteristics (pedoclimatic and relief) of the studied area (26,200 ha), we consider that surface erosion values exceeding 1.5 t ha^{-1} $year^{-1}$ (8.32%) represent potential risk areas, quantified as follows (Table 3):

- Low susceptibility, 1.5-4 t ha^{-1} $year^{-1}$ (7.08%), in areas with low erosion potential, affected by clear-cutting of forest stands (with recently developed shrub vegetation, on slopes with a gradient of more than 17°), within discontinuous human settlements with complex crop areas (on slopes with slope values usually between 6°-17°, in the villages of Șirnea, Ciocanu, Dâmbovicioara, Fundata, Fundățica, Șimon, Bran - Poarta valley and Moieciu de Sus).

- Medium susceptibility, > 4 t ha^{-1} $year^{-1}$ (1.24%), in areas with moderate potential erosion, mainly in the numerous sectors of gorges, on limestone rocks with discontinuous vegetation, and in the limestone quarry of Mount Mateiaș, in areas with slopes whose gradient usually exceeds 32°.

At the same time, the histogram of the final thematic map shows that the largest area of the Bran - Dragoslavele Corridor (91.68%) shows tolerable, low values of the analysed parameter, ranging between 0 and 1.5 t ha^{-1} $year^{-1}$, in areas covered with forest vegetation, pastures, meadows and secondary mountain meadows, as well as hay meadows alternating with forest and shrub vegetation (on the slopes of the neighbouring mountain units, in the Coja Ridge, the Măgurii Ridge and in the "gâlmelor" (hillocks) area from the central sector of the Bran - Dragoslavele Corridor), on slopes with slope values predominantly in the 17°- 32° range.

Discussion

The USLE model has already been used in analyses for hilly and mountainous areas in Romania (Anghel and Bilasco, 2008, Colniță *et al.*, 2016; Csiszér and Bilașco, 2018; Moldovan, 2019), but not in the Bran - Dragoslavele Corridor. Also, studies related to the analysis of the morphodynamic potential of the relief, also with regard to the surface washing of the soil (areal washing or pluviodenudation) have been carried out in mountain areas close to the Bran - Dragoslavele Corridor: the Ciucaș - Buzău Mountains (Ielenicz, 1984), the Curb Carpathians (Ielenicz, 1982) and in the mountains of the Timișului Basin (Mihai, 2005). However, soil erosion estimation using fieldwork is a time-consuming and costly approach that cannot cover the entire watershed and is confined to experimental plots within the catchment (Stefanidis and Chatzichristaki, 2017).

In the mountains of the Timișului Basin (Postăvaru, Piatra Mare, Predeal Cliffs and Timișu de Sus Depression), the areas with favorable potential for surface washing meet the following specific morphodynamic conditions: geodeclivity of 3° - 10°, lack of forest protection of the land (including in the built-up areas) and lower altitudes, usually 1300 - 1400 m (Mihai, 2005). Lands are protected by alteration barks with thicknesses frequently exceeding 0.5 m (Ielenicz, 1982). At the same time, in the Ciucaș - Buzău Mountains, in terms of geodeclivity, surface scouring becomes active from slopes greater than 5° and frequently to more than 10° where there is no forest. The process also occurs on slopes above 20° below sparse forests (Ielenicz, 1984).

In order to analyze the surface soil erosion in the Bran - Dragoslavele Corridor, the classification of geodeclivity values on genetic basis was used, "the most suitable to exemplify the typology of the processes that contributed to their occurrence" (Surdeanu, 1998), so the following classes of values were defined: 0° - 3° - fluvial accumulation relief predominates; 3° - 6° - slight erosion processes and colluvio-prolluvio-deluvial accumulation processes; 6° - 17° - landslide-type mass movement processes dominate; 17° - 31°(32°) - landslides are accompanied by intense processes of diffuse erosion (surface scouring and washouts), subsidence and gullying, and torrential downbursting; > 32° - gravitational processes of sliding, rolling and slumping. These classes of geodeclivity values, characteristic for the manifestation of different geomorphological processes, were used to outline the conditions for classifying the factors of the morphodynamic potential in the Bran - Dragoslavele Corridor (within the framework of the above-mentioned more comprehensive study), among which is also soil surface erosion, frequently associated with scouring, gullying, ravine, torrentiality, snow avalanches and solifluction.

It is well known that the slope (geodeclivity) plays an essential role as a potential factor in triggering geomorphologic processes of slope and bed, well represented and evidenced in the mountain area under our research. According to the geodeclivity map, the majority of slopes in the Bran - Dragoslavele corridor fall within the range of 17°-32° (52.08%) and 6°-17° (27.21%), which allows us to state that there is a high potential, from this point of view, for the triggering and manifestation of surface soil erosion and the processes associated with it. Synthesizing information from previous research and integrating it with concrete field observations (carried out in different seasons from 2014 to 2023 in almost the entire region), we were able to conclude that the 6° - 17° geodetic gradient is the most favorable for the initiation and manifestation of surface soil erosion in this mountainous area. To assess the same type of morphodynamic potential, we also used the interpretation of the morphometric indicator (related to geodeclivity) for each division of the relief of the Bran - Dragoslavele Corridor (three sectors), according to the geodeclivity map (Figure 6).

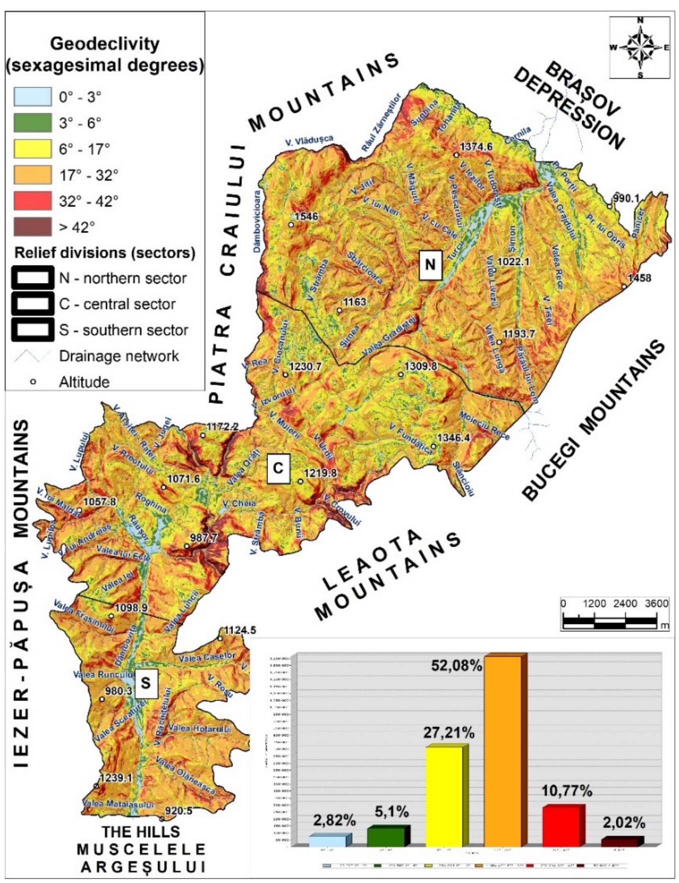

Figure 6. Map and histogram of the geodeclivity in the Bran - Dragoslavele Corridor

- For the northern sector, with a relatively uniform overall morphology, the most widespread values of geodeclivity (53.22%) are included in the range 17° - 32°, followed by those in the range 6° - 17° (27.64%).

- For the central sector, with an overall morphology fraught by numerous tectonic accidents, the most widespread values of geodeclivity (46.59%) are included in the range 17° - 32°, followed by those in the range 6° - 17° (30.15%), favorable to both surface and linear erosion, as well as to snow and solifluction (at altitudes above 1000 - 1100 m). The highest values of geodeclivity in the central sector characterize the steep (> 42°), very steep and overhanging slopes of the numerous key sectors, which represents the highest share of all three sectors of the Bran - Dragoslavele Corridor (3.57%).

- For the southern sector, characterized by the morphology of the Dâmbovița gorge, the most widespread values of geodeclivity (62.13%) are included in the range 17° - 32° (favorable to disaggregation on the Mateiaș limestones at altitudes above 1100 m, but also to torrential downpours), followed by those in the range 6° - 17° (19.06%).

In the Bran - Dragoslavele Corridor, under the conditions of an altitudinal range between 600 m and 1546 m, the other specific morphodynamic conditions (together with the geodeclivity) that outline the favorable potential for the production and manifestation of surface soil washing are: lithology (predominantly conglomerates, sandstones, marls, isyps and fluvio-lacustrine gravels, but also extensive areas of calcareous rocks with rendzinic soils), land cover/land use (predominantly areas with pastures, meadows and grasslands in various stages of exploitation/degradation, areas with poorly completed pastures, areas with clear-cutting and regenerating vegetation, but also areas of discontinuous human settlement) and the conditions of the mountain climate with moderate nuance (Teodoreanu, 1980) characterized overall by relatively low average temperatures (average of 4; 4 °C in the period 1896-1970, at the Fundata meteorological station, 1384 m) and rich precipitation both in terms of quantity (average amounts of 1020.2 mm in the period 1921-1970, at the Fundata meteorological station) and number of days with rain.

Conclusions

The application of the USLE model for the Bran - Dragoslavele Corridor revealed the territories susceptible to surface erosion, depending on morphological conditions, climatic characteristics, hydrological features specific to predominantly calcareous and conglomeratic areas, physical properties of soils (most types having short profiles), degree of cover and type of vegetation, as well as agro-pastoral and forestry activities with local specificity. It was firstly found that in most of the territory analysed, soil losses fall into the very low susceptibility class (0-1.5 t ha^{-1} $year^{-1}$), with insignificant potential erosion in areas relatively well covered by predominantly forest vegetation. The higher values, in the range 1.5-4 t ha^{-1} $year^{-1}$, show a low potential erosion and fall into the low susceptibility class that characterises the overall intra-urban areas of scattered mountain villages with predominantly pastoral activities. The highest values, above 4 t ha^{-1} $year^{-1}$, indicate a moderate potential erosion, included in the medium susceptibility class, on land characterised by medium and high geodeclivity and a low degree of cover, with discontinuity of the soil and vegetation protective cover. Under these conditions, the most affected territories are characteristic of rugged limestone areas (22 gorges sectors), as well as in the limestone mining area of the Mateiaș quarry.

Modelling results from the USLE model can suggest to local administrative authorities the application of different scenarios integrating mitigation or protection measures against land degradation that can aim at reducing the current level of surface soil erosion for different land use categories (Roșca, 2014). In order to prevent or reduce soil losses that may occur due to surface erosion, but also to achieve the highest economic efficiency in the exploitation of agricultural land (especially arable land), the following traditional agro-technical measures can be recommended for the studied area: perseverance in the application of the cultivation system with ploughing and sowing arranged along contour lines on slopes up to 4° (7%) - 6° (10.5%), terracing of sloping land for agricultural crops (where possible), as well as conservation through revegetation with tree and shrub species that can stop to a large extent the further degradation of land susceptible to deep erosion (gullying) and landslides on friable Cenomanian marls in the Rucar - Podu Dâmboviței area.

Authors' Contributions

Data curation: TS and ȘB; Formal analysis: TS and ȘB; Funding acquisition; Investigation; Methodology: ȘB; Project administration: TS and ȘB; Resources: TS and ȘB; Software: TS and ȘB; Supervision: ȘB; Validation: ȘB; Visualization: TS and ȘB; Writing - original draft: TS; Writing - review and editing: TS.

Both authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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