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Soil erosion risk assessments for the catchment of the Dzebelska River (East Rhodopes)

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Abstract

Soil erosion is recognized as one of the most serious soil threats in Bulgaria. The paper presents assessments of soil erosion factors and risk in the catchment of the Dzhebelska River (Eastern Rhodopes), Bulgaria. The assessments are based on the USLE approach, which was adapted for Bulgarian conditions and integrated with GIS. It is established that about 45% of the territory of the Dzhebelska River catchment are characterized with rains with an average erosivity between 600 and 800 MJ mm/ha h y. Largest percentage share (47%) of the lands in the catchment area is characterized by medium to high susceptibility to erosion (0.03-0.04 t ha h / MJ ha mm). Almost half of the lands in the studied catchment are with a slope above 15°. Significant share of land (32.5%) is with high potential risk of erosion (100-200 t/ha y). Due to the largest percentage share of forestland (57%), lands with actual erosion risk below 3 t/ha y cover about 58 % of the catchment area, while these with a risk above 40 t/ha y cover about 15 %.
Keywords: *soil erosion risk assessments, USLE, GIS, Dzhebelska River catchment, East Rhodopes, Bulgaria*

Introduction

Estimating soil loss from sheet water erosion has been a major research goal since the early 20th century. De Vente et. al. (2013) reported the need to measure soil erosion rates and deposition under different scenarios. Knowing current levels of soil erosion enables comparison with tolerable levels of soil erosion (Bilotta et al., 2012). Li et al., (2024) estimated global soil erosion using the USLE model and the results showed that the average global erosion rate was 5.78 t / ha y with a rate of 4.26 x 10 -3 t / ha y. Approximately 40% of the world's agricultural land is severely degraded. Every year, the planet's arable land is reduced by more than 100 million acres due to soil erosion.

The natural conditions on the territory of Bulgaria combined with the way of land use cause intensive development of soil erosion, which is the most widespread and intensively acting degradation process. Losses of soil from erosion in Bulgaria are also significant. The study of the state of land resources shows that more than 80% of the arable land and 15% of the forest land are at risk of water erosion. About 1,5-1,7 million ha of land are moderately or severely eroded and need basic improvement measures. About 9,6 million ha are at potential risk of sheet water erosion (Hristov, 2022). Although the Eastern Rhodope Mountains are mainly characterized by low-mountainous and hilly terrain with average altitude of 320 m, the rough and mountainous nature of the terrain, intensive grazing in the past, deforestation, as well as other complex factors have set conditions for development of intensive erosion processes in the area (Yangyozov, 2011). The assessment of the factors and the risk of water erosion of the soil for the area of the Jebel municipality is based on a model for predicting probable average annual soil losses from erosion validated for the conditions of Bulgaria (Rousseva, 2002; Nikolov et al., 2007). About 38% of lands are characterized by high potential risk (Rousseva et al., 2010). At the moment there are no studies reflecting the erosion processes for the watershed of the Dzhebelska River (Eastern Rhodopes) through the soil loss model USLE (Wishmeier & Smith, 1978) applied in parallel with Geographic Information Systems (GIS).

The purpose of this study is to assess soil erosion risk in the catchment of the Dzhebelska River (Eastern Rhodopes), based on the Universal Soil Loss Equation (Wischmeier & Smith, 1978) integrated with GIS.

Material and methods

The *East Rhodopes* are part of the Rhodope Mountains. Unlike the western and central parts, the eastern part of the mountain has mostly low-mountainous and hilly terrain. The average altitude is 320 m. The Eastern Rhodope region covers an area of 14,700 square km, of which 12,200 square km are on Bulgarian territory. The rest are in Greek.

Dzhebelska River, a left tributary of Varbitsa River, drains the high central parts of the Zhalti Dyal ridge and the northern slopes of Ustrenski ridge in the Eastern Rhodopes (Fig. 1). It springs at 1100 m above sea level, in the Eastern Rhodopes. The river, which is 26 km long, has

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a wide, highly fragmented and sparsely forested catchment, with an area of 92,8 km^2, which represents 9.8% of the catchment area of the Varbitsa River.

The river is mainly fed by rain, with the maximum in January and the minimum in August-September, due to the Mediterranean climatic influence. The average annual runoff at Dzhebel is 1.5 m^3/s. Climate is warm, humid, with low seasonal temperature amplitude (Geography of Bulgaria, 2002). The soil-forming materials are represented by sandstone, rhyolites, andesites, biotite gneiss and different shale (Geography of Bulgaria, 2002; Soil Survey Staff. 2010). The major area of the catchment is covered by Chromic Luvisols (Cinnamonic and Cinnamonic leached), Stagnic Luvisols (Cinnamonic podzolized) and Chromic Cambisols (Undeveloped). Relatively smaller area is covered by Rendzinas, Eutric Leptosols and Eutric Fluvisols (Alluvial and Delluvial) (Table 1; Fig. 2), (IUSS Working Group WRB, 2022).

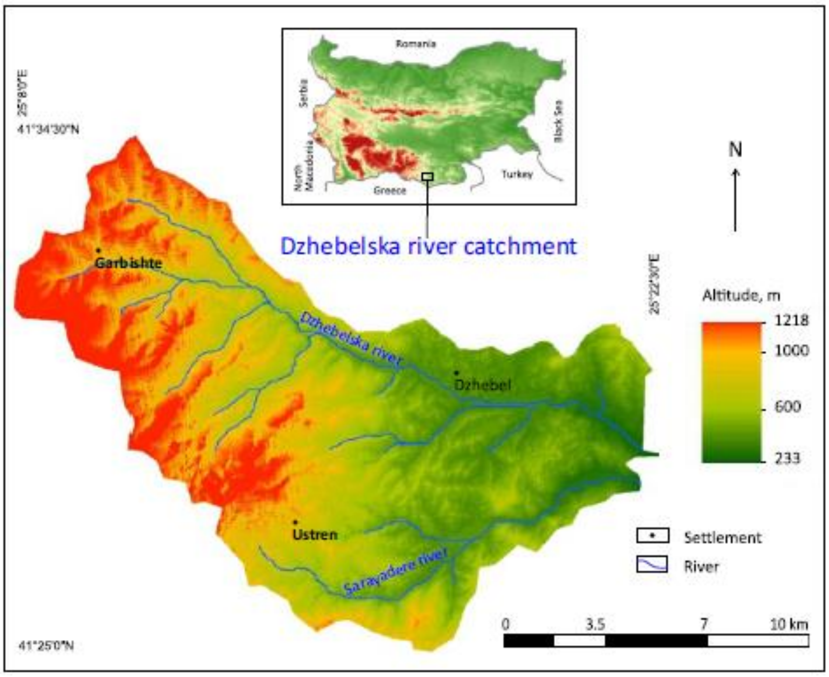

Figure 1: Map of the study area

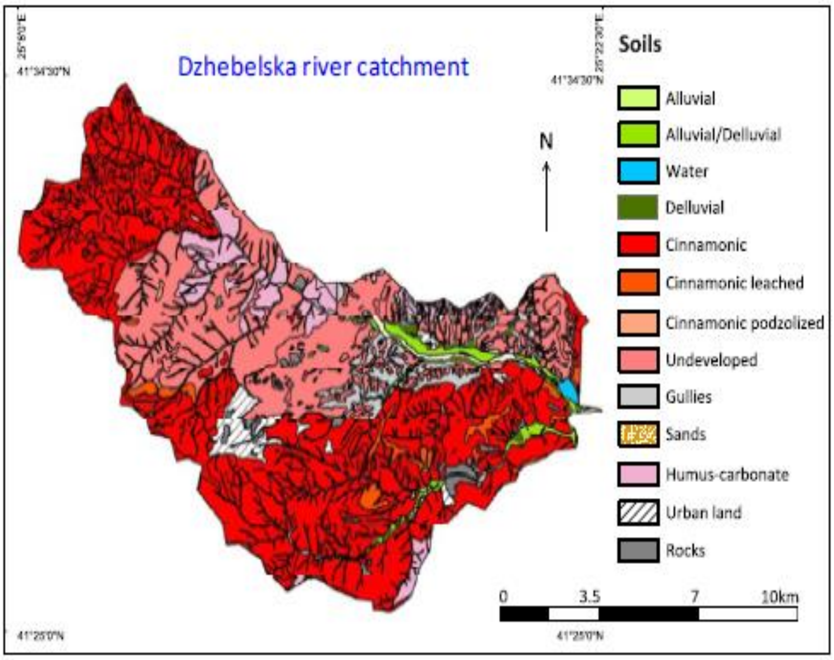

Figure 2: Map of soils distributed on the territory of Dzhebelska River catchment according to the national soil classification system

Table 1: Soil units referred to the WRB and Soil Taxonomy, main soil texture fractions - sand (2-0.050 mm), silt (0.050-0.002 mm), clay (<0.002 mm); total organic Carbon (OC)

Bulgarian soil classification	WRB (2022)	Soil Taxonomy (2010)	Sand, %wt	Silt, %wt	Clay, % wt	OC, %wt
Alluvial and alluvial meadow soil	Haplic Fluvisol	Typic Fluvents	38	38.4	23.6	2.1
Delluvial and delluvial meadow soil	Haplic Cambisol	Typic Orthents	42.6	30.8	26.6	2.2
Cinammomic forest soil	Epicalcic Luvisol	Calcic Haplexeralfs	23.3	32.8	43.9	2
Cinammomic leached	Haplic Luvisol	Typic Haplustalfs	35	29.6	35.4	1.6
Cinammomic podzolized	Luvic Endogleyic Planosol	Vertic Albaqualfs	46.4	40.7	12.9	1.0
Eroded soils	Regosols	Entisols	26.7	65.2	8.1	1.5
Rendzinas (Humus-Calcareous) soil	Rendzic Leptosol	Typic Haprendolls	20.1	47.5	32.4	2.5

Potential and actual risk of sheet water erosion were assessed as average annual soil loss [t / ha y], calculated following the model developed in the USA for soil conservation planning (Wischmeier & Smith, 1965, 1978), known as the Universal Soil Loss Equation – USLE:

$$A = R * K * LS * C * P \qquad /1/$$

Where:

- A is predicted average annual soil loss rate, t / hay,
- R is index of rainfall erosivity factor, MJ mm / ha h,
- K is index of soil erodibility factor, t ha h / MJ ha mm,
- LS is index of topography factor,
- C is index of crop and management factor,
- P is index of soil conservation measures factor.

The potential soil erosion risk values were calculated using formula /1/ with values of the indices for crop and management factor and the erosion control measures set equal to 1: C = 1 and P = 1 were further categorized in 7 groups: very low >0 ≤ 5, low >5 ≤ 10, low to moderate >10 ≤ 20, moderate >20 ≤ 40, moderate to severe >40 ≤ 100, severe >100 ≤ 200 and extreme >200 t/ha y.

The actual soil erosion risk values were calculated using formula /1/ and were further categorized in 7 groups: very low >0 ≤ T, low >T ≤ 3, low to moderate >3 ≤ 5, moderate >5 ≤ 10, moderate to severe >10 ≤ 20, severe >20 ≤ 40 and extreme >40 t/ha y.

The index of rainfall erosivity factor R (EI_{30}) was calculated following adapted for Bulgarian conditions (Rousseva, 2002) power model, defined by Richardson and Foster (1983), using published data (Kyuchukova et al., 1986) for annual and monthly values of number and frequency of intensive rainfalls of duration t ≤ 30 min, and the amount of single intensive rainfall with the same duration for the meteorological stations with long-term observations. Obtained 'annual' values were categorized in 8 classes: very low >0 ≤ 200, low >200 ≤ 400, low to moderate >400 ≤ 600, moderate >600 ≤ 800, moderate to severe >800 ≤ 1000, severe >1000 ≤ 1500, severe to extreme >1500 ≤ 2000 and extreme >2000 MJ mm / ha h.

The index of soil erodibility factor K, was calculated by the soil erodibility nomograph (Wischmeier et al., 1971) adapted for Bulgaria (Rousseva, 1997, 2001, 2002) using routine large-scale soil survey data about soil texture (parameter M = {% (0.1-0.002)}. {100 - % (<0.002)}, organic matter content (OM), soil structure class (b) and soil profile permeability class (c):

$$K = 2.77\ 10^{-7}\ M^{1.14}\ (12 - OM) + 0.0043\ (b - 2) + 0.0033\ (4 - c), \qquad /2/$$

when OM<4 g/100g and

$$K = 22.16\ 10^{-7}\ M^{1.14} + 0.0043\ (b - 2) + 0.0033\ (4 - c), \qquad /3/$$

when OM>4 g/100g

For the aims of this study, data from the reports of large-scale soil surveys at a scale M 1: 25 000 for the area of Dzhebelska River were used (Yolevski & Hadzhiyanakiev, 1977). The soil survey data, such as particle-size distribution (content of particles finer than 0.002 mm and particles from 0.1 to 0.002 mm), soil organic matter content, aggregation of the surface soil layer and hydraulic conductivity of soil profile, were used to calculate K-factor values for each soil unit established in the catchment, using the soil erodibility nomograph, which is represented analytically by the equation (Mitova et al., 2021). The calculated values of the index of soil erodibility are categorized in 6 classes: very low >0 ≤ 0.01, low >0.01 ≤ 0.02, moderate >0.02 ≤ 0.03, moderate to high >0.03 ≤ 0.04, high >0.04 ≤ 0.05 and extreme >0.05 t ha h / ha MJ mm.

The index of topography LS combines the influence of the degree (s, %) and the length (λ, m) of slope on soil erosion rate. The topography index was calculated by the formula proposed by Moore et al. (1993), where LS

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combines the influence of the slope degree (θ, °) and the specific area, contributing to the runoff formation (As, m²/m) on the soil erosion rate:

$$LS = 1{,}4\left(\frac{A_S}{22.13}\right)^{0.4}\left(\frac{\sin(\theta)}{0.0896}\right)^{1.3} \qquad /4/$$

The formula /4/ has the advantage against the original one (Wischmeier & Smidt, 1965, 1978), since it estimates the influence of the slope length by the means of the specific area contributing to surface runoff formation, which enables more precise assessments of soil erosion rates in 3D space. The approach of Van der Knijff et al. (2000) of using a constant value of the parameter As equal to 50 m²/m was followed in the present work. For the purposes of mapping, the topography factor was categorized in 6 classes: very low >0 ≤ 1, low >1 ≤ 2, average >2 ≤ 4, average to high >4 ≤ 6, high >6 ≤ 8 and extreme >8.

The estimates of *the soil protection effect of the vegetation C*. The estimates of the were based on the permanent land cover distributions obtained by CORINE (2018) assuming 14 major classes (Rousseva, 2002). Values of the vegetation index (C-factor) for field crops were calculated using the approach developed by Rousseva (2004) with respect to rainfall erosivity monthly distributions for the agro-ecological regions distinguished on the studied territory. Means of the obtained C-factor values were calculated for each agroecological region (Yolevski at al., 1980). The values of C-factor for cropland were based on crop rotations with specific proportion between cover crops and row crops, representative for each agro-ecological region. The values of the C-factor for grassland, rangeland, abandoned agricultural land and sparse vegetation are based on adaptation of the respective data of Wischmeier & Smith (1978) with regard to the findings of Djingov (1983) and Onchev et al. (1988). The C-factor values of burned land are set after Wischmeier & Smith (1978), while these for forestland are based on the data of Wischmeier & Smith (1978) and Mandev (1995).

Results and discussion

Index of rainfall erosivity (R-factor) in the catchment area of the Dzhebelska River

The data in Table 2 present the distribution of the territory of the Dzhebelska River catchment depending on the rainfall erosivity index. With the most extensive distribution of the territory (about 45%) are the rainfalls with an average erosivity between 600 and 800 MJ mm/ha h y, which fall into the fourth class. On 37% of the area of the watershed, the rainfalls of the third class – low to medium erosivity (between 400-600 MJ mm/ha h y) are spread. Moderate to highly erosive rains (class five) characterize about 18% of the catchment area and a minor percentage of 0.21% of erosive rains are highly erosive (sixth class) between 1000 - 1500 MJ mm/ha h y. The results are also graphically presented in Figure 3.

Table 2: Percentage distribution on the lands according to the rainfall erosivity index in the territory of the catchment of Dzhebelska River

Class	Rainfall erosivity (R-factor), MJ mm / ha h	Share of the catchment's territory (%)
3	> 400 ≤ 600	36.76
4	> 600 ≤ 800	45.10
5	> 800 ≤ 1000	17.94
6	> 1000 ≤ 1500	0.21

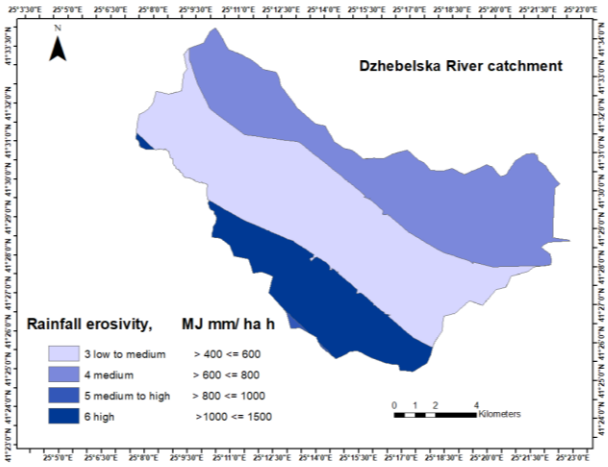

Figure 3: Distribution of the territory of Dzhebelska River catchment according to the rainfall erosivity index

Index of soil erodibility (K-factor) in the catchment area of the Dzhebelska River

Assessments of erodibility of soils in the catchment area of the Dzhebelska River were presented in Mitova et al. (2021). Considering the area, covered by different soils and their susceptibility to erosion it was found, that the largest percentage share (47.35%) of is covered by soils with medium to high susceptibility to erosion (0.03-0.04 t ha h / MJ ha mm) (Table 3 and Fig. 4).

Table 3: Percentage distribution of the lands according to the susceptibility to erosion of the soils in the territory of the catchment of Dzhebelska River assessed by the K-factor (after Mitova et al, 2021)

K-factor (t ha h / ha MJ mm)	Share of the catchment's territory (%)
0	16.22
> 0 ≤ 0.01	3.74
> 0.01≤ 0.02	1.72
> 0.02 ≤ 0.03	25.32
> 0.03 ≤ 0.04	47.35
> 0.04 ≤ 0.05	5.65

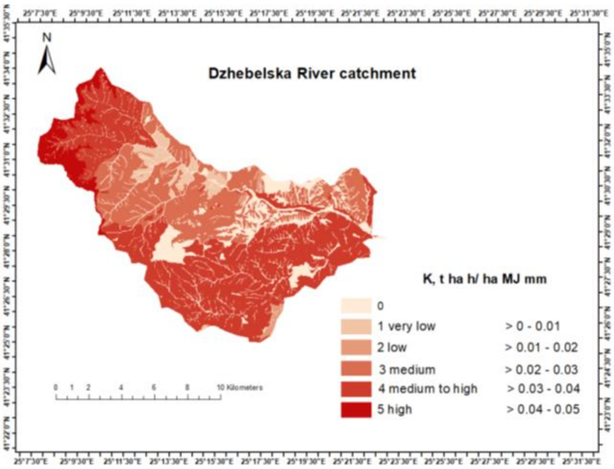

Figure 4: Map of the territory of the catchment of Dzhebelska River (East Rhodopes) according to the soil erodibility index (after Mitova et al., 2021)

Index of topography (LS- factor) of the territory of Dzhebelska River catchment

According to the assessment of the topographic index for the watershed of the Dzhebelska River (Table 4), the slope > 15° has the predominant share of the land (49.19% of the entire territory), followed by the land with a slope from 6 to 9° (19.09 %). The presence of lands with a slope of 9 to 12o is 11.77% while 11.02% of the territory of the watershed is occupied by lands with a slope of 3 to 6o. Lands with a slope from 0 to 3° occupy 4.79% and from 12 to 15° - 4.14% of the area of the watershed of the Dzhebelska River. According to Nikolova et al., (2022), topography index is calculated using the slope degree and specific contributing area. The values vary between 0 and 43.36.

Table 4: Percentage distribution of the territory of Dzhebelska River catchment according to the slope degree groups (LS-factor)

Slope groups (degree)	Share of the catchment's territory (%)
0 - 3	4.79
3 - 6	11.02
6 - 9	19.09
9 - 12	11.77
12 - 15	4.14
> 15	49.19

Potential risk of water erosion on the territory of Dzhebelska River catchment

According to the potential risk of water erosion, estimated by the soil loss equation (USLE), there are seven classes on the territory of the studied watershed of the Dzhebelska River (Table 5).

Table 5: Percentage distribution of the territory of Dzhebelska River catchment according to to the class of potential risk of water erosion

Class potential risk of water erosion (t/ha y)	Area (ha)	Share of the catchment's territory (%)
0	26160.409	16.20
1	970.394	0.60
2	3830.515	2.37
3	4708.286	2.92
4	13909.793	8.61
5	33049.574	20.46
6	52430.204	32.46

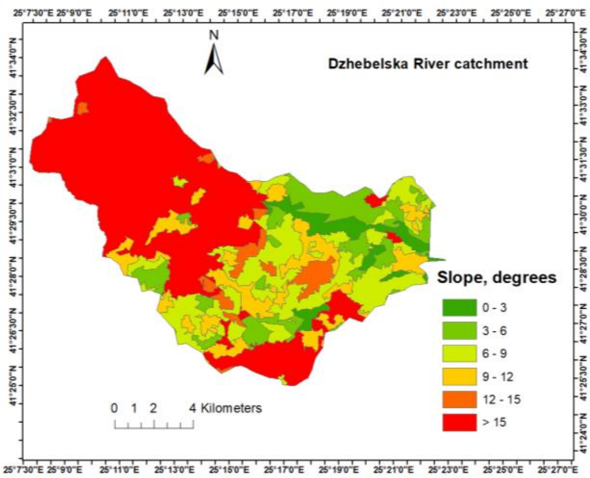

Figure 5: Map of distribution of the territory of Dzhebelska River catchment according to the slope degree groups

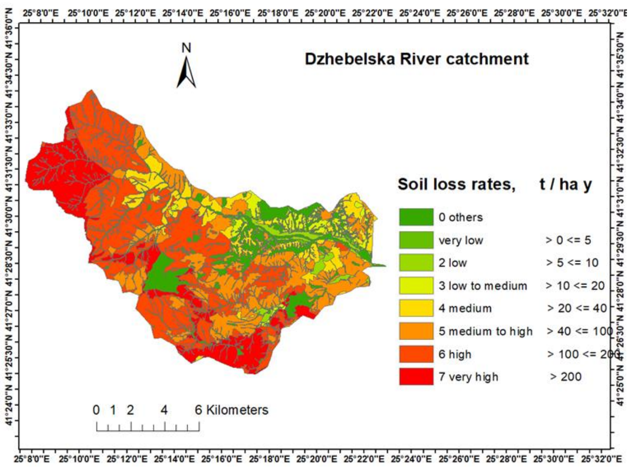

Figure 6: Map of distribution of the territory of Dzhebelska River catchment according to the potential soil erosion risk

A high potential risk with amounts of eroded soil of 100-200 t/ha y is spread over a significant share of land (32.5%) (Fig. 6). Moderate to high potential risk (40-100 t/ha y) characterises 2.46% of the lands, followed by very high potential risk (16.4%) with an amount of eroded soil >200 t/ha y. The lands with moderate potential risk (class 4) occupy 8.6%. The areas occupied by lands with low to moderate and low and very low potential risk are respectively 2.92%, 2.37% and 0.60% of the catchment area.

The soil protection effect of the vegetation (C-factor)

The studied watershed of the Dzhebelska River falls into the Kardjali and Rhodope agro-ecological regions (V4; VI7). According to the data obtained (Table 6), forests represent the largest percentage share with 57%, followed by other agricultural lands (24.12%). Rare vegetation is spread over 10.32% of the area. The field crops occupy 3.87% of the catchment area. The percentage share of pastures is 2.76% of the studied area, followed by urbanized lands with 1.39%. A minor share of the territory of the studied watershed is occupied by sands and rocks with 0.41%. On the table 7 can be seen of the values of vegetation index (C-factor).

Table 6: Percentage distribution of the territory of Dzhebelska River catchment according to permanent land cover (CORINE 2018)

Permanent land cover (CORINE)	Area (ha)	Share of the catchment's territory (%)
Forestland	92260.432	57.13
Other agricultural land	38948.787	24.12
Cropland	6255.501	3.87
Pastureland	4464.261	2.76
Sands and rocks	654.497	0.41
Sparse vegetation	16673.196	10.32
Urban land	2248.080	1.39

Table 7: Values of vegetation index (C-factor)

Permanent land cover (CORINE)	C-factor
Forestland	0.9
Other agricultural land	1.2
Cropland	3.0
Pastureland	0.3
Sparse vegetation	1.5

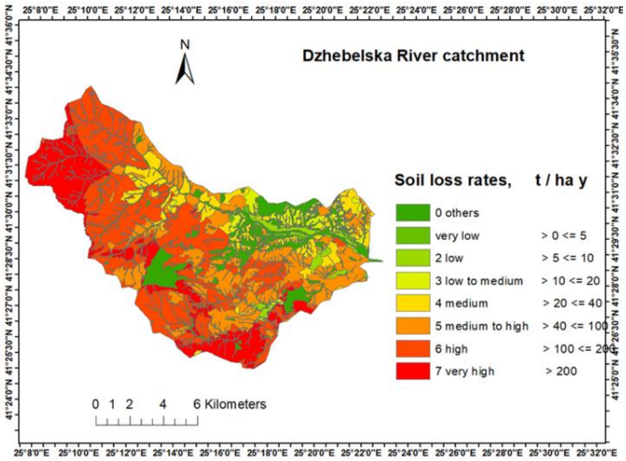

Figure 7: Map of distribution of the territory of Dzhebelska River catchment according to classes of permanent land cover

Actual risk of water erosion on the territory of Dzhebelska River catchment

According to the assessment of the actual risk of sheet water erosion (Table 8), seven classes of actual risk of water erosion were established on the territory of the watershed of the Dzhebelska River. The largest area of the studied catchment (57509.618 ha) is occupied by the lands on which a very low actual risk is observed (35.61%). Approximately 23% of the total area is occupied by lands with a low actual risk is spread. Urbanized lands cover 15.17%. The lands on which a very high actual risk is spread occupy about 15% of the catchment area. Lands on which a moderate to high actual risk of water erosion is spread account for 4.51% of the entire catchment area. Lands with high, low to moderate and moderate actual risk have the following percentage distribution for the catchment area – 4.08%, 1.67% and 1.47. The results are also graphically illustrated in Figure 8.

Table 8: Percentage distribution of the territory of Dzhebelska River catchment according to to the actual risk of water erosion

Class	Area (ha)	Share of the catchment's territory (%)
0	24506.081	15.17
1	57509.618	35.61
2	36742.478	22.75
3	2695.552	1.67
4	2380.787	1.47
5	7289.558	4.51
6	6586.613	4.08

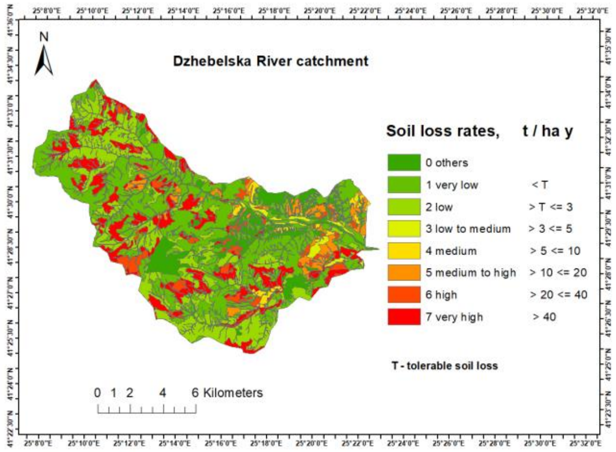

Figure 8: Map of distribution of the territory of Dzhebelska River catchment according to the actual soil erosion risk

Conclusions

Based on the results from the assessments for the soil erosion factors and rates in the catchment of Dzebelska River, conclusions can be drawn as follows. According to the results obtained from the assessment of the rainfall erosivity index (R-factor), 45% of the territory of the Dzhebelska river basin is characterized by rains with an average erosivity between 600 and 800 MJ mm/ha h y. With 47%, the lands on which medium to strong susceptibility of the soil to erosion between 0.03-0.04 t ha h / ha MJ mm (K-factor) is prevalent. The watershed of the Dzhebelska River fbelongs to the Kardjali and Rhodope agro-ecological regions. A high potential risk is spread over a significant proportion of land (32.5%) with predicted rates of eroded soil between 100-200 t/ha y. Based on the assessment of the actual risk of sheet water erosion, seven classes of actual risk have been established for the territory of the watershed of the Dzhebelska River. The lands with a very low actual risk occupy 35.61%, while those with actual risk above 10 t/ha y (classes 5, 6 and 7) cover 23.3% of the territory.

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Author contribution

All authors contributed equally to this work. All authors discussed the results and commented on the manuscript.

Conflicts of interest

The authors declare no conflict of interest.

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