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# ASSESSMENT OF SOIL EROSION INTENSITY USING THE EROSION POTENTIAL METHOD: A CASE STUDY OF THE GRDELICA GORGE, SERBIA

*Sonja BRAUNOVIĆ[1], Jovana CVETKOVIĆ[1], Filip JOVANOVIĆ[1], Siniša POLOVINA[2], Nenad ŠURJANAC[1], Vanja STOJANOVIĆ[1], Natalija MOMIROVIĆ[1]**

**Abstract:** *The South Morava River Basin was considered one of the most erosion-prone and flash flood-affected areas in the Republic of Serbia. This paper aims to apply the Erosion Potential Method (EPM) within a GIS environment to determine the spatial and temporal changes in the soil erosion coefficient, sediment production and transport, and to identify the factors contributing most significantly to erosion risk in the Grdelica Gorge for two reference years: 1970 and 2025. The intensity of soil erosion was analysed using the Erosion Potential Method according to Gavrilović. The results indicate that most of the area (62.03%) fell into slope category IV (27–70%), with all erosion categories represented. Processes of very slight erosion were predominant, covering 71.31% of the surface area (306.94 km²). The total annual sediment production ($W_{year}$) amounted to 110,233.97 $m^3year^{-1}$, while the specific sediment production ($W_{sp}$) was 256.1 $m^3km^{-2}year^{-1}$. The mean annual sediment transport was 81,573.14 m³/year, and the specific annual sediment transport was 189.51 m³/km²/year. A decline in population and the abandonment of arable land at higher elevations and steeper slopes, along with the implementation of extensive technical, biological, and biotechnical erosion control measures, contributed to erosion mitigation and enhanced vegetation recovery. Compared to the erosion intensity in 1970, the extent of severe erosion had notably decreased by 2025, while the proportions of slight and moderate erosion significantly increased. The mean erosion coefficient ($Z_{mean}$) had decreased from 0.50 to 0.23.*

**Keywords:** Grdelica Gorge, soil erosion, Erosion Potential Method (EPM), GIS

## PROCENA INTENZITETA EROZIJE ZEMLJIŠTA METODOM POTENCIJALA EROZIJE: STUDIJA SLUČAJA GRDELIČKA KLISURA (SRBIJA)

**Izvod***:* *U delove Republike Srbije koji su bili najugroženiji erozijom zemljišta i bujičnim poplavama svrstava se sliv Južne Morave. Cilj ovog rada je da se primenom Metode potencijala erozije u GIS okruženju utvrde prostorne i vremenske promene koeficijenta*

[1] Institute of Forestry, Belgrade, Serbia
[2] Faculty of Forestry, University of Belgrade, Belgrade, Serbia
*Corresponding author. E-mail: natalija.momirovic@forest.org.rs

*erozije zemljišta, produkcije i pronosa nanosa i identifikuju faktori koji najviše doprinose riziku od pojave erozije na području Grdeličke klisure za dva referentna perioda – 1970. i 2025. godinu. Intenzitet erozije zemljišta analiziran je primenom Metode potencijala erozije (MPE), prema Gavriloviću. Rezultati rada pokazuju da najveći deo područja (62,03%) pripada IV kategoriji nagiba (27–70%) i zastupljene su sve kategorije erozije. Na području su dominantni procesi vrlo slabe erozije i zahvataju 71,31% površine (306,94 km$^2$). Ukupna godišnja produkcija nanosa ($W_{year}$) iznosi 110233,97 m$^3$god$^{-1}$, a specifična produkcija nanosa ($W_{sp}$) iznosi 256,1 m$^3$km$^{-2}$god$^{-1}$. Srednjegodišnji transport nanosa na području je 81573,14 m$^3$km$^{-2}$god$^{-1}$ i specifični godišnji transport nanosa je 189,51 m$^3$km$^{-2}$god$^{-1}$. Opadanje broja stanovnika i napuštanje obradivih površina na većim nadmorskim visinama i nagibima, te veliki obim tehničkih, bioloških i biotehničkih protiverozionih radova, doveli su do ublažavanja erozije i pojačane obnove vegetacije. U odnosu na stanje intenziteta erozije u 1970. godini, stepen jake erozije je u opadanju, dok je procenat slabe i srednje erozije rapidno porastao. Srednja vrednost koeficijenta erozije (Zsr) smanjena je sa 0,50 na 0,23.*

**Ključne reči:** Grdelička klisura, erozija zemljišta, metod potencijala erozije (MPE), GIS

## 1. INTRODUCTION

Water erosion is one of the most pressing environmental challenges worldwide. This process has long-term ecological consequences, leading to the degradation of natural resources, loss of biodiversity, deterioration of water and soil quality, sedimentation of reservoirs and fertile arable land, damage to roads and settlements, and sometimes even the loss of human life. Many countries face this issue, particularly those located in regions characterised by high-intensity, short-duration rainfall, improper land use practices, and terrain configurations susceptible to erosion processes.

In the Republic of Serbia, erosion processes of varying intensity affect 86% of the national territory, 35% of which south of the Sava and Danube Rivers is exposed to excessive, severe and moderate erosion intensity (Lazarević, 1983; Dragićević et al., 2011; Ristić et al., 2012). More than 12,500 torrential streams have been recorded (Kostadinov et al., 2022). One of the most erosion-prone regions in Serbia is the South Morava River Basin, particularly the Grdelica Gorge, which has experienced the highest number of flash floods (Petrović et al., 2014; Braunović, 2013).

A holistic approach to addressing water erosion is essential, as soil erosion and flash floods are closely interrelated phenomena (Poesen & Hooke, 1997). The Erosion Potential Method (EPM), developed by Professor Slobodan Gavrilović, was originally designed to assess erosion in the southern and southeastern regions of the former Yugoslavia, now the Republic of Serbia (Gavrilović, 1970; 1972). The method has shown a high degree of reliability in determining erosion intensity and calculating sediment production and transport (Ristić et al., 2011). Over time, EPM has been adopted in Iran, Croatia, Bosnia and Herzegovina, Slovenia, Italy, Montenegro, and Chile (Dragičević, Karleuša, & Ožanić, 2016; Kouhpeima, Hashemi, & Feiznia, 2011; Globevnik et al., Holjevic, Petkovsek, & Rubinic, 2003).

Between 1907 and 2006, numerous technical and biotechnical erosion control measures were implemented, including riverbed regulation, the construction of check dams, afforestation on ridges and terraces, and contour trenching (Kostadinov, 2007). According to EPM-based research by Veličković et al. (2022), a significant reduction in soil loss—from 10.64 to 5.97 t $ha^{-1}$ $year^{-1}$—was observed between 1970 and 2018 in suburban areas located approximately 20 km from Belgrade. Ristić et al. (2011a) demonstrated that the implementation of appropriate erosion control measures in the Jelašnica River Basin would reduce the annual sediment transport by 44.1%, specific annual transport by 43.6%, and the representative erosion coefficient (Z) from 0.555 to 0.379. Similarly, Polovina et al. (2016) reported that the mean erosion coefficient ($Z_{mean}$) in the Likodra River Basin, the largest left tributary of the Jadar River, decreased from 0.275 in 1983 to 0.204. Despite Serbia's considerable technical and biotechnical erosion mitigation solutions, there remains a critical need for increased accountability and the implementation of concrete actions to address erosion risks (Ristić et al., 2011b).

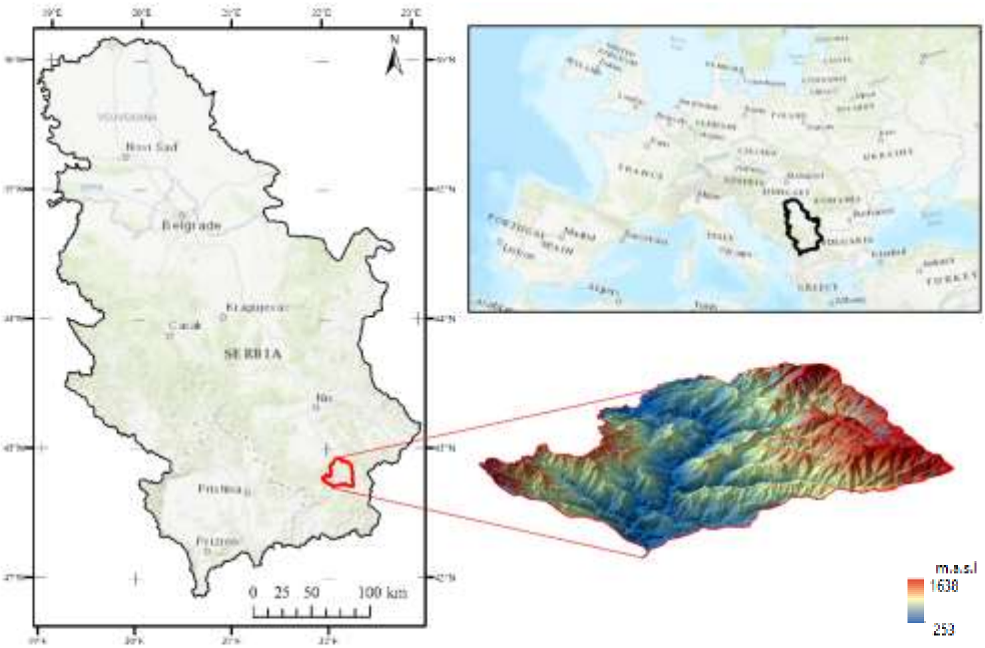
Our study aims to apply the Erosion Potential Method (EPM) within a GIS-based framework to assess spatial and temporal changes in the erosion coefficient, sediment production, and sediment transport in the Grdelica Gorge. The analysis focuses on identifying the primary contributing factors to erosion risk in the Grdelica Gorge area for two reference years: 1970 and 2025.

## 2. MATERIAL AND METHODS

### 2.1 Study area

The area comprising the Grdelica Gorge and the Vranje Valley was designated as a unified erosion control region under the Law on Erosion Control and Torrent Regulation adopted in 1954. This law identified the region as a distinct erosion-prone area in Serbia, highlighting its specific environmental features and challenges and granting it the highest priority for erosion control management (Official Gazette of the People's Republic of Serbia, No. 36/54). The boundaries defined by the law differ slightly from its natural geographic borders.

The Grdelica Gorge, covering an area of 430.44 $km^2$, belongs to the South Morava River Basin, extending from Grdelica to Vladičin Han. Administratively, it spans the municipalities of Leskovac, Grdelica, Vladičin Han, Surdulica, and Crna Trava. Along this stretch of the South Morava River, there are 137 torrential tributaries of different types and categories, ranging from minor gullies with insignificant catchment areas to highly destructive torrential rivers (District Section for Soil Erosion Control and Torrent Regulation, Vladičin Han, 1964). The hydrographic network density in the area is 0.64 $km \cdot km^{-2}$ (Table 1). In most mountain massifs of the Grdelica Gorge, the topography exhibits a highly dissected terrain shaped by complex tectonic structures and the torrential character of its hydrographic network (Cvijić, 1900). The hydrographic and topographic characteristics of the Grdelica Gorge are summarised in Table 1 and illustrated in Figure 1.




**Source:** *Author*

**Figure 1.** *Location of the Grdelica Gorge*

**Table 1.** *Hydrographic and Topographic Characteristics of the Grdelica Gorge*

| Parameter | Unit | Value |
|---|---|---|
| Area | km$^2$ | 430.44 |
| Perimeter | km | 99.57 |
| The length of main stream | km | 29.50 |
| Confluence point | m.a.s.l. | 324.00 |
| Peak point | m.a.s.l. | 253.00 |
| Stream winding coefficient | | 0.69 |
| Number of torrential tributaries | | 137 |
| Average channel gradient of the section | % | 2.41 |
| Total length of the waterways | km | 277.01 |
| Density of the hydrographic network | km·km$^{-2}$ | 0.64 |
| Mean width of the area | km | 14.59 |
| Asymmetry coefficient of the drainage basin | | 0.82 |
| Shape coefficient of the drainage area | | 0.54 |
| Highest elevation point in the basin | m.a.s.l. | 1638.00 |
| Mean elevation | m.a.s.l. | 789.57 |
| Medium elevation difference | m | 536.57 |

**Source:** *District Section for Soil Erosion Control and Torrent Regulation, Vladičin Han, 1964*

Between 1947 and 1977, a total of 5.96 km of channel regulation and 1,087 transverse structures (including check dams, sills, and cascades) were constructed along 58 tributaries of the South Morava River in the Grdelica Gorge. On the slopes of 19 catchments, 11,282.6 meters of wattling, 11,822 meters of terraces, 68,000 meters of bench terraces, 95.00 meters of horizontal walls, 93.43 hectares of orchards, and 35.4 hectares of reclaimed pastures were established. In addition, 1,041.2 hectares were afforested, and 1,210.5 hectares were grassed in this area (Kostadinov et al., 2018).

According to the Soil Map of the Grdelica Gorge and Vranje Valley at a scale of 1:50,000 (Institute of Pedology and Agrochemistry, 1960), the predominant soil types within the study area are Distric Cambisol, occupying 356.42 km² (82.80%), and Eutric Cambisol, covering 36.58 km² (8.50%). Other identified soil types include Calcocambisol (9.09 km², 2.11%), Regosol (8.70 km², 2.02%), Haplic Leptosol (8.49 km², 1.97%), Fluvisol (7.21 km², 1.68%), and Vertisol (3.95 km², 0.92%). The spatial distribution of these soil types is presented in Figure 2.

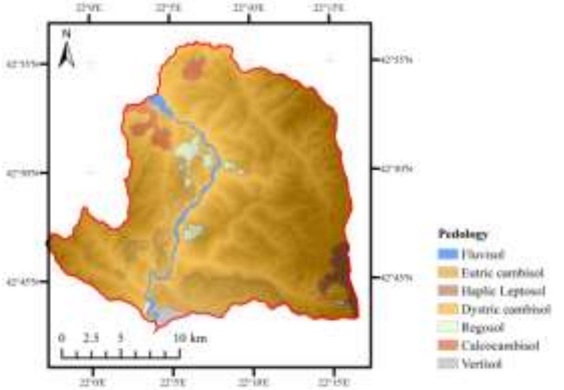



**Figure 2.** *Soil map*

According to the CORINE Land Cover (CLC) dataset (2018), the predominant land use in the study area is classified as broadleaved forests, covering 302.4 km² (70.25%). It is followed by land principally occupied by agriculture, with significant areas of natural vegetation 46.10 km² (10.71%), Complex cultivation patterns (32.38 km², 7.52%), transitional woodland/shrubs (24.36 km², 5.66%), mixed forests (8.76 km², 2.03%), pastures (5.68 km², 1.32%), natural grasslands (3.45 km², 0.80%), and coniferous forests (3.30 km², 0.77%). Land use classes with a share below 0.5% include construction sites (1.57 km², 0.36%), discontinuous urban fabric (1.56 km², 0.36%), mineral extraction sites (0.54 km², 0.13%), and non-irrigated arable land (0.34 km², 0.08%). The spatial distribution of land use categories is illustrated in Figure 3.

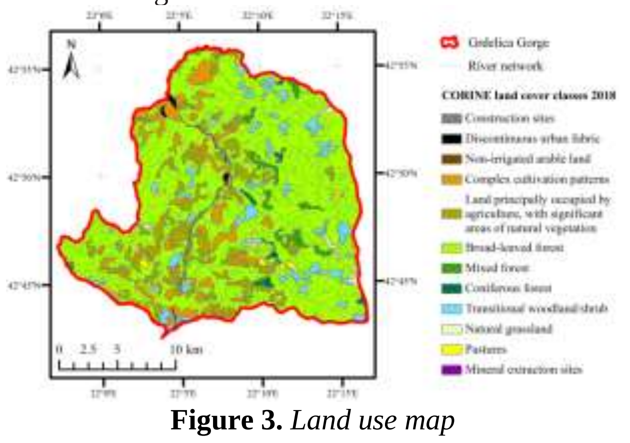



**Figure 3.** *Land use map*

The average annual rainfall in Grdelica Gorge for the period 1991–2020 amounted to 746.9 mm while the mean annual temperature was 8.9 °C.

The values and spatial distribution of mean annual precipitation and air temperature for the Grdelica Gorge area are presented in Figures 4 and 5, respectively.

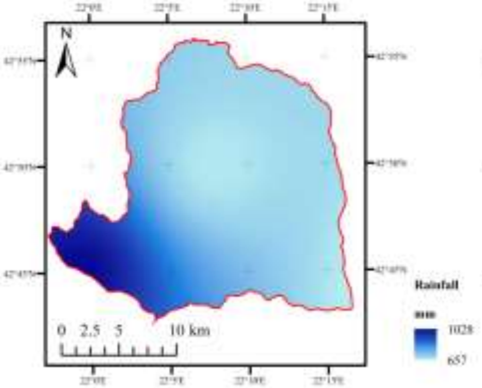



***Figure 4.*** *Mean Annual Precipitation Totals*

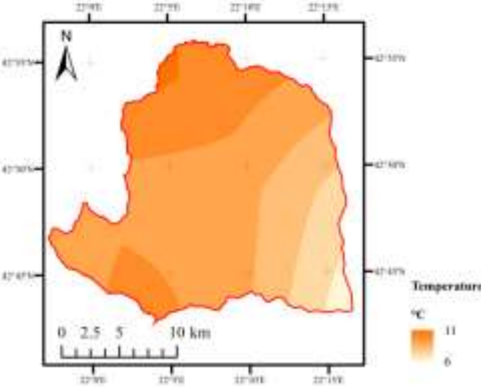



***Figure 5.*** *Mean Annual Air Temperatures*

## 2.2 Method

The intensity of soil erosion in the study area was analysed using the Erosion Potential Model (EPM) developed by Gavrilović (1972).

In order to calculate the specific annual erosion per km$^2$ Equation (1) was used:

$$W_{sp} = T \cdot H_{year} \cdot \pi \cdot \sqrt{Z^3}$$

where $W_{sp}$ is the specific annual erosion (m$^3$·km$^{-2}$·year$^{-1}$), $T$ is the temperature coefficient, $H_{year}$ is the mean annual precipitation (mm), π is Ludolf number (Archimedes' constant) and $Z$ is the erosion coefficient. Temperature coefficient ($T$) is calculated by the following equation (Equation 2):

$$\mathrm{T} = \sqrt{\frac{t^0}{10} + 0{,}1}$$

Where t is the mean annual temperature in °C.

Data on the mean annual precipitation totals for the period from 1991 to 2020 were obtained from the Meteorological Yearbooks (RHMS, 2025) for the stations in Leskovac, Kukavica, Babušnica, Predejane, and Vlasina. Data on mean annual air temperatures were sourced from the Digital Atlas of Climate and Climate Change of the Republic of Serbia (Ministry of Environmental Protection, 2022). The spatial distribution of mean annual precipitation was derived using the Inverse Distance Weighting (IDW) interpolation method in a GIS environment.

The erosion coefficient (Z) depends on factors such as soil types, erosion area management, visible erosion processes, and terrain slope. It is calculated using the following equation (Equation 3):

$$Z = Y \cdot X \cdot a\left( \varphi + \sqrt{I_{mean}} \right)$$

Where Y represent the coefficient of soil resistance to erosion, X·a is the land use coefficient, φ the coefficient of the observed erosion process and $I_{mean}$ is the mean slope of terrain.

To determine the soil resistance to erosion, coefficient values according to Gavrilović (1972) were assigned to soil types identified based on the Soil Map of the Grdelica Gorge and Vranje Valley at a scale of 1:50,000 (Institute of Pedology and Agrochemistry, 1960).

The land use coefficient**,** which ranges from 0 to 1, was determined based on the CLC 2018 database for the study area.

To identify visible and clearly expressed erosion processes, Sentinel-2 L2A satellite imagery was used for the period from January 1 to December 31, 2024, with cloud cover below 10%. Based on the available satellite images, the Bare Soil Index (Rikimaru et al., 2002) was calculated, serving as the primary input for determining the coefficient of visible and clearly expressed erosion processes (Polovina et al., 2024).

The slope was derived from a Copernicus Digital Elevation Model (COP-DEM_GLO-30-DTED) (Copernicus, 2020).

The calculation of the annual gross erosion $W_{year}$ in $m^3 \cdot year^{-1}$ for the entire study area was performed by multiplying the specific annual erosion ($W_{sp}$) with the area in $km^2$. In order to determine the specific sediment transport ($G_{sp}$) in $m^3\ km^{-2} god^{-1}$ and total sediment transport which reaches the hydrographic profile ($G_{year}$) in $m^3 year^{-1}$, $W_{sp}$ and $W_{year}$ were multiplied with the sediment delivery ratio (Ru) calculated using the following equation (Equation 4):

$$R_u = \frac{\sqrt{O \cdot D}}{0{,}25(L + 10)}$$

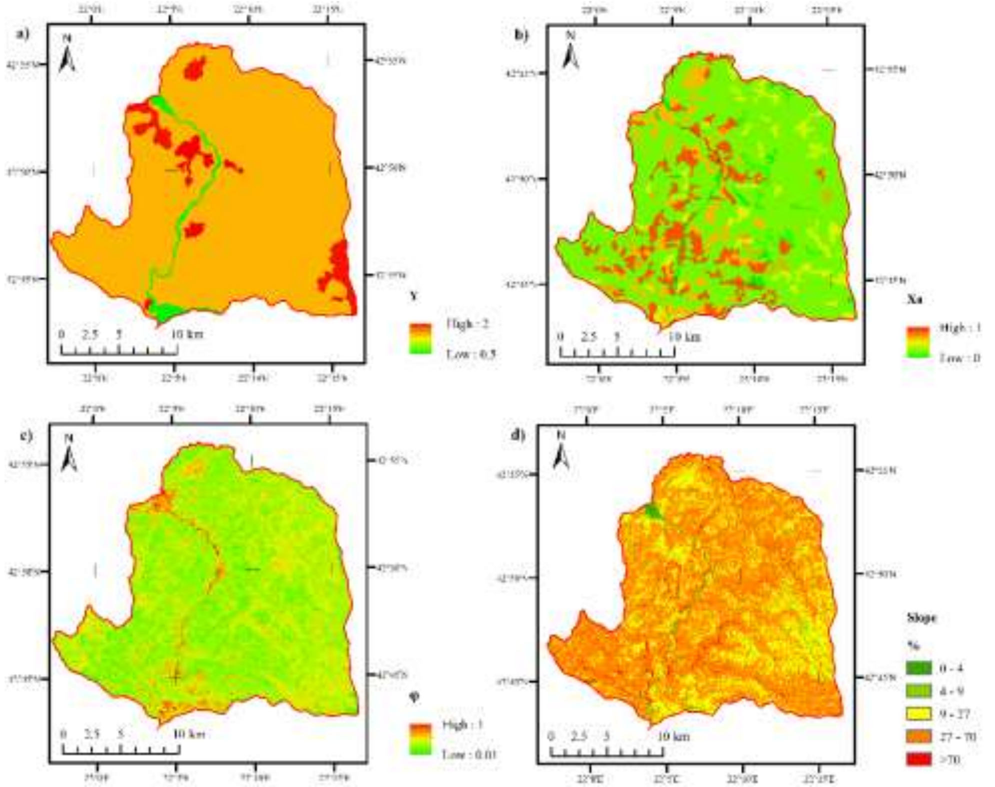
Where O is the perimeter of catchment (km), D is the average difference in elevation of the catchment (km) and L is the length of catchment (km).

The morphometric attributes were derived from a topographic map, scale 1:25,000.

The analysis of population change was conducted using census data from the years 1961, 1971, 1981, 1991, 2002, 2011, and 2023 for the following municipalities (or their parts) within the study area: Leskovac (25 settlements), Crna Trava (7 settlements), Vladičin Han (21 settlements), and Surdulica (4 settlements). Data were collected and analysed for a total of 57 cadastral municipalities (Statistical Office of the Republic of Serbia, 2023).

## 3. RESULTS AND DISCUSSION

By processing geospatial data in a GIS environment, thematic maps were generated (Figures 2–6), along with a synthesised map of erosion intensity (Figure 7).




**Source:** Author

**Figure 6.** S*patial distribution of the reciprocal value of the soil erosion resistance coefficient Y (a), the erosion control coefficient Xa (b), the numerical equivalent of visible and clearly expressed erosion processes φ (c), and the slope map (d)*

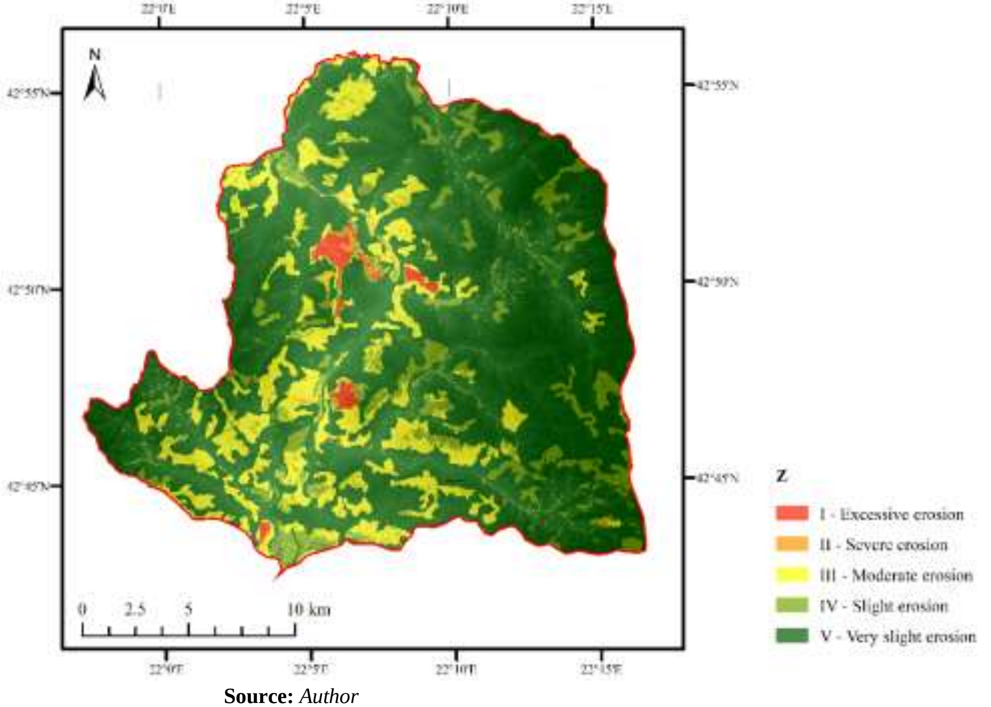
Table 2 presents the distribution of surface areas by slope categories (I–V) according to the International Geographical Union (IGU) slope classification from 1968, while their spatial distribution is shown in Figure 6d.

The majority of the Grdelica Gorge area (62.03%) falls within Category IV slopes, ranging from 27% to 70%.

***Table 2.*** *Slope Classification According to the International Geographical Union (IGU, 1968)*

| Category | Slope | Characteristics | Area | |
|---|---|---|---|---|
| | % | | km$^2$ | % |
| **I** | 0-4 | No visible signs of mass movement. Surface runoff reduced to minimum. | 5.01 | 1.16 |
| **II** | 4-9 | Visible indications of movement are present. Pronounced surface wash, soil flow, and landslides are present. | 13.07 | 3.04 |
| **III** | 9-27 | Severe erosion. Intense surface wash and mass movement are present. | 138.43 | 32.16 |
| **IV** | 27-70 | Excessive erosion. Enhanced surface wash and material removal are evident. | 267.02 | 62.03 |
| **V** | >70 | Mass movement is so pronounced that the accumulated material is only sporadically retained, and predominantly bare rocky surfaces occur. | 6.91 | 1.61 |
| | | Total | 430.44 | 100.00 |

The erosion map (Figure 7) presents the spatial distribution of erosion processes at a resolution of 30 m, providing insight into their intensity. All categories of erosion are present within the Grdelica Gorge (Table 3). Based on the calculated mean erosion coefficient ($Z_{mean}$ = 0.23) for the year 2025, the Grdelica Gorge is predominantly affected by low-intensity erosion processes.




**Source:** *Author*

**Figure 7.** *Erosion Processes in the Grdelica Gorge – Current Status*

**Table 3.** *Distribution of Erosion Categories in the Grdelica Gorge*

| Erosion category | Qualitative name of erosion category | In 2025 | |
|---|---|---|---|
| | | km$^2$ | % |
| **I** | Excessive erosion | 4.73 | 1.10 |
| **II** | Severe erosion | 2.96 | 0.69 |
| **III** | Moderate erosion | 62.45 | 14.51 |
| **IV** | Slight erosion | 53.37 | 12.40 |
| **V** | Very slight erosion | 306.94 | 71.31 |
| **Total** | | 430.44 | 100.00 |
| **Mean value of coefficient Z** | | Zmean = 0.23 | |

**Source:** *Author*

Processes of excessive erosion affect an area of 4.73 km², accounting for 1.10% of the Grdelica Gorge. These processes are concentrated within the immediate catchment of the South Morava River as it flows through the gorge, occurring on slopes ranging from 9% to over 70%, primarily on Regosol and soils predominantly used for agriculture, with substantial areas of natural vegetation. These areas include the surroundings of Predejane and the villages of Garinje, Kopitarce, Repište, and Balinovce (Vladičin Han municipality), as well as Graovo and Koraćevac (Leskovac municipality). Severe erosion occurs on slopes of 9% to 70%, primarily on Regosol, Distric Cambisol, and Eutric Cambisol soils, particularly in areas characterised by complex land cultivation practices and agricultural land use with notable natural vegetation cover. Affected areas include the surroundings of Predejane, the villages of Graovo and Koraćevac (Leskovac municipality), Mrtvice (Vladičin Han municipality), and Kijevac (Surdulica municipality). Very slight erosion processes are dominant in the Grdelica Gorge, covering 71.31% of the area (306.94 km²). These processes are mainly associated with Distric Cambisol under broadleaved, coniferous, and mixed forests. Moderate erosion affects 62.45 km², or 14.51% of the area, while slight erosion is present on 12.40% of the area.

The total annual sediment yield ($W_{year}$) in the Grdelica Gorge is estimated at 110,233.97 $m^3 \cdot year^{-1}$, with a specific sediment yield ($W_{sp}$) of 256.1 $m^3 \cdot km^{-2} \cdot year^{-1}$. The mean annual sediment transport amounts to 81,573.14 $m^3 \cdot year^{-1}$, while the specific annual sediment transport is 189.51 $m^3 \cdot km^{-2} \cdot year^{-1}$.

According to the 1970 Erosion Map of Serbia, the Grdelica Gorge was affected by erosion processes of varying intensities. In the immediate catchment of the South Morava River, processes of severe and excessive erosion were recorded, with excessive erosion also present in the higher (peripheral) areas of the gorge (Lazarević, 1983). The development of these processes was influenced not only by natural conditions but also by inappropriate land use practices, such as cultivation on steep slopes, ploughing along the slope gradient, overgrazing, leaf stripping, and high settlement density. The mean erosion coefficient at that time was $Z_{mean} = 0.50$, indicating a predominance of moderate erosion processes.

To quantify the changes in erosion intensity within the Grdelica Gorge, a comparative analysis was conducted between the erosion status in 1970 and 2025 (Table 4). The analysis revealed that slight erosion (Category IV) is the dominant process in the study area. The area affected by very slight erosion has increased by 34.36%, while slight erosion shows a marginal increase in 2025 compared to 1970. Moderate erosion has also increased by 11.27%. In contrast, the area under severe erosion has decreased by 47.67%. Excessive erosion, which was not recorded in

1970, is now present in only 1.10% of the total area (Table 4). In 1970, 48.36% of the catchment was affected by severe erosion. The current status shows a reduction in this category to 0.69%. The area affected by moderate erosion has increased from 14.51 km² in 1970 to 23.94 km² in 2025 an increase of 11.27%.

The mean erosion coefficient has decreased from $Z_{mean}$ = 0.50 in 1970 to $Z_{mean}$ = 0.23 in 2025 (Table 4).

**Table 4.** *Erosion categories in the Grdelička Gorge – 1970 and 2025*

| Erosion category | Qualitative name of erosion category | 1970[1] year | | 2025[2] year | |
|---|---|---|---|---|---|
| | | km$^2$ | % | km$^2$ | % |
| **I** | Excessive erosion | 0.00 | 0.00 | 4.73 | 1.10 |
| **II** | Severe erosion | 208.18 | 48.36 | 2.96 | 0.69 |
| **III** | Moderate erosion | 13.96 | 3.24 | 62.45 | 14.51 |
| **IV** | Slight erosion | 49.25 | 11.44 | 53.37 | 12.40 |
| **V** | Very slight erosion | 159.05 | 36.95 | 306.94 | 71.31 |
| **Total** | | 430.44 | 100 | 430.44 | 100 |
| **Mean value of coefficient Z** | | Zsr = 0.50 | | Zsr = 0.23 | |

**Source:** [1] Erosion Map, 1970 (Lazarević, 1983); [2] Author

The total annual sediment yield in the Grdelica Gorge was 377,679.07 m$^3$ year$^{-1}$ in 1970 and decreased to 110,233.97 m$^3$ year$^{-1}$ in 2025. The specific sediment yield was reduced from 878.42 m$^3$ km$^{-2}$ year$^{-1}$ in 1970 to 256.10 m$^3$ km$^{-2}$ year$^{-1}$ in 2025. In other words, due to changes in the intensity of erosion processes, the mean annual sediment transport in the study area was reduced by 197,909.4 m$^3$ year$^{-1}$, while the specific sediment transport decreased by 460.36 m$^3$ km$^{-2}$ year$^{-1}$.

**Table 5.** *Sediment Production and Transport in the Area of the Grdelica Gorg*

| Year | Catchment area km$^2$ | Sediment yield | | Retention coefficient | Sediment transport | |
|---|---|---|---|---|---|---|
| | | Specific | Total | | Specific | Total |
| | | Wsp m$^3$ km$^{-2}$year$^{-1}$ | Wyear m$^3$year$^{-1}$ | Ru | Gsp m$^3$ km$^{-2}$year$^{-1}$ | Gyear m$^3$year$^{-1}$ |
| **1970** | 430.44 | 878.20 | 377,679.07 | 0.74 | 649.87 | 279,482.51 |
| **2025** | | 256.10 | 110,233.97 | 0.74 | 189.51 | 81,573.14 |

**Source:** *Author*

In addition to the previously mentioned factors influencing the occurrence, development, and intensity of erosion processes, demographic changes have also played a significant role in the Grdelica Gorge. The most pronounced population decline during the study period occurred in the municipality of Crna Trava, where the number of inhabitants decreased by a factor of 28. In the municipality of Vladičin Han, the population was reduced fourfold, in Surdulica by 2.5 times, and in Leskovac by 1.8 times (Table 6).

**Table 6.** *Population by Municipality and Census Years*

| Municipality | 1971 | 1981 | 1991 | 2002 | 2011 | 2022 |
|---|---|---|---|---|---|---|
| **Leskovac** | 14242 | 14055 | 13229 | 12366 | 10611 | 8142 |
| **Crna Trava** | 1292 | 727 | 359 | 199 | 94 | 46 |
| **Vladičin Han** | 8679 | 7484 | 6029 | 4682 | 3304 | 2143 |
| **Surdulica** | 2271 | 1901 | 1185 | 665 | 339 | 288 |
| **Total** | 26484 | 24167 | 20802 | 17912 | 14348 | 10619 |

**Source:** *Author*

Of particular importance is the population decline in the municipalities of Crna Trava, Vladičin Han, and Surdulica, due to the area's topography and the abandonment of villages located at higher elevations, which has consequently led to the abandonment of agricultural land. Population decline has changed land use patterns, resulting in the overgrowth of former arable land and the natural regeneration of vegetation on these areas.

The results from the 1970 erosion intensity assessment differ significantly from those observed today. Very slight erosion was present on approximately 18% of the area, slight erosion on 25.2%, moderate erosion on 16.6%, while severe erosion affected 36.8% of the catchment.

A decreasing trend in erosion intensity is evident in catchments throughout Serbia. In the Grdelica Gorge, the mean erosion coefficient (Z) decreased from 0.84 in 1953 to 0.34 in 2010 (Braunović, 2013). In the Velika Morava catchment, soil erosion decreased by 21% between 1971 and 2011, with the Z value dropping from 0.529 to 0.420 (Srejić, 2023). In the hilly suburban area of Belgrade, the mean erosion coefficient declined from 0.506 to 0.332 over the period 1970–2018 (Veličković et al., 2022). Similarly, in the Rasina River basin, the erosion coefficient fell from 0.62 in 1968 to 0.35 in 2022 (Stefanović et al., 2024).

## 4. CONCLUSIONS

To assess land degradation in the study area, the Erosion Potential Method (EPM) originally developed for application in the Grdelica Gorge was employed.

The results indicate a significant difference in erosion intensity between 1970 and 2025, with the most notable changes occurring in the categories of very slight and severe erosion. While slight erosion is currently widespread across the entire study area, severe erosion remains concentrated on slopes ranging from 27% to 70% in the immediate catchment of the South Morava River through the gorge.

A continuous decline in population from 1971 to 2023, accompanied by the abandonment of arable land, particularly in areas with steep slopes and higher elevations and the implementation of extensive technical, biological, and biotechnical erosion control measures, has contributed to the mitigation of erosion processes and facilitated the spontaneous regeneration of vegetation.

It can be concluded that the extent of severe erosion is decreasing, whereas the proportions of slight and moderate erosion have increased considerably. Consequently, the average erosion coefficient ($Z_{mean}$) for the Grdelica Gorge currently stands at 0.23, indicating that the area is predominantly affected by slight erosion.

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## REFERENCES

Braunović, S. Z. (2013). *Efekti protiverozionih radova na stanje erozije u Grdeličkoj klisuri i Vranjskoj kotlini* [Doktorska disertacija, Univerzitet u Beogradu, Šumarski fakultet]. Phaidra. https://doi.org/10.2298/bg20131004braunovic

Copernicus. (2020). Copernicus Digital Elevation Model (COP-DEM), GLO-30-DTED product (Version 1.1) [Data set]. European Space Agency. Retrieved April 07, 2025, from https://dataspace.copernicus.eu

Cvijić, J. (1900). Struktura i podela planina balkanskog poluostrva. Glasnik srpske kraljevske akademije, LXIII, Beograd.

Dragičević, N., Karleuša, B., & Ožanić, N. (2016). A review of the Gavrilović method (Erosion Potential Method) application / Pregled primjene Gavrilovićeve metode (metoda potencijala erozije). Građevinar: Časopis Hrvatskog saveza građevinskih inženjera, *68(9)*, 715–725. https://doi.org/10.14256/JCE.1602.2016

Gavrilovic, S. (1970). *Savremeni nacini proracunavanja bujicnih nanosa i izrada karata erozije (Modern methods for calculation of torrential sediment yield and erosion mapping, in Serbo-Croatian).* Proceeding, Seminar Erosion, Torrents and Sediment, 85-100.

Gavrilović, S. (1972). Inženjering o bujičnim tokovima i eroziji. Izgradnja, special issue, 1–292.

Generalni projekat protiverozionog uređenja bujičnih tokova na području Grdeličke klisure (2008). Šumarski fakultet Beograd i Institut za vodoprivredu Jaroslav Černi, Beograd.

Globevnik, L., Holjevic, D., Petkovsek, G., & Rubinic, J. (2003). *Applicability of the Gavrilovic method in erosion calculation using spatial data manipulation techniques.* In Proceedings of Symposium HS01, Sapporo (279):224–233.

International Geographical Union (IGU) (1968). Commision on applied geomorphology, Subcommission on geomorphological mapping, The unfied key to the detailed geomorphological map of the world 1:25000–1:50000, Folia geographica, serias geoograpcia-physica, vol. II. Krakow.

Kostadinov, S. (2007). *Erosion and torrent control in Serbia: Hundred years of experiences*. In Proceedings of the International Conference: Erosion and Torrent Control as a Factor in Sustainable River Basin Management (CD).

Kostadinov, S., Braunović, S., Dragićević, S., Zlatić, M., Dragović, N., Rakonjac, N. (2018): Effects of Erosion Control Works: Case Study – Grdelica Gorge, the South Morava River (Serbia). *Water 10(8):*1094. https://www.mdpi.com/2073-4441/10/8/1094

Kostadinov, S., Momirović, N., Lazarević, K., Stefanović, T. (2022). Erozija i bujične poplave u Srbiji: iskustva i perspektiva odbrane. *Vodoprivreda, 54(317–318*):81–96.

Kouhpeima, A., Hashemi, S.A.A., & Feiznia, S. (2011). A study on the efficiency of erosion potential model (EPM) using reservoir sediments. *Elixir Pollution, 38,* 4135–4139.

Lazarević, R. 1983. The erosion map of Serbia 1:500000–Interpreter, Institute of Forestry and Wood Industry, Belgrade (In Serbian).

Ministarstvo zaštite životne sredine. (2022). Digitalni atlas klime i klimatskih promena

Republike Srbije. Projekat „Unapređenje srednjoročnog i dugoročnog planiranja mera prilagođavanja na izmenjene klimatske uslove u republici Srbiji“, https://atlas-klime.eko.gov.rs

Reonska sekcija za zaštitu zemljišta od erozije i uređenje bujica, Vladičin Han. (1964). Popis bujica desnih i levih pritoka Južne Morave na deonici Grdelica Vladičin – Han, Grdelička klisura. Registar bujičnih slivova i padina.

Republic Hydrometeorological Service of Serbia (RHMOS). (2025). Meteorological Annual Reports. Belgrade, Serbia. https://www.hidmet.gov.rs/ciril/meteorologija/klimatologija_godisnjaci.php

Republički Zavod za statistiku, Beograd. (2025). Uporedni pregled broja stanovnika 1948, 1953, 1961, 1971, 1981, 1991, 2002, 2011. i 2022. godine https://popis2022.stat.gov.rs/sr-Latn/popisni-podaci-eksel-tabele/

Pedološka karta područja Grdeličke klisure i Vranjske kotline 1:50 000. (1960). Institut za pedologiju i agrohemiju, Beograd.

Poesen, J., & Hooke, J.M. (1997). Erosion, flooding and channel management in Mediterranean environments of southern Europe. *Progress in Physical Geography, 21(2),* 157–199. https://doi.org/10.1177/030913339702100201

Ristić, R., Radić, B., Nikić, Z., Trivan, G., Vasiljević, N., Dragićević, S., Živković, N., & Radosavljević, Z. (2011). Erosion control and protection from torrential floods in Serbia—Spatial aspects. *Spatium, 25,* 1–6. https://doi.org/10.2298/SPAT1125001R

Ristić, R., Radić, B., Vasiljević, N., & Nikić, Z. (2011). Land use change for flood protection: A prospective study for the restoration of the river Jelašnica watershed. *Glasnik Šumarskog Fakulteta, 103,* 115–130. https://doi.org/10.2298/GSF1103115R

Službeni glsnik NRS br. 36/54. (1954). Zakon o zaštiti od erozije i uređenju bujica.

Srejić, T. (2023): *Prostorno-vremenska varijabilnost intenziteta mehaničke vodne erozije u neposrednom slivu Velike Morave*. Doktorska disertacija, Univerzitet u Beogradu, Geografski fakultet. http://www.eteze.bg.ac.rs/application/showtheses?thesesId=9752

Stefanović, I., Ristić, R., Dragović, N., Stefanović, M., Živanović, N. & Čotrić, J. (2024): Effects of Erosion Control Works: Case Study–Reservoir Celije, Rasina River Basin, the Zapadna Morava River (Serbia). *Water, 16,* 855.

Veličković, N., Todosijević, M., & Šulić, D. (2022). Erosion map reliability using a geographic information system (GIS) and erosion potential method (EPM): A comparison of mapping methods, Belgrade peri-urban area, Serbia. *Land, 11(7),* 1096. https://doi.org/10.3390/land11071096

Rikimaru, A., Roy P.S., & Miyatake, S. (2002): Tropical forest cover density mapping. *Trop. Ecol., 43*, 39-47.

Polovina, S., Radić, B., Ristić, R., & Milčanović, V. (2024). Application of Remote Sensing for Identifying Soil Erosion Processes on a Regional Scale: An Innovative Approach to Enhance the Erosion Potential Model. *Remote Sensing, 16(13),* 2390. https://doi.org/10.3390/rs16132390

**ASSESSMENT OF SOIL EROSION INTENSITY USING THE EROSION POTENTIAL METHOD: A CASE STUDY OF THE GRDELICA GORGE, SERBIA**

*Sonja BRAUNOVIĆ, Jovana CVETKOVIĆ, Filip JOVANOVIĆ,*
*Siniša POLOVINA, Nenad ŠURJANAC, Vanja STOJANOVIĆ,*
*Natalija MOMIROVIĆ*

**Summary**

The catchment area of the South Morava River, particularly the Grdelica Gorge, is among the most vulnerable regions in Serbia to soil erosion and torrential floods. Despite Serbia's notable achievements in technical and biotechnical erosion control, there remains a need for increased accountability and the implementation of concrete actions to mitigate erosion-related risks.

This study aims to assess the spatial and temporal variations in the erosion coefficient, sediment yield, and sediment transport within the Grdelica Gorge by applying the Erosion Potential Method (EPM) developed by Gavrilović (1972), within a GIS framework. The objective is to identify the primary contributing factors to erosion risk for two reference years—1970 and 2025.

The analysis revealed that the majority of the study area (62.03%) falls within the slope category IV (27–70%), encompassing all erosion intensity classes. According to the mean erosion coefficient ($Z_{mean}$ = 0.23) for 2025, the Grdelica Gorge is predominantly affected by slight erosion. Areas of excessive erosion cover 4.73 $km^2$ (1.10% of the total area), occurring on slopes ranging from 9% to over 70%, primarily on regosols and agricultural land with large areas of natural vegetation. These zones include the surroundings of Predejane and the villages of Garinje, Kopitarce, Repište, and Balinovce (municipality of Vladičin Han), as well as Graovo and Koraćevac (municipality of Leskovac). Severe erosion is found on slopes from 9% to 70%, mostly on regosols, dystric, and eutric cambisols, associated with complex land management practices and predominant agricultural use with substantial natural vegetation cover. Very slight erosion is the most prevalent process, affecting 71.31% of the area (306.94 $km^2$), mainly occurring on dystric cambisols under broadleaved, coniferous, or mixed forest cover. The estimated total annual sediment yield ($W_{year}$) for 2025 is 110,233.97 $m^3 year^{-1}$, with a specific yield ($W_{sp}$) of 256.1 $m^3 km^{-2} year^{-1}$. The average annual sediment transport is 81,573.14 $m^3$/year, while the specific transport is 189.51 $m^3 km^{-2} year^{-1}$.

A comparative analysis of erosion conditions between 1970 and 2025 shows that low-intensity erosion (Category IV) now predominates. The area affected by very slight erosion increased by 34.36%, while the extent of severely eroded land decreased by 47.67%. In 1970, severe erosion affected 48.36% of the catchment area, whereas by 2025, this figure had dropped to just 0.69%. The mean erosion coefficient ($Z_{mean}$) declined from 0.50 to 0.23. Total sediment yield decreased from 377,679.07 $m^3/year^{-1}$ in 1970 to 110,233.97 $m^3/year^{-1}$ in 2025, and specific sediment yield fell from 878.42 to 256.10 $m^3/km^2/year^{-1}$. The reduction in erosion intensity is attributed to population decline between 1971 and 2023, abandonment of arable land at higher altitudes and steeper slopes, and the extensive implementation of technical, biological, and biotechnical erosion control measures. These factors have mitigated erosion processes and enhanced vegetation recovery.

The findings indicate a marked reduction in severe erosion, accompanied by an increase in slight and moderate erosion. The current erosion coefficient ($Z_{mean}$ = 0.23) suggests that the Grdelica Gorge is now predominantly affected by slight erosion.

## PROCENA INTENZITETA EROZIJE ZEMLJIŠTA METODOM POTENCIJALA EROZIJE: STUDIJA SLUČAJA GRDELIČKA KLISURA (SRBIJA)

*Sonja BRAUNOVIĆ, Jovana CVETKOVIĆ, Filip JOVANOVIĆ, Siniša POLOVINA, Nenad ŠURJANAC, Vanja STOJANOVIĆ, Natalija MOMIROVIĆ*

### Rezime

U delove Republike Srbije koji su bili najugroženiji erozijom zemljišta i bujičnim poplavama svrstava se sliv Južne Morave, posebno Grdelička klisura. Iako Srbija ima značajnih tehničkih i biotehničkih rešenja, postoji potreba za većim stepenom preuzimanja odgovornosti i konkretnih koraka za problem erozije. Cilj ovog rada je da se primenom metode potencijala erozije u GIS okruženju utvrde prostorne i vremenske promene koeficijenta erozije zemljišta, produkcije i pronosa nanosa i identifikuju faktori koji najviše doprinose riziku od pojave erozije na području Grdeličke klisure za dva referentna perioda – 1970. i 2025. godinu.

Intenzitet erozije zemljišta na istraživanom području analiziran je primenom metode potencijala erozije (MPE) prema Gavriloviću (1972). Obradom geoprostornih podataka u GIS-u dobijene su tematske karte i sintezna karta intenziteta erozije.

Rezultati istraživanja pokazuju da najveći deo područja (62,03%) pripada IV kategoriji nagiba (27–70%) i zastupljene su sve kategorije erozije. Prema srednjoj vrednosti koeficijenta erozije (Zsr = 0,23) za 2025. godinu, Grdelička klisura je ugrožena procesima slabe erozije. Procesi ekscesivne erozije javljaju se na površini 4,73 $km^2$ (1,10% područja), na nagibima od 9% do preko 70%, na regosolu i pretežno poljoprivrednom zemljištu s velikim površinama prirodne vegetacije (okolina Predejana, okolina selâ Garinje, Kopitarce, Repište i Balinovce u opštini Vladičin Han i sela Graova i Koraćevca, u opštini Leskovac). Jaka erozija je prisutna na nagibima od 9% do 70%, na regosolu, distričnom i eutričnom kambisolu, sa složenim načinima obrade i zemljištu koje se pretežno koristi u poljoprivredne svrhe, s velikim površinama prirodne vegetacije. Na području su dominantni procesi vrlo slabe erozije i zahvataju 71,31% površine (306,94 $km^2$), uglavnom na distričnom kambisolu, pod listopadnim, četinarskim i mešovitim šumama. Ukupna godišnja produkcija nanosa ($W_{year}$) iznosi 110233,97 $m^3god^{-1}$, a specifična produkcija nanosa ($W_{sp}$) iznosi 256,1 $m^3km^{-2}god^{-1}$. Srednjogodišnji transport nanosa na području je 81573,14 $m^3km^{-2}god^{-1}$ i specifični godišnji transport nanosa je 189,51 $m^3km^{-2}god^{-1}$.

Poređenjem stanja erozije u 2025. sa stanjem u 1970. godini, utvrđeno je da na području dominanira erozija slabog intenziteta (IV kategorije). Povećana je površina zemljišta zahvaćena veoma slabom erozijom za 34,36%. Površine pod jakom erozijom su smanjene za 47,67%. Prema stanju iz 1970. godine 48,36% površine sliva bilo je zahvaćeno kategorijom jake erozije, dok sadašnje stanje pokazuje da je ova kategorija erozije smanjena na 0,69%. Vrednost Zsr smanjena je sa 0,50 na 0,23. Ukupna godišnja produkcija erozionog nanosa u 1970. bila je 377,679.07 $m^3god^{-1}$, a u 2025. je smanjena na 110,233.97 $m^3god^{-1}$. Specifična produkcija erozionog materijala je sa 878,42 $m^3km^{-2}god^{-1}$ smanjena na 256,10 $m^3km^{-2}god^{-1}$. Opadanje broja stanovnika od 1971. do 2023. godine i napuštanje obradivih površina u delovima sliva na većim nadmorskim visinama i nagibima, te veliki obim izvedenih tehničkih, bioloških i biotehničkih protiverozionih radova, doveli su do ublažavanja erozivnih procesa i pojačane obnove vegetacije.

Zaključuje se da je stepen jake erozije u opadanju, dok je procenat slabe i srednje erozije rapidno porastao, tako da Zsr na području Grdeličke klisure iznosi 0,23 (slaba erozija).