

Analysis of land use changes and soil erosion using the EPM-IntErO model in the Sokobanja Basin, Serbia

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Abstract

Soil erosion, with the progressive loss of fertile topsoil and its negative impact on agricultural productivity, has become a critical global environmental problem. In the second half of the 20th century, many municipalities in Serbia experienced significant changes in land use, vegetation, and environmental conditions. The drive towards industrialization and urbanization aimed to improve the living standards of the population, but as a consequence, it led to substantial depopulation of rural areas and the adoption of inadequate agricultural practices, which, in turn, further intensified soil erosion. This study focuses on the Sokobanjska Moravica River basin (Eastern Serbia), extending to the Bovan Lake Dam and upstream, with a total area of 540.4 km². The basin is situated in a characteristic karst landscape. Changes in erosion intensity and runoff from this basin are analyzed using the Intensity of Erosion and Outflow (IntErO) model, which algorithmically integrates the widely used Erosion Potential Method (EPM) with innovative computational techniques to predict sediment production and runoff from the river basin accurately. This analysis utilizes GIS software and official statistical yearbook data, focusing on the period from the second half of the 20th century, including the analysis of the current state. According to our research, the most intensive changes in land use occurred between 1961 and 1971, marking the beginning of the period of a decline in rural population and, consequently, a decrease in erosion intensity. Key findings indicate that predominant changes in land use and vegetation led to a shift from crop farming to animal husbandry. After 1971, ongoing depopulation, particularly in rural areas, resulted in a gradual and steady decrease in erosion intensity. The primary aim of this study is to support policymakers in developing more effective soil and water conservation regulations. By making recommendations for the protection of vegetation, and thus the soil within this river basin, this research helps ensure their long-term preservation. Future research should focus on the long-term impacts of current land use practices and develop strategies to mitigate erosion in the context of changing climate conditions.

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Keywords: erosion; IntErO; Sokobanjska Moravica; sustainable management; vegetation dynamics

Introduction

Soil erosion is a critical global environmental issue (Pavlova-Traykova and Dimitrov, 2023; Amundson *et al.*, 2015; Micić Ponjiger *et al.*, 2021; 2023; Costea *et al.*, 2022), posing significant threats to food security and ecosystem sustainability (Sartori *et al.*, 2019). Traditionally, Universal Soil Loss Equation (USLE)-type models have been extensively used for soil erosion assessments (Salik, 2019). However, these models often face limitations in large-scale applications and may not fully account for local conditions or complex terrain (Lukić *et al.*, 2021). There is a growing need for the assessment of global models to better understand their strengths and limitations (Benavidez *et al.*, 2018).

Global assessments of soil erosion are crucial for providing scientific evidence of the problem's magnitude and for identifying areas most exposed to erosion (Lukić *et al.*, 2019; Bammou *et al.*, 2024). These assessments have been included in major reports like the IPCC's Special Report on Climate Change and Land, which also highlights the impact of climate change on land degradation (Mandal and Roy, 2024). Despite efforts such as the FAO's Global Soil Erosion Map project, there is still no coordinated worldwide soil erosion monitoring program. Global modelling applications are invaluable for understanding the extent of soil erosion and its environmental impacts, as well as for designing effective conservation and mitigation strategies (Polovina *et al.*, 2024).

The current reliance on models for understanding soil erosion dynamics globally, despite their limitations, underlines the utility of these tools for land management and soil conservation. Large-scale models can identify erosion hotspots, support local monitoring, and refine soil erosion protection measures (Gholami *et al.*, 2024). However, many existing models, including USLE and its revisions (e.g., RUSLE), were originally designed for smaller-scale require thorough evaluation and adaptation for larger-scale applications (Keller *et al.*, 2021).

This study also highlights the need for additional soil erosion models beyond USLE-type models and evaluates the effectiveness of the IntErO model (Spalevic, 2011), which is based on the well-known Erosion Potential Model (EPM) developed by Gavrilović (1972), for estimating both gross and net erosion rates at the watershed scale.

The effectiveness of the IntErO and EPM models has been tested in various countries including Montenegro (Spalevic, 2011), Serbia (Kostadinov *et al.*, 2018), Bosnia and Herzegovina (Polovina *et al.*, 2024), Croatia (Dragičević *et al.*, 2016), Romania (Sestras *et al.*, 2023), Bulgaria (Pavlova-Traykova and Petrova, 2023), Greece (Efthimiou *et al.*, 2017), Italy (Milanesi *et al.*, 2015), Iran (Mohammadi *et al.*, 2021), North Africa (Ouallali *et al.*, 2020, 2024), Nepal (Chalise *et al.*, 2019), and Brazil (da Silva, 2014), demonstrating its global applicability and potential for enhancing soil erosion assessment and management.

The main advantage of the EPM-IntErO model application to this area compared to other models lies in its ability to encompass all components of the studied physical-geographical environment, particularly the geology and soils of the given area. This is significant for the research objectives of this study, as it focuses on a highly specific karst terrain, known as "karst bare". Furthermore, the predecessor of the IntErO model, the EPM method, has been developed since 1954 specifically for the southern and south-eastern regions of Serbia, where this river basin belongs. As a result, the EPM-IntErO model is the most adapted to these particular physical-geographical conditions.

A key aspect of this research is testing the applicability of the IntErO model on a watershed scale. This involves evaluating the model's sensitivity to input data, assessing its performance, and understanding sediment dynamics in the Sokobanjska Moravica River Basin in Serbia. This region, characterized by Jurassic transitional-

type karst terrain, faces significant erosion and water supply challenges. The application of the IntErO model here aims to provide insights into sediment movement and inform sustainable management practices for the Bovan Lake reservoir, crucial for irrigation and tourism.

The main objectives of this study are to systematically evaluate the IntErO model and its applicability for soil erosion assessment, specifically testing it for the first time in a river basin in Serbia. Primarily, the study aims to assess the sensitivity of the IntErO model to various input data, ensuring its reliability. Secondly, it will test the model's performance at a watershed scale using the Sokobanjska Moravica River Basin as a case study. Thirdly, the study seeks to provide insights into sediment movement within the watershed, contributing to sustainable management practices. Lastly, it aims to inform policy and land management by generating data to support policy decisions and soil conservation strategies at both global and local levels. This approach will address gaps in current modeling practices and provide actionable insights for effective soil erosion management.

Materials and Methods

Study area

The Sokobanjska Moravica River basin, located in the central part of Eastern Serbia, is a unique geographical area (Figure 1, Figure 2).

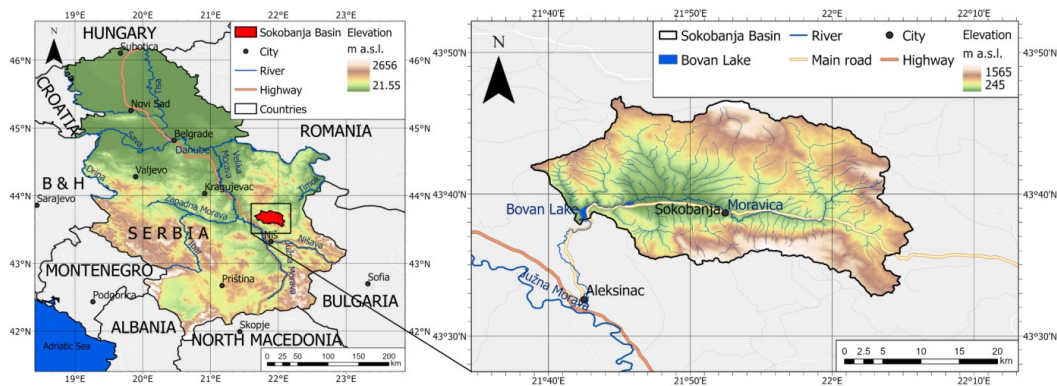


Figure 1. The geographical position of the Sokobanjska Moravica catchment, including the location of the Bovan Lake Dam

It represents a complex system due to its physical-geographical, socio-geographical, and demographic characteristics. The basin is situated between the Timok Basin to the north and the Morava Basin to the south. From a regional-geographic perspective, it falls within the Mountain-Basin-Valley macroregion and the Eastern Serbia mesoregion (Pavlović, 2019).

The area is part of the Carpatho-Balkan Mountains range, bordered by Rtanj to the north, Slemen and Krstatac to the east, Devica, Ozren, and Leskovik to the south, and Oštrokovac, Beljevin, and Bukovik Mountains to the west. Enclosed by these landmarks, the Sokobanjska Moravica basin spans an area of 540.4 km², extending from its headwaters to the Bovan Lake Dam.

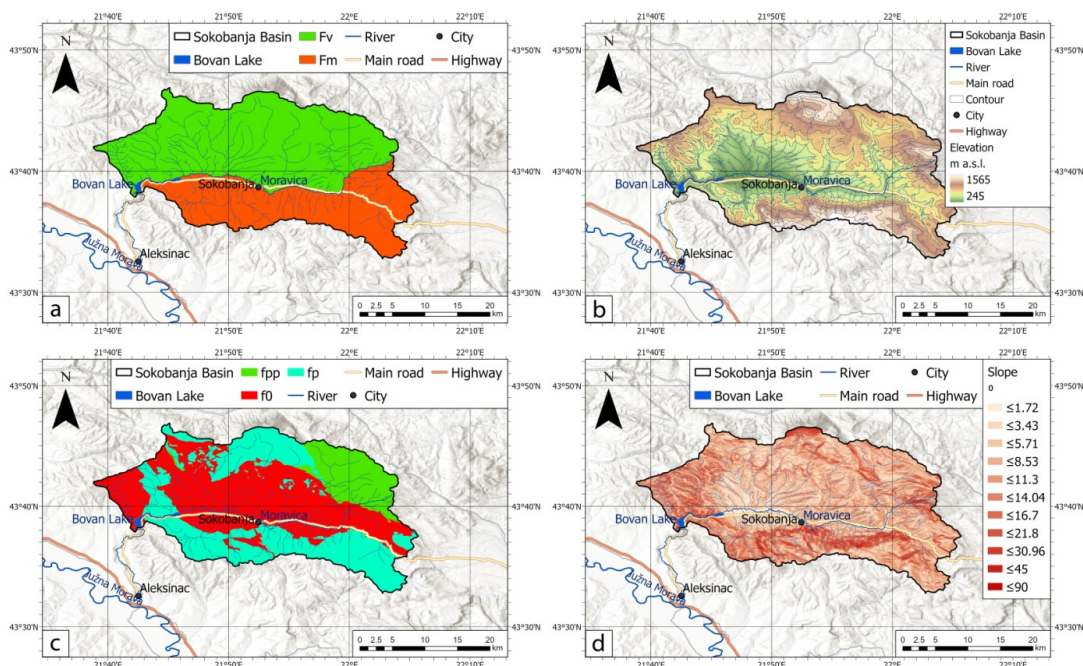


Figure 2. a) Asymmetry of the Sokobanja Basin; b) Relief of the basin; c) Slopes of the basin; d) Water permeability of the basin

Geological history

The observed area has a long geological history marked by intense tectonic movements, which created a distinctive geomorphological structure. Regionally, the Sokobanja Basin is identified as the Sokobanja Tertiary Basin, a structural basin formed by deep faults along which Mesozoic sediments subsided. This process led to the formation of a deep depression, which was later filled with water during geological evolution (Radivojević, 2008).

The complex tectonic history of the Sokobanja Basin has resulted in a diverse composition of rocks from various geological formations. Sedimentary formations are the most prevalent, followed by crystalline schists and volcanic rocks, estimated to be over a billion years old. Based on previous geological studies, four distinct lithostratigraphic series can be identified in the Sokobanja Basin area (Sučić, 1953): (1) Older Paleogene; (2) Middle Miocene (freshwater Čitluk coal-bearing series); (3) Pannonian (freshwater Vrmdža coal-bearing series); (4) Final Pliocene series. The basin is developed in karst terrains dating back to the Jurassic period.

A unique feature of the area is the “karst bare”. Studies of this phenomenon by Petrović and Petrović (1997) and Marković (1977) focus on the impact of water-holding sediments on the morphological and hydrological evolution of limestone masses in flood conditions. They concluded that when a river laterally cuts through a limestone mass, the riverbed becomes the lowest point for the discharge of underground water flows. In such cases, rather than plunging into the gorge, underground springs and hot springs appear at the gorge level. This phenomenon can be observed in the investigated basin.

Morphological units

From a morphological perspective, the Sokobanja Basin has an east-west orientation, deeply incised into the carbonate complex of the Rtanj-Kučaj zone. The entire area can be divided into three units (Dakić, 1967): (1) Valley Belt – Includes the alluvial plain of Sokobanjska Moravica River and its tributaries; (2) Transition Belt – Rises south and north of Sokobanjska Moravica River; it is lower in the western part, up to 420 m a.s.l., and higher in the eastern part, up to 620 m a.s.l.; (3) Mountain Belt – Forms the rim of the basin, with elevations ranging from 420 m a.s.l. to 1,560 m a.s.l. towards the north (Rtanj - Šiljak at 1,565 m a.s.l.); (4)

Tectonic processes played a crucial role in the formation of the basin. In later stages, the relief was modified by lake, river, and karst erosion.

Climate overview

The Sokobanja Basin exhibits unique characteristics influenced by its location and tectonic formation. Surrounded by high mountains, the basin connects with the Južna Morava Valley through the narrow Bovan Gorge, allowing continental influences from the north. To the east, it is exposed to continental air masses from Eastern and Northern Europe via the Wallachian lowlands and the Timok Basin. These morphological conditions contribute to a specific climate, marked by temperature fluctuations, varying atmospheric deposits, and distinct wind patterns.

According to the climatic regionalization of Serbia, the Sokobanja Basin falls within the Carpathian or Moravian-Svrljig region, characterized by long, hot summers; cold, snow-rich winters, and occasional Mediterranean influences. Precipitation follows a pluviometric regime (Rakićević, 1980; Milovanović *et al.*, 2017).

Official data from the Hydrometeorological Service of the Republic of Serbia indicates that the average temperature in Sokobanja from 1949 to 2021 is 10.7°C, with an average annual precipitation of 617.8 mm and average monthly torrential rainfall of 52 mm.

Forest and vegetation characteristics

This forest cover plays a crucial role in protecting against soil erosion by stabilizing the soil, reducing surface runoff, and maintaining the balance of the ecosystem. The diverse forest types, such as beech, oak, and hornbeam forests, are particularly effective in minimizing erosion on steep slopes and fragile limestone substrates. Their dense root systems help anchor the soil, while the canopy reduces the impact of rainfall on the surface.

Forest covers approximately 35% of the study area with the remaining landscape dominated by deforested mountain pastures, particularly on Rtanj Mountain. Lower elevations near rivers and streams, such as Sokobanjska Moravica, contain small patches of Poplar and Willow forests, which are mostly limited to areas up to 0.5 hectares. Between 550-900 meters above sea level, oak and hornbeam forests, including species like *Carpinus orientalis*, *Fraxinus ornus*, and *Acer campestre*, contribute to the region's biodiversity. Beech forests (*Fagetum montanum serbicum*) dominate northern and north-western slopes at elevations from 400 to 1000 meters a.s.l., growing primarily on limestone substrates and providing stability to the soil and habitat for various species. The oak forests are the climatogenic forest association, extending up to 800 meters a.s.l., and thrive on both silicate and limestone terrains.

At the base of the mountains, oak and hornbeam forests grow on gentler north-facing slopes up to 500 m a.s.l. These forests are rich in species, featuring dominant woody plants like *Quercus sessilis*, *Carpinus betulus*, and *Acer campestre*, along with a diverse shrub layer that includes *Corylus avellana* and *Cornus mas*. The favourable climatic conditions in the Sokobanja basin foster the development of this diverse vegetation (Radivojević, 2008).

At higher altitudes, mountain pastures dominate the landscape, where over 200 species of medicinal herbs have been documented. These pastures, particularly on Rtanj Mountain, contribute to the region's rich botanical and cultural heritage.

These forests and pastures not only preserve biodiversity but also act as natural barriers against soil degradation, making them vital for the long-term sustainability of the region's landscape.

The IntErO model

The IntErO model was the central focus of this study's methodology. It operates within the framework of the Erosion Potential Method (EPM), as detailed by Spalević (2011, see also www.geasci.org/IntErO)

This model provides a wide-ranging approach to erosion modelling of river basins, utilizing 22 input parameters and yielding 26 result parameters after processing. These parameters include coefficients such as river basin shape (A), watershed development (m), and the average distance between the boundaries of a river basin measured perpendicular to the main river channel (B), along with other factors like elevation differences and erosion characteristics.

The IntErO model integrates six factors: lithology, soil type, topography, precipitation, temperature, land cover (vegetation), and watercourse development. It offers a semi-quantitative approach, combining descriptive and quantitative methods. Notably, it uses descriptive evaluations for only three parameters—soil erodibility, soil protection, and erosion extent—while all other parameters are quantitatively described.

Justification for the use of IntErO/EPM

Gavrilović developed and tested the Erosion Potential Method (EPM) in the Grdelica Gorge area, located near the Sokobanja region in southern Serbia. Both methods, EPM and IntErO as its successor, have been developed over the past decades, and are utilized for assessing erosion processes, which is crucial for land conservation and water resource management. Sokobanja, situated approximately 70 kilometers northeast of the Grdelica Gorge—EPM's reference site—presents a similar geographical context, allowing for the application of these methods for erosion assessment.

Grdelica Gorge as an EPM pilot polygon and Sokobanja share several key similarities in their physical-geographic and climatic conditions. Both regions are characterized by their rugged terrain and diverse topography, featuring a mix of steep cliffs, valleys, and rolling hills. The Grdelica Gorge is carved by the Južna Morava River, while Sokobanja, settled in the (Sokobanjska) Moravica River Basin, showcases a varied relief of hilly and flat areas.

The mountainous and hilly terrain in both regions significantly influences their local ecosystems and land use patterns.

Climatically, Grdelica Gorge and Sokobanja experience similar temperate continental climates. Both areas have distinct seasons with hot summers and cold winters, and their climate is marked by relatively moderate rainfall distributed throughout the year. The presence of surrounding mountain ranges affects local weather patterns, contributing to variations in temperature and precipitation. These climatic conditions support a range of flora and fauna adapted to the temperate continental environment, creating comparable ecological characteristics in both Grdelica Gorge and Sokobanja.

Based on the aforementioned points, the application of the IntErO model in Sokobanja is justified and is expected to yield reliable results in assessing and managing erosion processes. This confirms the model's validation and effectiveness for these specific physical-geographic and climatic conditions.

Data analysis and sources

Most of the analyses were conducted using ArcGIS Pro 2.5.0. The catchment was delineated using open-source Digital Elevation Model (DEM) data with horizontal resolutions ranging from 1 arc-second (30 m) (SRTM) to 12.5 m (ALOS PALSAR RT1) (Das *et al.*, 2015; Marković *et al.*, 2024). Das *et al.*, (2015) stated that ALOS-PALSAR images with optimum baseline parameters produced high-resolution DEM with great height accuracy. Also, the validated DEM was used for topographic correction of ALOS-PALSAR images compared with ASTER and SRTM-DEM in the same region. ALOS-PALSAR images showed much better results than ASTER and SRTM-DEM.

Climate data were obtained from the official database of the Republic Hydrometeorological Service of Serbia, using meteorological yearbooks for the period from 1949 to 2021. The 72 years of data line up with the standards set by the World Meteorological Organization (WMO) and cover two thirty-year climate cycles.

Hydrological analyses were also based on the same DEM models. A key reference for the studied region is the PhD thesis “Geographical Changes in the Sokobanja Basin and Their Impact on Regional Development” (Radivojević, 2008). CORINE Land Cover data was used for the year 2012 vegetation changes (Büttner, 2014).

The pedological (soil) map for the Sokobanjska Moravica catchment was georeferenced and analyzed based on this thesis. Additionally, we simplified the basic geological map obtained from the Geological Institute of the Republic of Serbia's official website (<https://geoliss.mre.gov.rs/prez/OGK/RasterSrbija/>). For a better understanding, the data on rock permeability in the Sokobanjska Moravica basin (or investigated area) were interpreted based on the geological map sheets Sokobanja, Boljevac and Knjaževac.

Results and Discussion

Data on erosion intensity and runoff were generated using the IntErO model. The input data are presented in Table 1. The total river basin area is 540.4 square kilometres, and the watershed extends 127 kilometres in length. The total distance that the river follows from its source to its mouth is 43.8 kilometres, while the direct line distance between the source and the mouth is 28.9 kilometres. Additionally, the combined total length of the main watercourse, including its I and II class tributaries, is 453.8 kilometres.

Table 1. IntErO model inputs generated by the IntErO model

Parameter / Input data	Symb.	1961	1971	1981	1991	2002	2012	2023	
River basin area	F	540.4	540.4	540.4	540.4	540.4	540.4	540.4	km ²
Watershed Length	O	127	127	127	127	127	127	127	km
Main watercourse	Lv	43.8	43.8	43.8	43.8	43.8	43.8	43.8	km
Distance Fountainhead-Mouth	Lm	28.9	28.9	28.9	28.9	28.9	28.9	28.9	km
Watercourse and Tributaries	ΣL	453.8	453.8	453.8	453.8	453.8	453.8	453.8	km
Length - Parallel Line Measurement	Lb	41.78	41.78	41.78	41.78	41.78	41.78	41.78	km
The area of the bigger river basin part	Fv	337.6	337.6	337.6	337.6	337.6	337.6	337.6	km ²
The area of the smaller basin part	Fm	202.8	202.8	202.8	202.8	202.8	202.8	202.8	km ²
Altitude of the first contour line	h0	300	300	300	300	300	300	300	m
The lowest river basin elevation	H_{min}	245	245	245	245	245	245	245	m
The highest river basin elevation	H_{max}	1565	1565	1565	1565	1565	1565	1565	m
Highly Permeable Section of Basin	fp	0.39	0.39	0.39	0.39	0.39	0.39	0.39	
Moderately Permeable Section	fpp	0.13	0.13	0.13	0.13	0.13	0.13	0.13	
Low Permeability Section of Basin	fo	0.48	0.48	0.48	0.48	0.48	0.48	0.48	
A part under forests	fs	0.35	0.34	0.35	0.35	0.35	0.4	0.41	
Grasslands, Meadows, and Orchards	ft	0.36	0.42	0.42	0.41	0.42	0.39	0.38	
Bare and Ploughed Lands	fg	0.29	0.24	0.24	0.24	0.23	0.21	0.21	
The volume of the torrent rain	hb	52	52	52	52	52	52	52	mm
Average annual air temperature	t0	10.7	10.7	10.7	10.7	10.7	10.7	10.7	°C
Average annual precipitation	H_{year}	671.8	671.8	671.8	671.8	671.8	671.8	671.8	mm
Coefficient of the river basin planning	Xa	0.520	0.520	0.520	0.520	0.510	0.53	0.53	
Indicators of Erosion Processes	φ	0.31	0.31	0.31	0.31	0.31	0.11	0.11	

The Results - Outputs, presented in Table 2, provide comprehensive data on land use and soil erosion intensity from 1961 to 2023, offering detailed insights into trends and changes over this period. The maximal outflow (Q_{max}) gradually decreases over the years, from $393 \text{ m}^3\text{s}^{-1}$ to $378 \text{ m}^3\text{s}^{-1}$. This suggests a reduction in water flow intensity, which is influenced by changes in land use, improved vegetation cover, or hydrological conditions within the basin. The trend shows a steady decline, reflecting potential improvements in water retention capacity and decreased runoff.

The real soil losses (G_{year}) show a reduction from $53,161 \text{ m}^3\text{year}^{-1}$ to $44,813 \text{ m}^3\text{year}^{-1}$, a decrease of approximately 15.7%. This consistent decrease indicates positive trends in preserving soil integrity across the basin. Similarly, real soil losses per km^2 decline showing a proportional reduction in soil erosion across the basin (Table 2).

Table 2. IntErO model outputs generated by the IntErO model

Parameter / Input data	Symb.	1961	1971	1981	1991	2002	2012	2023	
Coefficient of the river basin form	A	0.57	0.57	0.57	0.57	0.57	0.57	0.57	
Basin development coefficient	m	0.53	0.53	0.53	0.53	0.53	0.53	0.53	
Average river basin width	B	12.93	12.93	12.93	12.93	12.93	12.93	12.93	km
(A)symmetry of the river basin	a	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
Density of the basin network	G	0.84	0.84	0.84	0.84	0.84	0.84	0.84	
Basin tortuousness coefficient	K	1.52	1.52	1.52	1.52	1.52	1.52	1.52	
Average river basin altitude	H_{sr}	605.9	605.9	605.9	605.9	605.9	605.9	605.9	m
Basin average elevation difference	D	360.9	360.9	360.9	360.9	360.9	360.9	360.9	m
Average river basin decline	I_{sr}	18.92	18.92	18.92	18.92	18.92	18.92	18.92	%
Height of the Local Erosion Base	H_{leb}	1320	1320	1320	1320	1320	1320	1320	m
Coefficient of the permeability	S₁	0.73	0.73	0.73	0.73	0.73	0.73	0.73	
Vegetation cover coefficient	S₂	0.79	0.78	0.78	0.78	0.77	0.76	0.76	
Inflow Water Retention	W	0.6173	0.6173	0.6173	0.6173	0.6173	0.6173	0.6173	m
Energy Potential of Flow	2gDF^{1/2}	1956	1956	1956	1956	1956	1956	1956	mkms ⁻¹
Maximal outflow from the basin	Q_{max}	393	389	388	387	385	379.36	378	m ³ s ⁻¹
Coefficient of the basin erosion	Z	0.308	0.308	0.305	0.303	0.3	0.276	0.275	
Production of erosion material	W_{year}	211212	210885	207676	206083	203012	179143	178045	m ³ y ⁻¹
Deposit retention coefficient	R_u	0.252	0.252	0.252	0.252	0.252	0.252	0.252	
Real soil losses	G_{year}	53161	53078	52271	51870	51097	45089	44813	m³ y⁻¹
Real soil losses per km²	G₇ km⁻²	98.37	98.22	96.73	95.98	94.55	83.44	82.93	m³ y⁻¹

Land use trends

Understanding the relationship between soil erosion and landscape patterns is crucial for optimizing sustainable management in river basins. Vujačić *et al.* (2023) stressed the significant impact of changes in land use and landscape patterns on soil erosion, highlighting the need for a complete understanding of these processes to enhance conservation strategies.

The trend of calculated variables for Grasslands, Meadows, and Orchards; ft for the period from 1961 to 2023 is presented in Figure 3. The graph shows an initial increase from 0.36 in 1961 to a peak of 0.42 in 1971. Following this peak, the values stabilized between 0.41 and 0.42 until 2002. In recent years, a downward trend is evident, indicating a decline in the variable over the past two decades. From 1961 to 2023, the value increased by approximately 5.56%, calculating the value in 2023 at 0.38.

The trend of the calculated variables for Bare and Ploughed Lands; fg is presented in Figure 4. The graph shows a consistent decrease from 0.29 in 1961 to 0.24 in 1971. This decline continues steadily, with values stabilizing around 0.23 from 1981 to 2002. In more recent years, the values continue to decrease to 0.21, which is observed in both 2012 and 2023. Overall, from 1961 to 2023, the value of the variable decreased by approximately 27.59%, reflecting a significant reduction in the area of ploughed lands over the observed period.

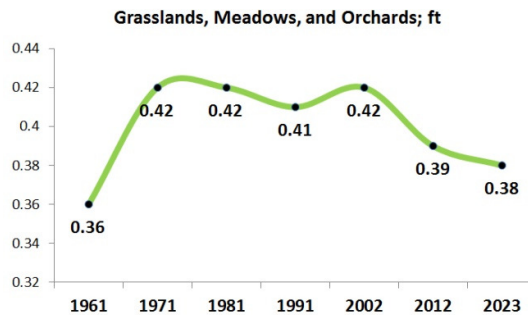


Figure 3. Area with grasses & orchards (ft coefficient, dimensionless)

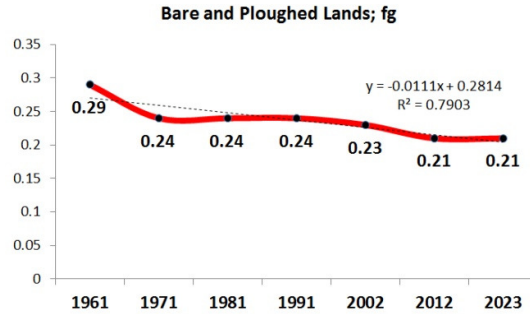


Figure 4. Area covered by barren lands (fg coefficient, dimensionless)

The trend of the considered variables for a part under forests; fš for the studied period is presented in Figure 5. The data shows an initial slight decrease from 0.35 in 1961 to 0.34 in 1971. Following this, the values stabilize at 0.35 from 1981 through 1991. An increase occurs starting from 2002, with the value rising to 0.38, reaching 0.41 in 2023. This rising trend is particularly evident in the last two decades. From 1961 to 2023, the value of the variable increased by approximately 17.14%, reflecting a growth in the forested areas over the observed period.

The coefficient of the river basin planning (xa) shows stability, with a constant value of 0.520. From 1961 to 2023, we recorded an increase of approximately 1.92% (Figure 6).

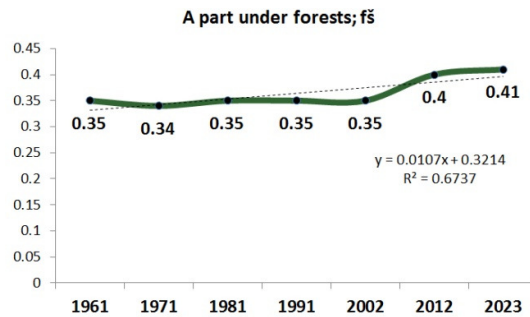


Figure 5. The area under forests (fš coefficient, dimensionless)

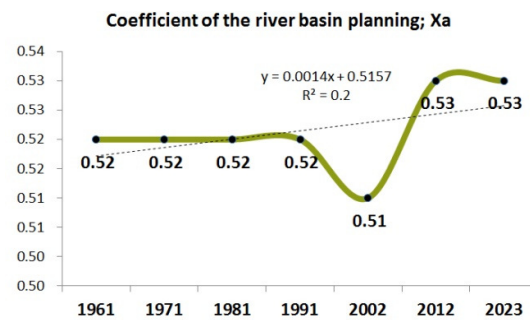


Figure 6. Basin planning coefficient (xa coefficient, dimensionless)

Soil erosion indicators

The vegetation cover coefficient (S2)

Vegetation plays a crucial role in mitigating the impact of rainfall on the soil and is reducing surface runoff, at the same time enhancing water infiltration, all of which contribute to reducing soil erosion. This parameter reflects the influence of vegetation on soil erosion and runoff processes. It is a factor in models

assessing potential soil erosion and land degradation, quantifying the protective effect of vegetation cover on the soil surface. The coefficient of vegetation cover ranges from 0 to 1, where 0 indicates no vegetation cover (fully exposed land, highly susceptible to erosion), and 1 represents full vegetation cover (well-protected soil with minimal erosion risk). The value of S_2 is influenced by several factors, including the type, density, and coverage of vegetation.

Recent data shows that the Coefficient of Vegetation Cover (S_2) decreased for the studied area by 3.8%. This change reflects a complex interaction between land use changes, forest management practices, and soil erosion processes over several decades.

While the forested area has grown, this increase does not necessarily indicate improved forest quality or density. Some previously well-established forest areas have decreased due to exploitation, with degraded or less dense forests replacing certain pasturelands. The decline in livestock farming has allowed former grazing lands to revert to forest, but not of high quality. This scenario underlines the importance of not only increasing forest cover but also enhancing the quality and management of forests to ensure long-term environmental sustainability.

The maximum runoff from the catchment (Q_{max})

It refers to the highest rate at which water flows out of a river basin, measured in cubic meters per second ($m^3 s^{-1}$). This parameter is crucial for understanding the river's discharge capacity and its ability to handle and transport water. Our calculations show a decreasing trend in Q_{max} , from $393 m^3 s^{-1}$ in 1961 to $378 m^3 s^{-1}$ in 2023 (Figure 7). This reduction indicates improved water retention and suggests a potential decrease in soil erosion, likely resulting from changes in land use (Dong *et al.*, 2022; Spalevic, 2011).

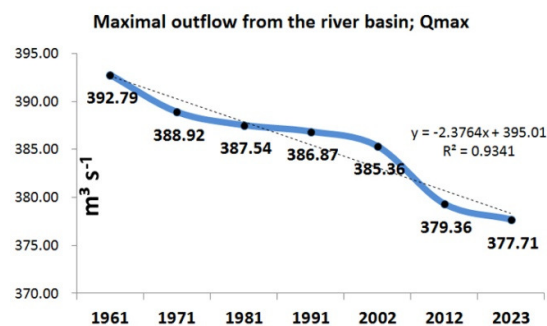


Figure 7. The Peak discharge (Q_{max} , expressed in $m^3 s^{-1}$)

The catchment erosion coefficient (Z)

The areas with high Z values ($Z > 0.50$) have erosion processes with negative environmental impacts, including increased sedimentation in rivers and streams, which affects aquatic habitats and water quality. For areas with high erosion coefficients, strategies such as contour plowing, terracing, and reforestation can be effective in reducing erosion and improving soil conservation.

A lower coefficient Z ($Z \leq 0.20$) indicates reduced erosion potential, well-vegetated catchments with stable soil conditions. These areas are less prone to soil degradation and erosion, contributing to better soil health and water quality (Gavrilovic, 1972; Morgan, 2005).

The Coefficient Z values for the studied region show a consistent decline from 0.308 to 0.275 over the recorded period (Figure 8). This reduction suggests that soil erosion has decreased, due to enhanced vegetation cover, which stabilizes the soil and reduces surface runoff. Additionally, changes in land use practices, such as reduced agricultural activity, have also contributed to lower erosion rates.

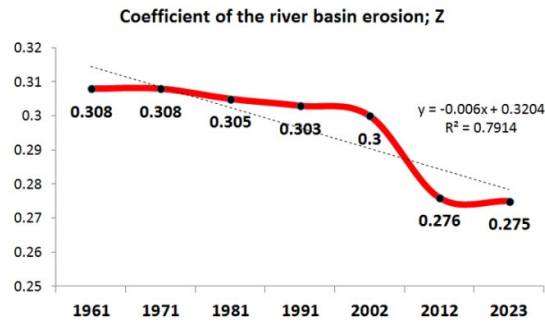


Figure 8. Basin erosion coefficient (Z coefficient, dimensionless)

The calculated production of erosion material in the basin (W_{year}) shows a gradual decrease from $211,212 \text{ m}^3\text{year}^{-1}$ to $178,045 \text{ m}^3\text{year}^{-1}$ (Figure 10). This decline indicates a reduction in the material available for erosion, likely due to improvements in vegetation cover. Real soil losses have decreased from $53,161 \text{ m}^3\text{year}^{-1}$ to $44,813 \text{ m}^3\text{year}^{-1}$ (Figure 11). This reduction in actual soil losses demonstrates the effectiveness of recent land use changes in reducing soil loss annually. The real soil losses per square kilometre have decreased from $98.37 \text{ m}^3\text{km}^2\text{year}^{-1}$ to $82.93 \text{ m}^3\text{km}^2\text{year}^{-1}$ (Figure 12). Despite the favourable trends in reduced erosion intensity, erosion control measures may still be necessary to prevent further soil degradation and safeguard soil productivity.

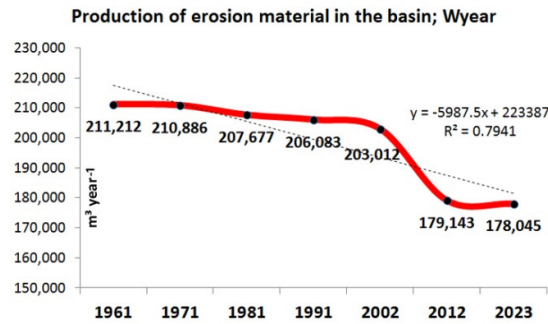


Figure 9. Erosion material production

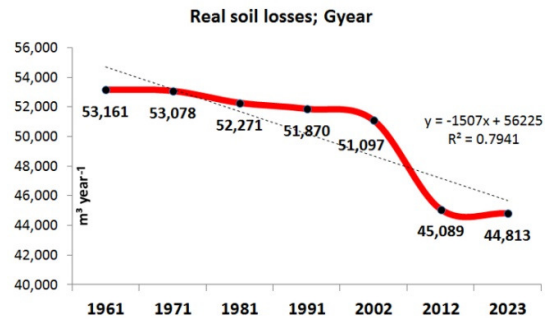


Figure 10. Real soil losses

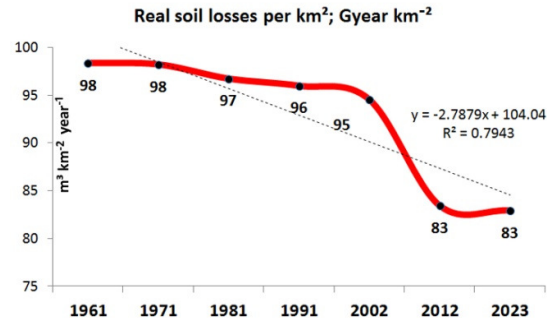


Figure 11. Real soil loss per square kilometre

Details illustrating vegetation cover and geographical features are shown in Figure 12.



Figure 12. Geographical Features: a) Bukovik; b) Rtanj; c) Gorge of the Moravica River; d) Timber Extraction in Bukovik; e) Ozren; f) Ripaljka Waterfall; g) Krstatac

Climate change is anticipated to drive significant environmental changes, including increased soil erosion. Research by Perović *et al.* (2019) indicates that, by the end of the century, the impact of climate change on spatial and temporal patterns in Southeast Serbia (specifically the Vranjska Valley) will lead to a 41.84% reduction in average soil loss compared to baseline levels. This decrease in soil erosion rates during the latter half of the century is primarily attributed to a 17.19% decline in total precipitation, which will inevitably alter both natural and artificial ecosystems. The given study indicates that R-factor (rainfall erosivity) values are expected to decrease, ranging from 515.80 to 538.49 MJ mm ha⁻¹ h⁻¹ yr⁻¹, with an average value of 523 MJ mm ha⁻¹ h⁻¹ yr⁻¹. This finding aligns with the results of Micić Ponjiger *et al.* (2023), which reported R-factor values between 480 and 560 MJ mm ha⁻¹ h⁻¹ yr⁻¹, and the maximum R-factors for clusters exhibit a less homogeneous distribution over the past 30 years. Perović *et al.* (2019) further highlight that a reduction in the rainfall

erosivity factor along with changes in the crop management factor, is projected to lead to a decrease in soil loss of 6.57% by 2050 and 41.84% by 2100.

Projections for Serbia indicate that annual precipitation will decrease by the end of this century, with more pronounced reductions expected in the southern regions (Kržič *et al.*, 2011). In the southernmost parts of Serbia, results from various regional climate models consistently indicate a downward trend in precipitation. This finding provides a robust basis for anticipating changes in these areas, whereas there is less agreement among climate models for the central and northern regions of the country. This uncertainty in the latter regions makes them intriguing for further investigation, as it narrows down the potential outcomes in terms of expected changes. Moreover, recent findings by Manojlović *et al.* (2022) emphasize that the intensity of soil erosion results from the interplay of natural factors and various human activities. This is particularly evident in the Vranjskobanjska River watershed in southeastern part of Serbia, which features a relatively low number of settlements and significant rural depopulation. The demographic decline of rural areas has led to the disappearance of progressive types of settlements and the widespread abandonment of arable land. This shift in the demographic and agrarian landscape contributes to a reduction in soil erosion rates, driven by deagrarianization and depopulation processes that are key factors in land abandonment.

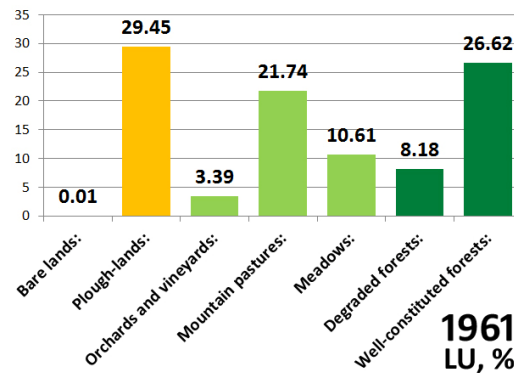


Figure 13. Land use structure, 1961

Migration Patterns in the Sokobanja Region (1961-2023)

Migration patterns from the Sokobanja region in southern Serbia from 1961 to 2023 have been influenced by various socio-economic changes. Each decade has its distinct characteristics and reasons for migration, whether it was from rural areas to cities or to foreign countries (Radivojević, 2008).

1960s: Beginning of Industrialization. During the 1960s, the onset of industrialization in Yugoslavia prompted significant migration from rural areas to cities (Jovanovic, 1979; Radice, 1976). The studied region of Sokobanja, like other regions, saw its residents moving to urban centres such as Niš, Leskovac, and Vranje in search of employment in newly established factories. This movement was driven by the promise of better living conditions and job opportunities in industrial hubs. As a result, rural populations began to decrease, while urban areas expanded rapidly. Simultaneously, this era marked the rise of economic migration to Western Europe. Known as Gastarbeiter (foreign or migrant workers, guest workers), many people from the studied area of Sokobanja departed to countries like Germany, Austria, and Switzerland. They sought higher wages and improved living standards, and their allowances played a crucial role in enhancing their economic status.

Reflections on Land use structure for the period of the 1960s (1961-time profile) is presented in Figure 14.

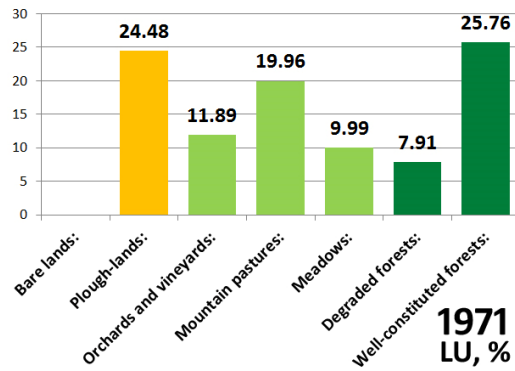


Figure 14. Land use structure, 1971

1970s: Continued Industrialization. The 1970s witnessed the continuation of industrialization and urbanization. More factories were established, and the attraction of urban life grew stronger. Cities continued to grow as rural populations decreased further. The pattern of migration to urban centres remained robust, driven by the desire for stable employment and better services. Economic migration to Western Europe also intensified during this decade. The trend of seeking better economic opportunities abroad persisted, reinforcing the region’s reliance on remittances from expatriates.

Reflections on Land use structure for this period is presented in Figure 15 (1971).

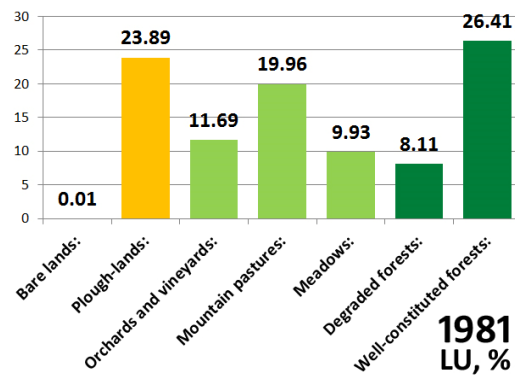


Figure 15. Land use structure, 1981

1980s: Economic and Social Instability. The 1980s brought economic stagnation and social instability, slowing down internal migration to some extent. Although urban centres remained attractive, the economic crisis made it harder for people to find new opportunities. Despite this, the trend of rural depopulation and urban growth continued, albeit at a slower pace. Economic migration to foreign countries gained momentum as the domestic economic situation worsened. More individuals sought employment abroad to escape economic uncertainty. This maintained the critical flow of remittances to their families back home.

Land use structure for this section (1981) is presented in Figure 16.

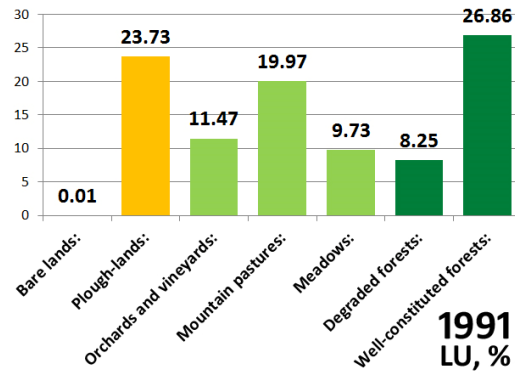


Figure 16. Land use structure, 1991

1990s: Wars in the Region and Social Crisis. The 1990s were marked by the Yugoslav wars and severe economic collapse, leading to massive displacements. The Sokobanja region experienced an influx of refugees and internally displaced persons, straining urban resources. The wars and resulting socio-economic crisis pushed many to seek refuge and better prospects abroad. The land use structure for this section (1991) is presented in Figure 17.

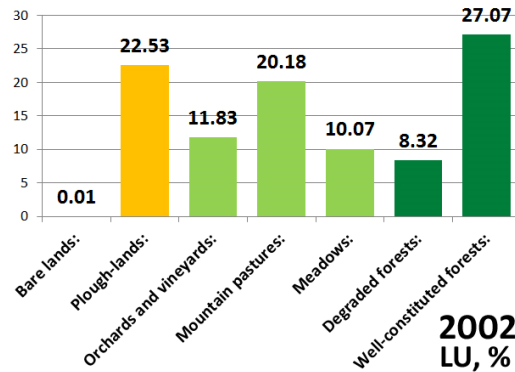


Figure 17. Land use structure, 2002

2000s: Region Post-War Reconstruction and EU Prospects. The 2000s brought a period of stabilization and reconstruction in a wider region. Efforts to rebuild war-torn areas in the region led to some internal migration back to rural areas, but the overall trend continued towards urbanization. The prospect of European Union membership for Serbia also influenced migration patterns, with many seeking better opportunities in EU countries. The attraction of better educational and professional opportunities abroad remained strong, maintaining significant migration flows out of rural areas. Despite some return migration for reconstruction efforts, general depopulation of rural areas persisted. The land use structure for this section (2002) is presented in Figure 18.

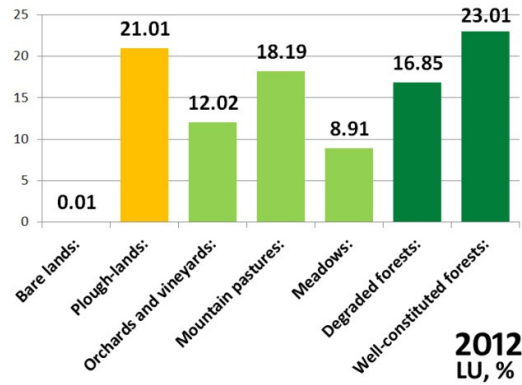


Figure 18. Land use structure, 2012

2010s: Globalization and Economic Migration. The 2010s were characterized by globalization and increased connectivity. Migration trends continued with a noticeable pattern of young individuals and families moving to urban centres or abroad for higher education and better job prospects. Urban areas continued to grow as economic opportunities in agriculture and rural industry remained limited. The rural-to-urban migration, along with international migration, maintained the trend of rural depopulation. The role of remittances remained crucial in supporting the local economy. Land use structure for this period are presented in Figure 19 (2002), 19 (2012) and 20 (2023).

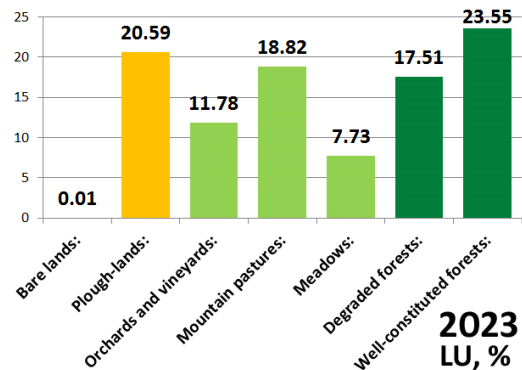


Figure 19. Land use structure, 2023

2020s: Technological Advancements and Rural Decline. The current decade has seen significant technological advancements and increased digital connectivity. Despite these advancements, rural depopulation continues as younger generations move to urban areas for better opportunities. The trend of migration to EU countries and other parts of the world remains strong, influenced by economic, educational, and social factors. Rural areas face challenges of aging populations and reduced economic activities, furthering the reliance on remittances from abroad.

Dependence of rural depopulation on soil erosion intensity

Socio-economic factors, particularly land use and population dynamics, significantly influence soil erosion, with proper land use generally reducing erosion and population growth intensifying it. These effects depend on region-specific socio-economic dynamics and land use patterns. Therefore, to achieve a sustainable balance between development and ecological health, it is crucial to consider these factors when planning, monitoring, and implementing large-scale ecological programs, ensuring that land use and industrial structures are aligned with environmental goals (Wang *et al.*, 2022).

The Sokobanja Basin faces a significant population decline, leading to various economic, social, and strategic issues. Despite the favourable climate, soil conditions, and opportunities for diversified economic activities, the basin is notably depopulated. Census data from 1948 to 2022 reveal a population decrease of more than 50%. In 1953, the basin was inhabited by 26,818 people, whereas the 2022 census reports 13,325 inhabitants. Natural resources have determined the area's dominant functions, which include agriculture, mining, tourism, and other service activities.

A well-established correlation exists between rural depopulation and a reduction in erosion intensity globally (Bhandari & Damsawasdi, 2014; Dragičević & Milevski, 2010; Ferreira *et al.*, 2016; Kostadinov *et al.*, 2014; Manojlović *et al.*, 2018; Zorn and Komac, 2009). More recent work of Srejić *et al.* (2023) observed similar trends in their analysis of the link between agricultural land use changes and soil erosion in the Velika Morava River Basin (Central Serbia). They identified land use changes, increasing migration flows, and shifts in natural conditions as key determinants of erosion intensity. The authors argue that agricultural land abandonment, which began intensively in post-socialist Central and Eastern European countries and European Russia in the 1950s, has been driven by technological, political, and demographic factors. This abandonment has generally led to a reduction in soil erosion intensity.

Tošić *et al.* (2019) found a strong correlation between anthropogenic factors, such as depopulation, and changes in erosion intensity, as indicated by decreased sediment production across broader areas of Republika Srpska - Bosnia and Herzegovina. Their work highlights how socio-geographical processes, low agricultural productivity, and natural conditions significantly influence soil erosion intensity and overall erosion processes.

This trend is also evident in the Sokobanja region, as demonstrated by the results of this study. As the population moves from rural areas to urban centres, the use of land for agriculture and the exploitation of forests for fuel decreases. This reduction in activities that directly contribute to soil erosion has resulted in a decrease in the annual production of sediment over time. According to calculations, this trend can be traced from 1961 to 2023, during which the reduction in the rural population has led to less intensive erosion, finally resulting in the stabilization of land and ecosystems in the wider Sokobanja region.

Soil conservation practices should be closely linked and take into consideration socio-economic development trends, and ecological activities should be formulated and coordinated with local socio-economic conditions (Barbier, 2010). The intensity of soil erosion is significantly influenced by socio-geographical processes, low agricultural productivity, and natural conditions; thus, the relationship between socio-economic development and soil erosion warrants further exploration (Bryan *et al.*, 2018; Panagos *et al.*, 2020).

Conclusions

The study of soil erosion in the Sokobanjska Moravica River Basin in Serbia using the IntErO model reveals several significant trends. During the second half of the 20th century, land use changes, particularly the shift from agricultural land to animal husbandry, along with ongoing rural depopulation, resulted in a steady decrease in erosion intensity. Forest cover increased, contributing to improved soil retention and a reduction in erosion. The results underscore the positive impact of land management practices that enhance vegetation cover and reduce bare, arable land areas in mitigating soil erosion.

The findings are crucial for informing soil and water conservation policies, particularly in regions with similar geographic and climatic conditions. As erosion intensity has decreased over the decades, it is essential to establish the implementation of sustainable land use practices to maintain and further reduce soil erosion levels. Additionally, the study highlights the importance of integrating advanced models like IntErO with local data to accurately predict erosion patterns and guide effective conservation strategies.

Future research should focus on assessing the long-term impacts of current land use practices under changing climate conditions, aiming to develop strategies that further mitigate soil erosion and enhance environmental sustainability in similar terrains. Additionally, conducting bathymetric analyses of Bovan Lake,

alongside comparative studies using the USLE and RUSLE models, would provide valuable insights into sediment dynamics and erosion control in the region.

Authors' Contributions

Conceptualization: RSM, AR, TL, MG, VS, SC, BD; Data curation: RSM, AR, TL, MG, VS; Funding: RSM, AR, TL, MG, VS, SC, BD; Investigation: RSM, AR, TL, MG, VS; Project administration: RSM, VS, SC, BD; Supervision: AR, VS; Validation: AR, VS, SC, BD; Visualization: RSM, AR, VS; Writing - original draft: RSM, AR, TL, MG, VS, SC, BD; Writing - review and editing: RSM, AR, TL, MG, VS, SC, BD. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

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

References

- Amundson R, Berhe AA, Hopmans JW, Olson C, Sztein AE, Sparks DL (2015). Soil and human security in the 21st century. *Science* 348(6235):1261071. <https://doi.org/10.1126/science.1261071>
- Atanacković SB (1959). Phytogeographic Overview of the Ozren Amphitheater Basin and Its Immediate Surroundings. Collection of Papers of the SANU Geographical Institute "Jovan Cvijić", Belgrade 16:121-148. http://www.gi.sanu.ac.rs/media/gi/pdf/en/journal/016/gijc_zr_16_007_atanackovic.pdf
- Bammou Y, Benzougagh B, Abdessalam O, Brahim I, Kader S, Spalevic V, Sestras P, Ercişli S (2024). Machine learning models for gully erosion susceptibility assessment in the Tensift catchment, Haouz plain, Morocco for sustainable development. *Journal of African Earth Sciences* 213:105229. <https://doi.org/10.1016/j.jafrearsci.2024.105229>
- Barbier EB (2010). Poverty, development, and environment. *Environment and Development Economics* 15:635-660. <https://doi.org/10.1017/S1355770X1000032X>
- Benavidez R, Jackson B, Maxwell D, Norton K (2018). A review of the (Revised) Universal Soil Loss Equation ((R)USLE): with a view to increasing its global applicability and improving soil loss estimates. *Hydrology and Earth System Sciences* 22(11):6059-6086. <https://doi.org/10.5194/hess-22-6059-2018>

- Bhandari KP, & Damsawasdi, R (2014). Sensitivity analysis of soil erosion on impacts of land use landcover change in Phewa watershed. *International Journal of Current Engineering and Technology* 4(3):2075-2082. <https://inpressco.com/wp-content/uploads/2014/06/Paper1712075-2082.pdf>
- Bryan BA, Gao L, Ye Y, Sun X, Connor JD, Crossman ND, ... Hou X (2018). China's response to a national land-system sustainability emergency. *Nature*: 559:193-204. <https://doi.org/10.1038/s41586-018-0280-2>
- Büttner G (2014). CORINE land cover and land cover change products. In *Land use and land cover mapping in Europe: practices & trends*. Dordrecht: Springer Netherlands, pp 55-74. https://doi.org/10.1007/978-94-007-7969-3_5
- Chalise D, Kumar L, Spalevic V, Skataric G (2019). Estimation of sediment yield and maximum outflow using the IntErO Model in the Sarada River Basin of Nepal. *Water* 11:952. <https://doi.org/10.3390/w11050952>
- Costea A, Bilasco S, Irimus I-A, Rosca S, Vescan I, Fodorean I, Sestras P (2022). Evaluation of the risk induced by soil erosion on land use. Case study: Guruslău Depression. *Sustainability* 14(2):652. <https://doi.org/10.3390/su14020652>
- da Silva RM, Santos CAG, Silva AM (2014). Predicting soil erosion and sediment yield in the Tapacurá catchment. *Journal of Urban and Environmental Engineering* 8:75-82. <https://doi.org/10.4090/juee.2014.v8n1.075082>
- Dakić B. (1967). Sokobanja Basin: an economic-geographical study. Special Editions, Geographical Institute "Jovan Cvijić", Vol 19, Belgrade.
- Das A, Agrawal R, Mohan S (2015). Topographic correction of ALOS-PALSAR images using InSAR-derived DEM. *Geocarto International* 30(2):145-153. <https://doi.org/10.1080/10106049.2014.883436>
- Dong H, Song Y, Chen L, Liu H, Fu X, Xie M (2022). Soil erosion and human activities over the last 60 years revealed by magnetism, particle size and minerals of check dams sediments on the Chinese Loess Plateau. *Environmental Earth Sciences* 81:162. <https://doi.org/10.1007/s12665-022-10245-8>
- Dragičević N, Karleuša B, Ožanić N (2016). A review of the Gavrilović method (erosion potential method) application. *Gradjevinar* 68:715-725. <https://doi.org/10.14256/JCE.1602.2016>
- Dragičević S, Milevski I (2010). Human impact on the landscape - Examples from Serbia and Macedonia. In: Zlatić (Ed). *Global change - Challenges for soil management*. Advances in Geocology 41:298-309. Reiskirchen: Catena Verlag.
- Efthimiou N, Lykoudi E, Karavitis C (2017). Comparative analysis of sediment yield estimations using different empirical soil erosion models. *Hydrological Sciences Journal* 62:2674-2694. <https://doi.org/10.1080/02626667.2017.1404068>
- Ferreira V, Samora-Arvela A, Panagopoulos T (2016). Soil erosion vulnerability under scenarios of climate land-use changes after the development of a large reservoir in a semi-arid area. *Journal of Environmental Planning and Management* 59(7):1238-1256. <https://doi.org/10.1080/09640568.2015.1066667>
- Gavrilovic S (1972). *Engineering of Flash Floods and Erosion*. Izgradnja, Beograd.
- Gholami H, Jalali M, Rezaei M, Mohamadifar A, Song Y, Li Y, Wang Y, Niu B, Omidvar E, Kaskaoutis DG (2024). An explainable integrated machine learning model for mapping soil erosion by wind and water in a catchment with three desiccated lakes. *Aeolian Research* 67-69:100924. <https://doi.org/10.1016/j.aeolia.2024.100924>
- Jovanović B (1979). *Industrialization and economic policy in Yugoslavia*. Cambridge University Press. <https://www.cambridge.org/9780521153300>
- Keller B, Centeri C, Szabó JA, Szalai Z, Jakab G (2021). Comparison of the applicability of different soil erosion models to predict soil erodibility factor and event soil losses on loess slopes in Hungary. *Water* 13:3517. <https://doi.org/10.3390/w13243517>
- Kostadinov S, Braunović S, Dragičević S, Zlatić M, Dragović N, Rakonjac N (2018). Effects of erosion control works: Case study – Grdelica Gorge, the South Morava River (Serbia). *Water* 10:1094. <https://doi.org/10.3390/w10081094>
- Kostadinov S, Zlatić M, Dragičević S, Novković I, Košanin O, Borisavljević A, Lakićević M, Mladjan D (2014). Anthropogenic influence on erosion intensity changes in the Rasina river watershed-Central Serbia. *Fresenius Environmental Bulletin* 23(1a):254-263. https://www.prt-parlar.de/download_list/?c=FEB_2014
- Kržić, A, Tošić, I, Djurdjević, V, Veljović, K, Rajković B (2011). Changes in climate indices for Serbia according to the SRES-A1B and SRES-A2 scenarios. *Climate Research* 49(1):73-86. <https://doi.org/10.3354/cr01008>
- Lukić T, Lukić A, Basarin B, Ponjiger TM, Blagojević D, Mesaroš M, ... Janičević S (2019). Rainfall erosivity and extreme precipitation in the Pannonian basin. *Open Geosciences* 11(1):664-681. <https://doi.org/10.1515/geo-2019-0053>

- Lukić T, Micić Ponjiger T, Basarin B, Sakulski D, Gavrilov M, Marković S, ... Petrović A (2021). Application of Angot precipitation index in the assessment of rainfall erosivity: Vojvodina Region case study (North Serbia). *Acta Geographica Slovenica* 61(2):123-53. <https://doi.org/10.3986/ags.8754>
- Mandal D, Roy T (2024). Climate change impact on soil erosion and land degradation. In: Pathak H, Chatterjee D, Saha S, Das B (Eds). *Climate Change Impacts on Soil-Plant-Atmosphere Continuum. Advances in Global Change Research*, Singapore: Springer 2024. https://doi.org/10.1007/978-981-99-7935-6_5
- Manojlović S, Antić M, Šantić D, Sibinović M, Carević I, Srejić T (2018). Anthropogenic impact on erosion intensity: Case study of rural areas of Pirot and Dimitrovgrad municipalities, Serbia. *Sustainability* 10(3):1-20. <https://doi.org/10.3390/su10030826>
- Manojlović, S, Sibinović, M, Srejić, T, Novković, I, Milošević, MV, Gatarić, D, Carević, I, Batočanin N (2022). Factors controlling the change of soil erosion intensity in mountain watersheds in Serbia. *Frontiers in Environmental Science* 10. <https://doi.org/10.3389/fenvs.2022.8889>
- Marković ĐJ (1977). Relief of the Sokobanjska Moravica Basin. In: *Proceedings, Geographical Institute "Jovan Cvijić"*, vol. 29, Belgrade.
- Marković R, Mudelsee M, Radaković MG, Radivojević AR, Schaetzl RJ, Basarin B, ... Lukić T (2024). An index for snowmelt-induced landslide prediction for Zavoj Lake, Serbia. *Atmosphere* 15(3):256. <https://doi.org/10.3390/atmos15030256>
- Micić Ponjiger T, Lukić T, Basarin B, Jokić M, Wilby RL, Pavić D, ... Morar C (2021). Detailed analysis of spatial-temporal variability of rainfall erosivity and erosivity density in the Central and Southern Pannonian Basin. *Sustainability* 13(23):13355. <https://doi.org/10.3390/su132313355>
- Micić Ponjiger T, Lukić T, Wilby RL, Marković SB, Valjarević A, Dragičević S, ... Morar C (2023). Evaluation of rainfall erosivity in the Western Balkans by mapping and clustering ERA5 reanalysis data. *Atmosphere* 14(1):104. <https://doi.org/10.3390/atmos14010104>
- Milanesi L, Pilotti M, Clerici A (2015). The application of the erosion potential method to Alpine areas: Methodological improvements and test case. In: Lollino G, Arattano M, Rinaldi M, Giustolisi O, Marechal JC, Grant G (Eds). *Engineering Geology for Society and Territory - Volume 3*. Cham: Springer, pp 347-50. https://doi.org/10.1007/978-3-319-09054-2_73
- Milovanović B, Ducić V, Radovanović M, Milivojević M (2017). Climate regionalization of Serbia according to Köppen climate classification. *Journal of the Geographical Institute Jovan Cvijić SASA* 67(2):103-114. <https://doi.org/10.2298/ijgi1702103m>
- Mišić V, Dinić A (2022). Relict forest vegetation in the Moravica Gorge near Sokobanja. In: *Proceedings of the VI Symposium on the Flora of Southeast Serbia and Adjacent Areas; Sokobanja, Serbia*.
- Mohammadi M, Khaleidi Darvishan AK, Spalevic V, Dudic B, Billi P (2021). Analysis of the impact of land use changes on soil erosion intensity and sediment yield using the IntErO Model in the Talar Watershed of Iran. *Water* 13:881. <https://doi.org/10.3390/w13060881>
- Morgan RPC (2005). *Soil Erosion and Conservation* (3rd ed.). Blackwell Publishing.
- Ouallali A, Aassoumi H, Moukhchane M, Moumou A, Houssni M, Spalevic V, Keesstra S (2020). Sediment mobilization study on Cretaceous, Tertiary and Quaternary lithological formations of an external Rif catchment, Morocco. *Hydrological Sciences Journal* 65:1568-1582. <https://doi.org/10.1080/02626667.2020.1755435>
- Ouallali A, Kader S, Bammou Y, Aqnouy M, Courba S, Beroho M, Briak H, Spalevic V, Kuriqi A, Hysa A (2024). Assessment of the erosion and outflow intensity in the Rif Region under different land use and land cover scenarios. *Land* 13(2):141. <https://doi.org/10.3390/land13020141>
- Panagos P, Ballabio C, Poesen J, Lugato E, Scarpa S, Montanarella L, Borrelli P (2020). A soil erosion indicator for supporting agricultural, environmental and climate policies in the European Union. *Remote Sensing* 12:1365. <https://doi.org/10.3390/rs12091365>
- Pavlova-Traykova E, Dimitrov DP (2023). Soil erosion rates based on anatomical changes in exposed roots – case study from southwest Bulgaria. *Silva Balcanica* 24(3):27-33. <https://doi.org/10.3897/silvabalkanica.24.e116223>
- Pavlova-Traykova E, Petrova K (2023). Soil loss assessment by applying IntErO model. *Forest Science* 24(3):41-46. https://naukazagorata.com/wp-content/uploads/2023/07/ng_59special_5.pdf
- Pavlović M (2019). *Geographic Regions of Serbia 2: Mountain-Basin-Valley Macroregion*. Belgrade: Faculty of Geography, University of Belgrade; 2019. (In Serbian).

- Perović, V, Kadović, R, Djurdjević, V, Braunović, S, Čakmak, D, Mitrović, M, Pavlović P (2019). Effects of changes in climate and land use on soil erosion: a case study of the Vranjska Valley, Serbia. *Regional Environmental Change* 19(4):1035-1046. <https://doi.org/10.1007/s10113-018-1456-x>
- Petrović D, Petrović J (1997). *Morphology and Hydrology of Karst*. Textbook Publishing Institute, Belgrade.
- 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* 16:2390. <https://doi.org/10.3390/rs16132390>
- Radice H (1976). *Yugoslav Economic Development and Political Change: The Socialisation Controversy*. Routledge.
- Radivojević A, Filipović I, Dimitrijević L, Nikolić M (2010). Geographical basis of tourist development of the Sokobanja basin. *Bulletin of the Serbian Geographical Society* 90(3):111-25. <https://glasniksgd.rs/index.php/home/article/view/319>
- Radivojević A (2008). *Geografske promene u Sokobanjskoj kotlini i njihov uticaj na regionalni razvoj*. [PhD dissertation]. Belgrade: Faculty of Geography, University of Belgrade; 2008. (In Serbian)
- Rakićević T (1980). Climatic Regionalization of Serbia. In: *Proceedings, Geographical Institute of the Faculty of Mathematics, University of Belgrade*, vol. XXVII, Belgrade.
- Salik AW (2019). The application of Universal Soil Loss Equation (USLE) for predicting the soil erosion: A review. *Scientific Journal of Research in Natural Science Kabul University* 2:234-242.
- Sartori M, Philippidis G, Ferrari E, Borrelli P, Lugato E, Montanarella L, Panagos P (2019). A linkage between the biophysical and the economic: Assessing the global market impacts of soil erosion. *Land Use Policy* 86:299-312. <https://doi.org/10.1016/j.landusepol.2019.05.014>
- Sestras P, Mircea S, Cîmpeanu SM, Teodorescu R, Roșca S, Bilașco Ș, ... Spalević V (2023). Soil erosion assessment using the intensity of erosion and outflow model by estimating sediment yield: Case study in river basins with different characteristics from Cluj County, Romania. *Applied Sciences* 13(16):9481. <https://doi.org/10.3390/app13169481>
- Spalević V (2011). *Impact of land use on runoff and soil erosion in Polimlje*. Ph.D. Thesis, Faculty of Agriculture, University of Belgrade, Serbia, pp 260.
- Srejić T, Manojlović S, Sibinović M, Bajat B, Novković I, Milošević MV, Carević I, Todosijević M, Sedlak MG (2023). Agricultural land use changes as a driving force of soil erosion in the Velika Morava River Basin, Serbia. *Agriculture* 13(4):778. <https://doi.org/10.3390/agriculture13040778>
- Sučić Z (1953). Contribution to the knowledge of the geological constitution of the Ozren and Devica Mountains (Eastern Serbia). *Geološki anali Balkanskoga poluostrva* 21:77-123.
- Tošić R, Lovrić N, Dragičević S (2019). Assessment of the impact of depopulation on soil erosion: Case study – Republika Srpska (Bosnia and Herzegovina). *Carpathian Journal of Earth and Environmental Sciences* 14(2):505-518. <https://doi.org/10.26471/cjees/2019/014/099>
- Vujačić D, Milevski I, Mijanović D, Vujović F, Lukić T (2023). Initial results of comparative assessment of soil erosion intensity using the WIntErO model: A case study of Polimlje and Shirindareh drainage basins. *Carpathian Journal of Earth and Environmental Sciences* 18(2):385-404. <https://doi.org/10.26471/cjees/2023/018/267>
- Wang B, Zeng Y, Li M, Chen D, Wang H, Wang Y, Ni L, Fang N (2022). Evaluation of the driving effects of socio-economic development on soil erosion from the perspective of prefecture-level. *Frontiers in Environmental Science* 10:1066889. <https://doi.org/doi:10.3389/fenvs.2022.1066889>
- Zorn M, Komac B (2009). Response of soil erosion to land use change with particular reference to the last 200 years (Julian Alps, Western Slovenia). *Revista de Geomorfologie* 11:39-47. <https://revistadegeomorfologie.ro/geo/index.php/revista/issue/view/11/12>



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