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Research Article

Hiking trail impacts on eutrophication of the Seven Rila Lakes, Rila National Park, Bulgaria

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Abstract

Recreational impacts on water resources are a current issue in the scientific literature, but remain insufficiently studied. This is particularly relevant to the Seven Rila Lakes (Rila National Park, Bulgaria), where recreational activities are believed to accelerate eutrophication. Given the lack of targeted research, this study investigates how hiking trails in the catchment areas of five of the lakes contribute to the deterioration of the lakes' ecosystems. A Spearman's rank correlation analysis was conducted to examine: (1) abiotic environmental factors and (2) key characteristics of tourist trails, alongside data for assessing the lakes' ecological status, based on Biological Quality Elements (BQE). The results indicate that, while natural factors are the primary drivers, recreational pressure has a secondary impact. It is suggested that the expansion and degradation of informal trails may introduce substances into the lake waters, causing changes in physicochemical parameters. These changes, although minor, appear to affect phytoplankton and zooplankton communities, ultimately influencing the trophic status of the lakes.The study underscores the need for regular monitoring of both the ecological status of the lakes and the trail conditions in the lakes' catchments and also visitor management measures. Further research with expanded datasets and scale is recommended to refine these findings.

Keywords

recreation-induced eutrophication, oligotrophic lake ecosystems, trail-based ecological indicators, informal trail impacts, visitor-driven soil erosion

Introduction

The eutrophication of lakes, catalysed by recreational activities, has been a longstanding issue (Toro and Granados 2002, Hadwen et al. 2003), but scientific research on this matter is extremely limited and interest in the topic has only grown in recent years (Toro et al. 2006, Bigler et al. 2007, Hadwen and Arthington 2011, Sienkiewicz and Gąsiorowski 2014, Dokulil 2014, Dynowski et al. 2019, Senetra et al. 2020). The focus of these recent limnology studies predominantly comprises oligotrophic lakes of various types subject to tourist pressure, with particular attention paid to high-mountain lakes and those located in protected areas. These studies employ various methodologies. However, attributing responsibility to tourism and recreation often relies on subjective judgements. This assessment usually does not clearly distinguish between natural eutrophication processes and human influence and there is often insufficient evidence to separate the contributions of human activities from those of natural phenomena. Methodologically, there is a sense of 'feeling in the dark,' without a clear understanding of what the exact mechanism of recreational impact is, which hinders decision-making and the implementation of preventative measures for sustainable management of recreation in lake-based tourist destinations.

On the other hand, if we searched for answers to these questions in the recreation-ecological literature, it turns out that the issue has not been sufficiently studied. In his review article on the sustainability of tourist trails, Marion (2023) emphasises that very little is known about the effects of trails on water resources and such studies are severely limited. The author highlights the neglect in tourist literature of the significance and sustainability of trail networks, particularly concerning protected areas, regardless of the undeniable achievements of recreational ecology and trail science. Tourist trails are essential for protected areas as they provide access to attractions, form the basis of recreational experiences and simultaneously should protect surrounding areas by concentrating visitor flow (Leung and Marion 1996, Marion and Leung 2001, Marion et al. 2016). Additionally, as direct traces left by visitors, hiking trails provide important clues about the negative ecological impacts of recreational activities. On this basis, their characteristics can play a useful role as indicators in the tourism development monitoring systems of nature-based destinations. Such an approach was proposed by Mileva et al. (2024), with the assumption that trail characteristics can be used to identify the most significant ecological recreational impacts in mountain and forest areas.

The issue of lake eutrophication caused by recreation is particularly relevant in the case of the Seven Rila Lakes (Rila National Park) in Bulgaria which are a popular tourist destination that attracts thousands of visitors annually. The condition of the Seven Rila Lakes concerns not only scientists, but also society as a whole. The ecological status of the lakes has been the subject of research in numerous publications, such as those by Naidenow and Beshkova (2000), Beshkova (2000), Kalchev et al. (2004), Ognjanova-Rumenova et al. (2006), Boteva et al. (2008), Ognjanova-Rumenova et al. (2009), Ognjanova-Rumenova et al. (2010), Ognjanova-Rumenova et al. (2011), Velchev et al. (2011), Nikolova et al. (2012), Nikolova (2014)Ilieva et al. (2016), Nikolova et al. (2021), Zafirov (2021). All of them address the eutrophication of the lakes and many express concerns about the deterioration of the lakes' ecological condition due to tourist pressure. These concerns escalated in the media space after 2009 when a chairlift to the Seven Rila Lakes was put into operation, which significantly increased the level of accessibility to the lakes. It is believed that the increased tourist flow intensifies the eutrophication of the lakes, but targeted studies on the problem have not been conducted. The present study aims to fill this gap by investigating the relationship between the ecological state of the Seven Rila Lakes and the characteristics and condition of the trail network in their watersheds by trying to distinguish naturally-occurring processes from those caused specifically by tourism and recreation activities.

This study aims to establish the impact of hiking trails as a prerequisite for eutrophication processes in the area of the Seven Rila Lakes using a recreational-ecological approach. The main research questions which the present study seeks to answer are: How do the processes of trail degradation — such as widening and incision — impact the ecological state of the lakes? How does visitor flow pressure, represented through the spatial model of the trail network, impact the ecological state of the lakes? Can trail characteristics be reliably used as environmental indicators for monitoring and managing the impacts of recreation on high-mountain lake ecosystems?

Data and Methods

The study’s conceptual framework is grounded on the DPSIR model (Driving Forces – Pressure – State – Impact – Responses) developed by the European Environment Agency (Smeets and Weterings 1999). This model provides a systematic basis for hypothesising that recreational activities, along with related processes of soil and vegetation degradation in catchment areas, significantly intensify the eutrophication of the Seven Rila Lakes. The application of the DPSIR model enables a structured analysis of the interconnections between humans (particularly recreational activities) and environmental changes by clearly outlining the causes, pressures, state, impacts and necessary management responses. Furthermore, the model provides an appropriate framework for selecting specific indicators to monitor the adverse effects of recreational activities in the area (Fig. 1).

The study’s working hypothesis recognises that, while eutrophication processes in the lakes are naturally occurring, they are markedly intensified by recreational activities. To address this complexity, the conceptual model delineates natural abiotic processes and the intrinsic state of ecosystems from anthropogenic pressures. This distinction enables targeted management strategies by identifying actionable factors, such as recreational use, in contrast to non-actionable natural processes.

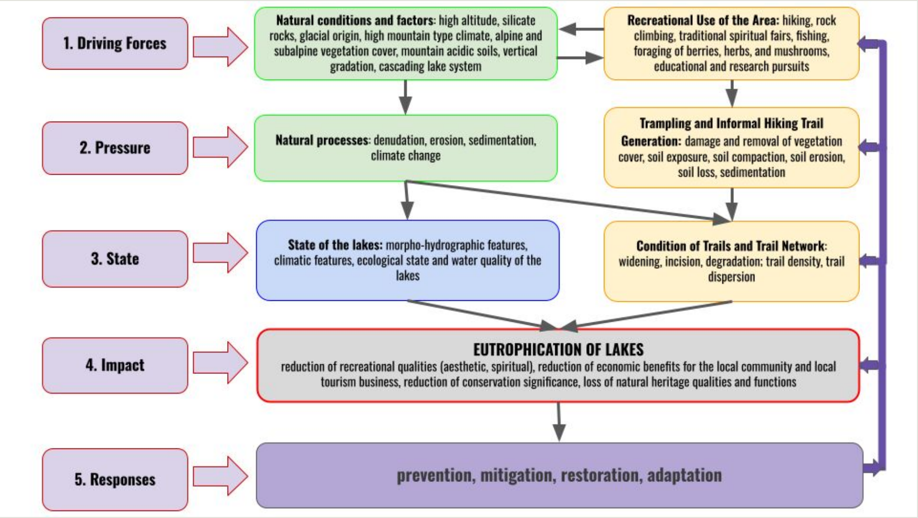

Figure 1.

Conceptual Framework of the Study (: Author).

In order to ensure the relevance of the study, it is based on the recreational-ecological approach. This approach is a concept that examines the interaction between outdoor recreational activities and ecological processes. Traditionally, recreational ecology is perceived as a scientific field that examines the negative ecological impacts of recreational activities on a given area and provides guidelines for their sustainable management (Monz et al. 2010, Leung and Marion 2000). Various recreational activities produce differing negative effects and numerous recreational-ecological studies show that vegetation, soil, wildlife and water are the most severely affected environmental components by recreational pressure (Liddle 1997, Marion and Leung 2001, Cole 2004). Although they have not been sufficiently studied, it is known that the recreational impacts on water bodies are manifested through direct influences (introduction of exotic species, increased water turbidity, higher nutrient influx and deterioration of water quality) and indirect influences (deterioration of aquatic ecosystems, changes in species composition and increased algal growth) (Leung and Marion 2000). Recent studies frame the interaction between recreation and the natural environment as a social-ecological system. This perspective advocates for an integrated management approach that acknowledges the dual nature of these interactions, highlighting both the potential negative impacts on ecosystems and the positive opportunities for fostering human-nature synergies. Additionally, considering recreation within a broader landscape management context is deemed essential for the sustainable management of such areas (Morse 2020, Miller et al. 2022).

The methodological algorithm applied in this research is illustrated in a schematic diagram in Fig. 2 and the details are presented in the text below.

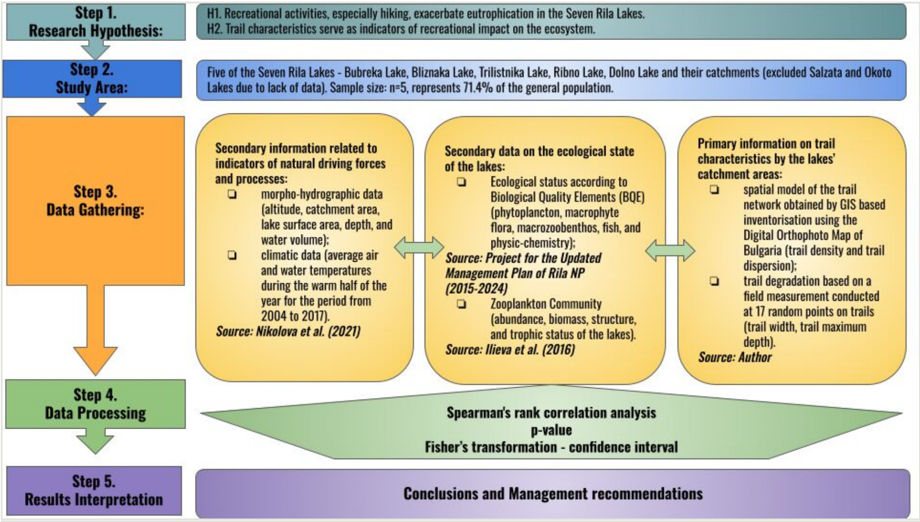

Figure 2.

Research Methodological Scheme (*Source*: Author).

Study Area

The Seven Rila Lakes (Sulzata Lake, Okoto Lake, Bubreka Lake, Bliznaka Lake, Trilistnika Lake, Ribno Lake and Dolno Lake), situated in the highest mountain range on the Balkan Peninsula, Rila (Musala Peak, 2,925 m), are of glacial origin and display significant geodiversity, biodiversity, landscape diversity and habitat heterogeneity in their surroundings (Assenov et al. 2015). They are small lakes, arranged in a stepped formation and interconnected as part of a cascading lake system. Streams link the individual lakes, with Sulzata Lake, Okoto Lake and Bubreka Lake functioning as outflow lakes, while Bliznaka Lake, Trilistnika Lake, Ribno Lake and Dolno Lake acting as flow-through lakes. The waters of the Seven Rila Lakes ultimately drain into the Dzherman River, which channels them out of the entire Seven Rila Lakes Cirque. (Fig. 3)

The bedrock of the Seven Rila Lakes Cirque consists of ancient magmatic and metamorphic silicate rocks, as detailed in multiple studies (Dimitrova 1960, Zhelyazkova-Panayotova et al. 1972a, Zhelyazkova-Panayotova et al. 1972b, Ermolaev et al. 1977, Kamenov et al. 1979, Vylkov et al. 1989, Marinova 1991, Marinova 1993, Dimov and Damyanova 1996, Sarov 2009, Sarov et al. 2011 etc.). The landscape is characterised by a range of geomorphological forms, including relict, relict-glacial, relict-periglacial, contemporary periglacial and modern erosional-denudational features (Ivanov 1954, Baltakov 1984, Baltakov and Mladenova 1989, Baltakov 2004, Gikov and Dimitrov 2010, Velchev et al. 2011, Dimitrov and Velchev 2012, Nikolova et al. 2012, Kuhlemann et al. 2013, Sinnyovsky 2014, Sinnyovsky 2015, Tsvetkova and Sinnyovsky 2015, Gikov 2019 etc.). Located in the alpine and subalpine zones, at elevations between 2,095 and 2,673 m a.s.l., the catchment area of the Seven Rila Lakes is predominantly covered by acidophilic grasslands and shrub communities (Assenov et al. 2015). Vegetation is supported by diverse soil types, including lithosols, rankers and mountain-meadow soils in the uplands, with peaty-marsh soils found near the lakeshores (Mitova 2022). The landscape structure in the Seven Rila Lakes area is represented by cold humid landscape types (Konteva et al. 2001, Velchev et al. 2003) in the initial phase of recreational anthropogenic modification (Gikov 2019). The ecosystems in the Lakes' area and, particularly, the Lakes themselves, possess a high capacity to provide cultural and regulating ecosystem services, while their capacity to deliver provisioning ecosystem services is limited (Nedkov et al. 2014). The ecosystems of the Seven Rila Lakes are highly sensitive to both global climate changes and human activity, emphasising the need for careful ecological management and conservation (Nikolova et al. 2012, Nojarov 2013, Nikolova 2014, Nikolova et al. 2021, Zafirov 2021 etc.).

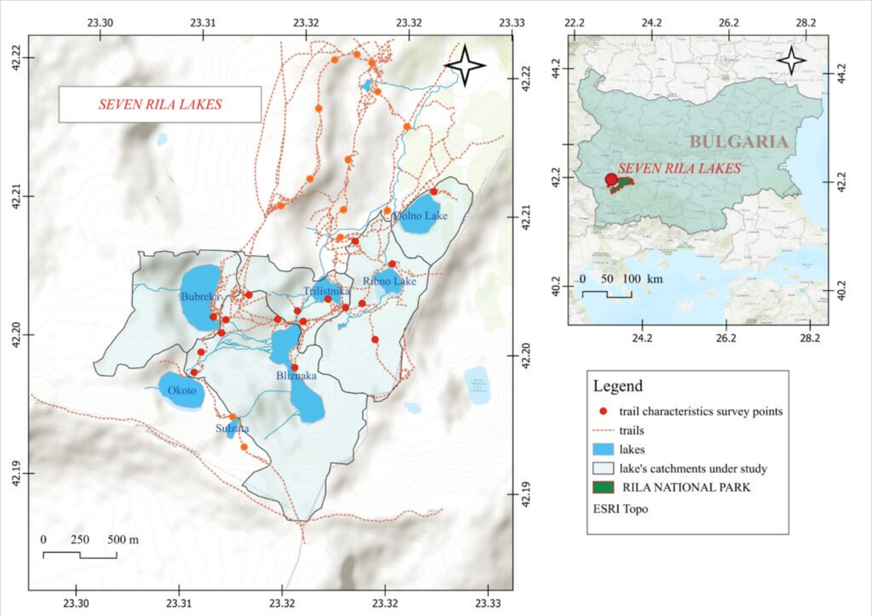

Figure 3.

Study Area - Seven Rila Lakes Location, Catchment areas, Hiking Trails, Trail Characteristic Survey Points (*Source*: Author).

The conservation significance of the Seven Rila Lakes is widely acknowledged at both national and European levels. Categorised as Oligotrophic Mountain lakes in intermediate stages of developmental progression according to the Red Book of Bulgaria, these Lakes are characterised by sediment accumulation on their beds and proliferation of aquatic flora, such as *Sparganium angustifolium* and *Ranunculus aquatilis*. Their evolutionary trajectory suggests a transition towards peatlands and wet meadows interspersed with meandering streams. The lakes' vulnerability is ascribed to tourism and mountain animal husbandry, identified as primary drivers intensifying eutrophication processes (Ivanov 2011).

The very first research on the hydrobiological and hydrobotanical characteristics of the Seven Rila Lakes was conducted by Valkanov (1932), Valkanov (1938) and Vodenicharov (1960). In 1964, the National Institute of Meteorology and Hydrology published a morpho-hydrographic characterisation of Bulgarian lakes, including the Seven Rila Lakes (National Institute of Meteorology and Hydrology 1964). These data were recently verified by Vasilev and Hristova (2022), who concluded that the morphometric parameters established in the 1960s do not differ significantly from contemporary values, indicating stability in the natural conditions. The water quality monitoring of the Lakes, conducted by the responsible state institutions, indicates very good ecological status and good chemical status of the waters of the Seven Rila Lakes (Executive Environment Agency 2023).

However, recent studies on the Seven Rila Lakes reveal significant impacts on the ecosystems from climate change and anthropogenic pressure. Eutrophication has been observed in some lakes, shifting from oligotrophic to mesotrophic conditions due to increased organic matter input (Ognjanova-Rumenova et al. 2009, Ilieva et al. 2016). The composition of zooplankton, phytoplankton and diatom communities is sensitive to water chemistry changes, temperature changes and substrate conditions (Kalchev et al. 2004, Ognjanova-Rumenova et al. 2006). Sediment data from the Lakes reveal the cumulative effects of atmospheric pollution and reduced snow cover over the past 150 years (Ognjanova-Rumenova et al. 2010, Ognjanova-Rumenova et al. 2011). Nutrient concentrations in the Lakes depend on soil coverage in the drainage basin, affecting water transparency and trophic status (Kalchev et al. 2004).

The Seven Rila Lakes serve as repositories of palaeoclimatic data, providing insights into historical climatic conditions and their temporal fluctuations over the past several millennia. Such climatic archives bear substantial scientific and cognitive value, particularly pertinent amidst contemporary concerns regarding global warming and climate change (Gachev 2011). Multiple scholarly works advocate for the recognition of the Seven Rila Lakes as geoheritage and as a natural heritage site (Sinnyovsky 2014, Sinnyovsky 2015, Tsvetkova and Sinnyovsky 2015, Nikolova et al. 2021). However, this heritage value is underutilised for tourism purposes and for reaching a wider audience outside of scientific circles.

Located within Rila National Park and encompassed by the management zone delineated in the extant Management Plan of Rila National Park 2001-2010 (2001), the Seven Rila Lakes also fall entirely within the Rila Protected Area BG 00000495 of the European ecological network "Natura 2000". Management protocols adhere to directives stipulated by the European Union for the Conservation of Wild Birds (79/409/EEC) (European Parlament 2009), Conservation of Natural Habitats and of Wild Fauna and Flora (92/43/EEC) (European Economic Community 1992), as well as conventions ratified under the Bern Convention (since 1991) (Council of Europe 1994) and the Biodiversity Convention (since 1996) (United Nations 1992) (Ilieva et al. 2016).

Besides their ecological and conservation significance, the Seven Rila Lakes hold substantial recreational appeal and serve as a popular hiking destination in Bulgaria.

Strategically located within an hour's drive from the capital city of Sofia, the Lakes attract a considerable tourist influx, further bolstered by their aesthetic allure, characterised by picturesque glacial formations and pristine waters. Since 1929, the Lakes have also served as a revered site for members of The Universal White Brotherhood, a philosophy-religious movement founded by Peter Deunov. Traditionally, during the summer months, thousands of Brotherhood adherents from across the globe gather in tents around the Lakes. Additionally, two nearby huts provide accommodation, with a combined capacity of 227 beds.

Permissible recreational activities in the vicinity include hiking, rock climbing, traditional spiritual fairs, fishing, foraging of berries, herbs and mushrooms, as well as educational and research pursuits. Recreational use standards have been set for all of these activities (Management Plan of Rila National Park 2001-2010 2001). However, official records regarding visitor statistics and visitor behaviour are scarce and inconsistent. While the Ministry of Environment and Water reported 45,300 visitors in 2017, with the highest visitation occurring in August (28,000) and the lowest in April (356), the Municipality of Sapareva Banya, within whose jurisdiction the Lakes reside, claims over 100,000 annual visitors from 35 countries during the summer months. Numerous media reports and social media commentary attest to concerns regarding overcrowding. Observations indicate that the visitor flow is neither regulated nor organised and the established norms for recreational use are not being followed. Recreational use is highest during the summer months, particularly on weekends. In the recreational zone of the Seven Rila Lakes Cirque, the visitor flow has generated nearly 35 km of informal trail networks over an area of approximately 4.5 km^2 (Mitova 2020), half of which are showing signs of moderate to extreme degradation level (Mitova 2021).

Sample

This study focuses on five of the Seven Rila Lakes - Bubreka, Bliznaka, Trilistnika, Ribno and Dolno Lake and their catchments. (Fig. 3) Salzata and Okoto Lakes were excluded from the analysis due to inherent limitations in available data about their ecological status and quality of their water necessary for this analysis. Although the number of observed cases is small (n = 5), it represents 71.4% of the general population. On the other hand, the small sample size determines the low statistical power of the study, the lower reliability of the obtained results and the limited generalisability of the conclusions.

Data Gathering

Morphometrical and Hydro-climatic Characteristics Data

Data pertaining to the hydro-climatic and morphometrical characteristics of the Lakes under examination were obtained from Nikolova et al. (2021). This dataset comprises information such as altitude, catchment area, lake surface area, depth and water volume of the Lakes, based on data from the National Institute of Meteorology and Hydrology (1964) with reflected additions and clarifications by Botev (2000), Kalchev et al. (2004), Nikolova et al. (2012) and Zafirov (2021). Additionally, Nikolova et al. (2021) provide averaged climate observations for the warm half of the year from 2004 to 2017, specifically for the area of the Seven Rila Lakes, including average surface water temperature and average air temperature. This is the only existing climate data specifically for the area of the Seven Rila Lakes. All these metrics are considered key indicators of natural abiotic factors influencing the ecological condition of the Lakes, particularly the eutrophication process (Table 1).

Table 1.

Morphometric and Hydro-climatic Characteristics of the Seven Rila Lakes (*Source:* *Nikolova et al. (2021)*).

Lake	Altitude (m)	Catchment area (ha)	Surface area (ha)	Depth (m)	Water volume (m^3)	Average surface water temperature during the warm half of the year (°C)	Average air temperature during the warm half of the year (°C)
Bubreka	2282	51	8.5	28	1170000	13.4	14.1
Bliznaka	2243	205	9.1	27.5	590000	11.8	14.1
Trilistnika	2216	223	2.6	6.5	54000	13.5	14.4
Ribno	2184	251	3.5	2.5	38000	12.8	14.8
Dolno	2095	281	5.9	11	240000	14.5	15.9

Ecological Status Data

Ecological status assessment data - Biological Quality Elements (BQE) for the lakes were sourced from Appendix 1.10.3 "Summary results of the ecological status of rivers and lakes in Rila NP," within the Project for the Updated Management Plan of Rila NP (2015-2024) (Council of Ministers 2015). The assessment indicators encompassed the state of phytoplankton, macrophyte flora, macrozoobenthos, fish and physico-chemistry of the lakes. Fish and physico-chemistry data were excluded from the analysis due to maximum estimates across all five Lakes, suggesting minimal deviations from their natural state and, thus, minimal recreational impact. Notably, this dataset did not cover the highest lakes in the Seven Rila Lakes group - Okoto and Salzata, initially limiting sample size for this study. (Table 2)

In addition, zooplankton community data for the same lakes were obtained from the publication by Ilieva et al. (2016) “Biodiversity of zooplankton in Rila mountain glacial lakes in Natura 2000 zones - BG 000495 and BG 000496”. The data provide information on the abundance, biomass and structure (diversity, dominance and evenness) of the zooplankton community, as well as the trophic status of the lakes from the perspective of zooplankton (Table 3).

Both studies on the ecological state of the Seven Rila Lakes used were conducted in 2015 according to established standardised methodologies for assessing the ecological status of surface waters in accordance with the European Union's Water Framework Directive (WFD 2000/60/EC) (European Parlament 2000), Regulation N-4 for characterising surface waters (Ministry of Environment and Water 2012) and BDS EN 15110:2006 - Water quality - Guidance standard for the sampling of zooplankton from standing waters (European Commitee for Standardisation 2006).

Table 2.

Ecological status according to Biological Quality Elements (BQE) (Source: Project for the Updated Management Plan of Rila NP 2015-2024) (Council of Ministers 2015).

Lake	Phytoplankton			Macrophyte flora	Macrozoobenthos	Fish	Physico-chemistry
	biomass (mm^{3}/l)	AGI	EQR				
Bubreka	1.375	2.68	0.994	na	good	excellent	excellent
Bliznaka	1.343	3.19	0.992	na	excellent	excellent	excellent
Trilistnika	1.452	3.16	0.992	moderate	moderate	excellent	excellent
Ribno Lake	0.583	1.63	0.996	moderate	moderate	excellent	excellent
Dolno Lake	0.854	0.49	0.999	moderate	moderate	excellent	excellent

Table 3.

Indicators of Zooplankton Community (*Source: Ilieva et al. (2016)*

Lake	Abundance / ind.m-^{3}; +P3:U13	Biomass / mg.m^{3}	Biodiversity index (H) by Shannon-Weaver (1963)	Index of Dominance by Simpson (1949)	Index of Evenness according to Pielou (1975)	RCC trophic index
Bubreka	5932	4.53	1.66	0.21	0.85	25
Bliznaka	5408	73.24	1.54	0.27	0.79	21
Trilistnika	24450	71.57	1.87	0.23	0.71	2
Ribno Lake	25108	50.14	1.36	0.36	0.59	2
Dolno Lake	2236	44.52	0.52	0.76	0.26	1

Trail Characteristics Data

The analysis incorporates findings from previous investigations on the spatial strain caused by the trail network (Mitova 2020) and trail erosion (Mitova 2021) within the Seven Rila Lakes Cirque recreational zone. Data on trail width and trail maximum depth were collected during a field survey in 2020, based on a random sample of 31 points along the trail network in the area. For the purposes of the present study, data from 17 points within the catchment areas of the lakes included in the research were utilised (Fig. 3). A derived indicator for the cross-sectional area of the trails has been calculated, based on the half-product of the trail width and their maximum depth. It has been interpreted as an indicator of trail degradation level. Trail density and trail dispersion data were obtained from a GIS-based trail inventory grounded on the Digital Orthophoto Map of Bulgaria (Ministry of Agriculture and Food 2013), covering all trails in the Seven Rila Lakes Cirque area. For this analysis, both datasets were averaged across the respective watersheds of each lake included in the study (Table 4).

Table 4.

Trail Characteristics by the Catchment Area of the Lakes (*Source*: Author).

Lake catchment	Average trail width sm	Average trail max depth sm	Average trail cross-sectional area sm^2	Average trail density m/ha	Average trail dispersion n/ha
Bubreka	170	10	850	49.2	1.2
Bliznaka	432.6	30.7	12677.9	59.15	1
Trilistnika	140.8	12.3	465.6	147.7	3.1
Ribno	195	20.5	2967.5	86	1
Dolno	0	0	0	21.7	0.7

Data Processing

Given the characteristics of the available data, such as its small sample size, heterogeneity, potential non-linear relationships and the presence of outliers, Spearman's rank correlation coefficient was used to analyse the relationship between: 1. abiotic environmental factors and conditions; 2. the trampling effects from recreational activities, trail degradation; and 3. various eutrophication processes. To address the limitations of the small sample size and validate the observed relationships, p-values were calculated. Additionally, confidence intervals were computed using Fisher’s transformation, which stabilises the correlation distribution and provides a reliable range for the true value of the correlation. Confidence intervals are calculated at a 95% confidence level. Combining p-values with confidence intervals enabled a comprehensive assessment of the results. The p-values indicated statistical significance, while the confidence intervals clarified the precision and variability of the estimates, ensuring a robust interpretation of the data despite its limitations.

Results

Correlation Between Abiotic Factors and Ecological Status of Lakes

In Table 5, the obtained results for Spearman's rank correlation coefficient, p-values and confidence intervals between the data on the morphometric and hydro-climatic characteristics of individual lakes and the data on their ecological status are presented. The results reflect the influence of abiotic environmental factors on the ongoing eutrophication processes in the lakes.

Table 5.

Correlation Analysis of Ecological Indicators and Abiotic Factor Indicators: Spearman Coefficients, p-Values and Confidence Intervals (Source: *Author*).

Indicators	Altitude	Catchment area	Surface area	Depth	Water volume	Average surface water temp. during the warm half of the year	Average air temp. during the warm half of the year
Phytoplankton - biomass	**0.6** *(p = 0.5)* [-0.6; 0.97]	**-0.6** *(p =0 .5)* [-0.97; 0.6]	**-0.1** *(p > 0.5)* [-0.9; 0.86]	**0.4** *(p > 0.5)* [-0.75; 0.95]	**0.4** *(p > 0.5)* [-0.75; 0.95]	**0.2** *(p > 0.5)* [-0.83; 0.92]	**-0.525** *(p = 0.5)* [-0.96; 0.67]
Phytoplankton - AGI	**0.7** *(p = 0.5)* [-0.48; 0.98]	**-0.7** *(p = 0.5)* [-0.98; 0.48]	**0.3** *(p > 0.5)* [-0.79; 0.93]	**0.3** *(p > 0.5)* [-0.79; 0.93]	**0.3** *(p > 0.5)* [-0.79; 0.93]	**-0.6** *(p = 0.5)* [-0.97; 0.6]	**-0.775** *(p = 0.5)* [-0.98. 0.34]
Phytoplankton - EQR	**-0.625** *(p = 0.5)* [-0.97; 0.57]	**0.675** *(p = 0.5)* [-0.51; 0.98]	**-0.075** *(p > 0.5)* [-0.9; 0.86]	**-0.175** *(p > 0.5)* [-0.92; 0.84]	**-0.175** *(p > 0.5)* [-0.92; 0.84]	**0.475** *(p > 0.5)* [-0.7; 0.96]	**0.775** *(p = 0.5)* [-0.34; 0.98]
Macrophyte flora	**-0.625** *(p = 0.5)* [-0.97; 0.57]	**0.875** *(p = 0.2)* [-0.03; 0.99]	**-0.625** *(p = 0.5)* [-0.97; 0.57]	**-0.625** *(p = 0.5)* [-0.97; 0.57]	**-0.625** *(p = 0.5)* [-0.97; 0.57]	**0.625** *(p = 0.5)* [-0.57; 0.97]	**0.9** *(p = 0.1)* [0.086; 0.99]
Macro-zoobenthos	**0.8** *(p = 0.2)* [-0.28; 0.99]	**-0.6** *(p = 0.5)* [-0.97; 0.6]	**0.9** *(p = 0.1)* [0.086; 0.99]	**0.8** *(p = 0.2)* [-0.28; 0.99]	**0.8** *(p = 0.2)* [-0.28; 0.99]	**-0.5** *(p = 0.5)* [-0.96; 0.68]	**-0.625** *(p = 0.5)* [-0.97; 0.57]
Zooplankton - abundance	**0.1** *(p > 0.5)* [-0.86; 0.9]	**-0.1** *(p > 0.5)* [-0.9; 0.86]	**-0.6** *(p = 0.5)* [-0.97; 0.6]	**-0.6** *(p = 0.5)* [-0.97; 0.6]	**0.1** *(p > 0.5)* [-0.86; 0.9]	**-0.3** *(p > 0.5)* [-0.93; 0.79]	**-0.025** *(p > 0.5)* [-0.89; 0.88]
Zooplankton - biomass	**0** [-0.88; 0.88]	**0** [-0.88; 0.88]	**0** [-0.88; 0.88]	**-0.3** *(p > 0.5)* [-0.93; 0.79]	**-0.3** *(p > 0.5)* [-0.93; 0.79]	**-0.5** *(p = 0.5)* [-0.96; 0.68]	**-0.175** *(p > 0.5)* [-0.92; 0.84]
Zooplankton - Biodiversity Index by Shannon-Weaver (1963)	**0.7** *(p = 0.5)* [-0.48; 0.98]	**-0.7** *(p = 0.5)* [-0.98; 0.48]	**-0.2** *(p > 0.5)* [-0.92; 0.83]	**0.2** *(p > 0.5)* [-0.83; 0.92]	**0.2** *(p > 0.5)* [-0.83; 0.92]	**-0.1** *(p > 0.5)* [-0.9. 0.86]	**-0.625** *(p = 0.5)* [-0.97; 0.57]

Indicators	Altitude	Catchment area	Surface area	Depth	Water volume	Average surface water temp. during the warm half of the year	Average air temp. during the warm half of the year
Index of Dominance by Simpson (1949)	**-0.9** ($p = 0.1$) [-0.99; -0.09]	**0.9** ($p = 0.1$) [0.086; 0.99]	**-0.1** ($p > 0.5$) [-0.9; 0.86]	**-0.5** ($p = 0.5$) [-0.96; 0.68]	**-0.5** ($p = 0.5$) [-0.96; 0.68]	**0.2** ($p > 0.5$) [-0.83; 0.92]	**0.825** ($p = 0.2$) [-0.21; 0.99]
Index of Evenness according to Pielou (1975)	**1** ($p = 0.02$) [1; 1]	**-1** ($p = 0.02$) [-1; -1]	**0.5** ($p = 0.5$) [-0.68; 0.96]	**0.7** ($p = 0.5$) [-0.48; 0.98]	**0.7** ($p = 0.5$) [-0.48; 0.98]	**-0.5** ($p = 0.5$) [-0.96; 0.68]	**-0.925** ($p = 0.1$) [-1; -0.23]
RCC trophic index	**0.975** ($p = 0.1$) [0.66; 1]	**-0.925** ($p = 0.1$) [-1; -0.23]	**0.575** ($p = 0.5$) [-0.62; 0.97]	**0.675** ($p = 0.5$) [-0.51; 0.98]	**0.675** ($p = 0.5$) [-0.51; 0.98]	**-0.575** ($p = 0.5$) [-0.97; 0.62]	**-0.85** ($p = 0.2$) [-0.99; 0.13]

Indicators related to the distribution and condition of phytoplankton in the lakes show weak to moderate correlations with abiotic environmental factors. Phytoplankton biomass exhibits a strong positive correlation with altitude (rho = 0.6) and a strong negative correlation with the size of the lake's catchment area (rho = -0.6). A moderate negative correlation is observed between phytoplankton biomass and the mean air temperature during the warm season (rho = -0.525), while moderate positive correlations are found with lake depth and water volume (rho = 0.4). In contrast, phytoplankton biomass shows weak or negligible correlations with lake surface area (rho = -0.1) and the mean water temperature during warmer months (rho = 0.2). In all cases, these correlations do not reach statistical significance, raising concerns about the reliability of the results. Furthermore, broad confidence intervals suggest no clear relationships between the variables considered.

A similar pattern emerges in the analysis of the Algal Group Index (AGI). AGI exhibits a strong positive relationship with altitude (rho = 0.7) and strong negative relationships with the lake catchment area (rho = -0.7), mean water temperature (rho = -0.6) and especially the mean air temperature during the warm season (rho = -0.775). Correlations with other hydrographic parameters, such as lake surface area, depth and water volume, are weak (rho = 0.3).

Hydrological indicators of lakes show either no correlation or very weak relationships with the Ecological Quality Ratio (EQR). The correlation coefficient ranges from -0.075 to -0.175. However, altitude shows a strong negative correlation (rho = -0.625), while the size of the catchment area and the mean air temperature exhibit strong positive correlations with EQR (rho = 0.675 and rho = 0.775, respectively). A moderate positive relationship is observed between EQR and water temperature during warmer months. Despite the high correlation coefficients, the results lack statistical significance and the confidence intervals do not support the likelihood of any clear relationships.

Ecological assessments of lakes based on macrophyte flora exhibit higher correlation coefficients with abiotic environmental factors compared to phytoplankton indicators. For example, the correlation coefficients between assessments by macrophytes and the size of the catchment area (rho = 0.875, p = 0.2), as well as the mean air temperature during the warm season (rho = 0.9, p = 0.1), show very strong positive relationships. Although these results are not statistically significant, the p-values are closer to the threshold of significance. While the confidence intervals remain wide, the relationship between assessments by macrophytes and the mean air temperature falls entirely within the positive range, enhancing the reliability of these results. Indicators such as altitude, lake surface area, depth and water volume show strong negative correlations with macrophyte assessments, but these results are less reliable due to high p-values and wide confidence intervals. The water temperature during the warmer months also shows a strong positive correlation, but it is not statistically significant and has a wide confidence interval.

Assessments based on macrozoobenthos demonstrate strong to very strong correlations with abiotic environmental factors. Unlike the previously discussed indicators, hydrological factors are particularly significant in this context. These assessments show a very strong positive relationship with lake surface area (rho = 0.9). Although the confidence interval is broad, it remains within the positive spectrum and the p-value approaches the conventionally accepted level of significance (p = 0.1). Similarly, very strong positive correlations are observed between macrozoobenthos assessments and altitude, lake depth and water volume (rho = 0.8 for each). While the p-values approach significance, the confidence intervals broaden to include values from the negative range, reducing the reliability of these results. The remaining indicators, catchment area and temperature-related factors, show moderate to strong correlations with macrozoobenthos assessments. However, the statistical significance levels remain unsatisfactory and the confidence intervals are excessively wide, questioning the reliability of these findings.

The correlation patterns for zooplankton community indicators are inconsistent. Zooplankton abundance does not demonstrate clear relationships with abiotic factors. Elevated correlation coefficients are observed only between zooplankton abundance and lake surface area and depth. However, these associations remain questionable due to high p-values and wide confidence intervals.

Zooplankton biomass shows no correlation with altitude, catchment area or lake surface area (rho = 0). Very weak negative and statistically insignificant relationships are noted between zooplankton biomass and lake depth and water volume. A moderate increase in the correlation coefficient is observed between zooplankton biomass and the mean water temperature during the warm season (rho = 0.5), but this association lacks statistical significance.

The hydrological characteristics of water bodies, such as surface area, depth and water volume, as well as the mean water temperature during warm months, exhibit very weak positive or negative correlations with the Shannon-Weaver Biodiversity Index (1963) for zooplankton. The correlation coefficients range between -0.1 and 0.2. Strong, but statistically insignificant relationships are observed between this biodiversity index and altitude (rho = 0.7), catchment area size (rho = -0.7) and mean air temperature during the warm season (rho = -0.625). Although these results are highly uncertain, as indicated by wide confidence intervals, they outline potential trends and dependencies in zooplankton community development.

The Index of Dominance by Simpson (1949) shows notable correlations, particularly with catchment area (rho = 0.9), suggesting that larger watershed areas are associated with greater species dominance. A very strong negative correlation with altitude (rho = -0.9) points to a potential inverse relationship between species dominance and elevation. While these results are not statistically significant, they approach established thresholds and the confidence intervals confirm interdependence. A very strong positive, but uncertain correlation is observed between the Simpson Dominance index and the mean air temperature during the warm half of the year (rho = 0.825, p = 0.2, [-0.21, 0.99]). Water depth and volume show moderate inverse correlations with the dominance index, but these findings are undermined by high p-values and wide confidence intervals. Lake area and mean water temperature exhibit weak and uncertain correlations with the dominance index.

The Index of Evenness according to Pielou (1975) shows a perfect positive and statistically significant correlation with altitude (rho = 1, p = 0.02) and a perfect negative correlation with catchment area (rho = -1, p = 0.02). These results suggest that higher elevations are associated with greater species evenness, while larger catchment areas correspond to lower evenness. A very strong inverse relationship exists between the Evenness index and the mean air temperature during the warm season. This relationship is supported by a relatively narrow confidence interval, entirely within the negative range of values and approaches statistical significance (rho = -0.925, p = 0.1, [-1, -0.23]). Clear positive, but statistically uncertain results are observed between the Evenness index and both the depth and volume of lake water (rho = 0.7, p = 0.2). A moderate direct correlation exists between the Evenness index and lake size (rho = 0.5). Conversely, a moderate inverse correlation is observed between the Evenness index and mean water temperature during warm months (rho = -0.5). These latter results are questionable due to high p-values and wide confidence intervals.

The RCC trophic index shows a strong inverse correlation with altitude (rho = -0.975, p = 0.1, [0.66, 1]). Although this result is not statistically significant, it suggests a reliable trend. A weaker, but still notable inverse correlation is observed with the mean air temperature during the warmer half of the year (rho = -0.85, p = 0.2, [-0.99, 0.13]). Hydrological parameters, including warm-season water temperatures, show moderate to strong correlations with the trophic index, but these relationships demonstrate low reliability.

Correlation between Trail Characteristics and Ecological Status of Lakes

Table 6 presents the results of the conducted correlation analysis between the data on the ecological status of the lakes and the data on the characteristics of the hiking trails distributed by the lakes' watershed basins. The obtained results are indicative of the impact of recreational activities, particularly the effects of trampling, trail degradation and extension of trails on the ongoing eutrophication processes in the lakes.

Indicators related to the state of phytoplankton in lakes reveal significant diversity in their relationships with the characteristics of hiking trails, both in terms of strength and direction. While phytoplankton biomass shows weak and statistically insignificant correlations with most trail indicators, a notable positive correlation is observed between phytoplankton biomass and the average dispersion of the trail network (rho = 0.825). Although this result carries some uncertainty due to the high p-value (p = 0.2) and the wide confidence interval that includes zero ([-0.21, 0.99]), it suggests a potential trend.

The Algal Group Index (AGI) displays moderate to strong positive correlations with all trail indicators, though these relationships are not statistically significant. The strongest correlations are observed with trail degradation indicators, such as the mean width, mean maximum depth and mean cross-section of trails. Spearman correlation coefficients for these relationships range from 0.6 to 0.7.

Table 6.

Correlation Analysis of Ecological Indicators and Trail Characteristics Indicators: Spearman Coefficients, p-Values and Confidence Intervals (Source: *Author*).

Indicators	Average trail width	Average trail max depth	Average trail cross-sectional area	Average trail density	Average trail dispersion
Phytoplankton - biomass	-**0.2** *(p > 0.5)* [-0.92, 0.83]	-**0.1** *(p > 0.5)* [-0.9, 0.86]	-**0.2** *(p > 0.5)* [-0.92, 0.83]	**0.3** *(p > 0.5)* [-0.79, 0.93]	**0.825** *(p = 0.2)* [-0.21, 0.99]
Phytoplankton - AGI	**0.6** *(p = 0.5)* [-0.6, 0.97]	**0.7** *(p = 0.5)* [-0.48, 0.98]	**0.6** *(p = 0.5)* [-0.6, 0.97]	**0.5** *(p = 0.5)* [-0.68, 0.96]	**0.575** *(p = 0.5)* [-0.62, 0.97]
Phytoplankton - EQR	-**0.425** *(p > 0.5)* [-0.95, 0.73]	-**0.575** *(p = 0.5)* [-0.97, 0.62]	-**0.425** *(p > 0.5)* [-0.95, 0.73]	-**0.575** *(p = 0.5)* [-0.97, 0.62]	-**0.625** *(p = 0.5)* [-0.97, 0.57]
Macrophyte flora	-**0.375** *(p > 0.5)* [-0.94, 0.76]	-**0.125** *(p > 0.5)* [-0.91, 0.85]	-**0.375** *(p > 0.5)* [-0.94, 0.76]	**0.375** *(p > 0.5)* [-0.76, 0.94]	**0.025** *(p > 0.5)* [-0.88, 0.89]
Macrozoobenthos	**0.7** *(p = 0.5)* [-0.48, 0.98]	**0.5** *(p = 0.5)* [-0.68, 0.96]	**0.7** *(p = 0.5)* [-0.48, 0.98]	-**0.1** *(p > 0.5)* [-0.9, 0.86]	**0.175** *(p > 0.5)* [-0.84, 0.92]
Zooplankton - abundance	**0.3** *(p > 0.5)* [-0.79, 0.93]	**0.4** *(p > 0.5)* [-0.75, 0.95]	**0.3** *(p > 0.5)* [-0.79, 0.93]	**0.8** *(p = 0.2)* [-0.28, 0.99]	**0.575** *(p = 0.5)* [-0.62, 0.97]

Zooplankton - biomass	**0.5** *(p = 0.5)* [-0.68, 0.96]	**0.8** *(p = 0.2)* [-0.28, 0.99]	**0.5** *(p = 0.5)* [-0.68, 0.96]	**0.6** *(p = 0.5)* [-0.6, 0.97]	**0.125** *(p > 0.5)* [-0.85, 0.91]
Zooplankton - Biodiversity Index by Shannon-Weaver (1963)	**0.1** *(p > 0.5)* [-0.86, 0.9]	**0.2** *(p > 0.5)* [-0.83, 0.92]	**0.1** *(p > 0.5)* [-0.86, 0.9]	**0.6** *(p = 0.5)* [-0.6, 0.97]	**0.975** *(p = 0.1)* [0.66, 1]
Index of Dominance by Simpson (1949)	-**0.2** *(p > 0.5)* [-0.92, 0.83]	-**0.1** *(p > 0.5)* [-0.9, 0.86]	-**0.2** *(p > 0.5)* [-0.92, 0.83]	-**0.3** *(p > 0.5)* [-0.93, 0.79]	-**0.825** *(p =0.2)* [-0.99, 0.21]
Index of Evenness according to Pielou (1975)	**0.5** *(p = 0.5)* [-0.68, 0.96]	**0.3** *(p > 0.5)* [-0.79, 0.93]	**0.5** *(p = 0.5)* [-0.68, 0.96]	**0.1** *(p > 0.5)* [-0.86, 0.9]	**0.625** *(p = 0.5)* [-0.57, 0.97]
RCC trophic index	**0.625** *(p = 0.5)* [-0.57, 0.97]	**0.375** *(p > 0.5)* [-0.76, 0.94]	**0.625** *(p = 0.5)* [-0.57, 0.97]	-**0.075** *(p > 0.5)* [-0.9, 0.86]	**0.525** *(p = 0.5)* [-0.62, 0.97]

The Ecological Quality Ratio (EQR) shows weak relationships with trail characteristics. All Spearman coefficients are negative, with varying magnitudes from moderate to strong. The highest correlation is observed with average trail dispersion (rho = -0.625). However, the statistical significance of these results is low, with a wide confidence interval that raises questions about their reliability.

Macrophyte flora assessments correlate poorly with trail indicators. Negative correlation coefficients suggest that as trail degradation increases, macrophyte flora estimates tend to decrease. A positive correlation is observed between macrophyte flora scores and the spatial distribution of trails, but these findings are considered unreliable due to high p-values and a wide confidence interval.

Macrozoobenthos estimates show a moderate to strong correlation with trail characteristics indicative of path degradation, but display insignificant multidirectional correlations with indicators related to the spatial distribution of the trail network. The Spearman correlation coefficient reaches 0.7 for relationships between macrozoobenthos estimates and both the average maximum trail width and average cross-sectional area. In contrast, the correlation with average maximum trail depth is lower (rho = 0.5). These results are not statistically significant and the confidence interval offers limited support for drawing definitive conclusions.

Zooplankton abundance displays varying strengths of positive correlations with all trail characteristics, especially with spatial dispersion indicators. A very strong correlation (rho = 0.8) is found between zooplankton abundance and trail density. Although this finding is not entirely reliable (p = 0.2; [-0.28, 0.99]), it suggests a potential relationship. A moderately strong (rho = 0.575), but less reliable correlation is observed with average trail dispersion. Conversely, relationships between zooplankton abundance and trail degradation indicators (average trail width, average maximum depth and average cross-sectional area) are much weaker and statistically insignificant.

Zooplankton biomass demonstrates positive relationships with trail characteristics, though the strength of these correlations varies. For instance, zooplankton biomass has a very strong correlation with average maximum trail depth (rho = 0.8, p = 0.2, [-0.28, 0.99]). Despite some uncertainty, the high correlation coefficient, relatively low p-value and narrow confidence interval suggest a probable interaction. The correlation with average trail density is also strong, but less certain. Moderate correlations are found with average trail width and cross-sectional area, while the relationship with average trail dispersion is weak. Importantly, all these relationships are statistically insignificant.

The Zooplankton Biodiversity Index by Shannon-Weaver (1963) correlates more strongly with trail network distribution indicators than with those related to trail degradation. In all cases, the correlations are positive. A particularly strong relationship is found between this biodiversity index and average trail dispersion, approaching statistical significance with a narrow confidence interval (rho = 0.975, p = 0.1, [0.66, 1]). The relationship with trail density is also strong, but lacks sufficient reliability (rho = 0.6, p = 0.5, [-0.6, 0.97]). In contrast, trail degradation indicators, such as average width, maximum depth and cross-section, correlate poorly with the biodiversity index, raising concerns about the validity of these findings, based on p-values and confidence intervals.

The average dispersion of the trails exhibits a strong negative correlation with the Simpson Dominance Index (1949), though this correlation is somewhat less reliable (rho = -0.825, p = 0.2, [-0.99, 0.21]). Other parameters in the trail network model, such as mean width, mean maximum depth, mean cross-section and mean density, show weak, negative and statistically insignificant results.

The Evenness index (Pielou 1975) shows weak to moderate correlations with trail characteristics, all of which are positive. Unlike the previously discussed indices related to zooplankton community structure, the Evenness index is more strongly connected to trail degradation indicators, particularly with trail widening and average cross-section. These correlations are moderate in strength, but unreliable due to high p-values and wide confidence intervals. A notable relationship is found between the Evenness index and the average trail dispersion (rho = 0.625), although the p-value is still too high and the confidence interval remains broad. The relationships with average maximum trail depth and trail density are significantly weaker and equally uncertain.

A similar pattern emerges with the RCC trophic index and trail network parameters. These relationships are generally moderate to weak, causing some uncertainty. The trophic index shows stronger correlations with average trail width (rho = 0.625), average trail cross-section (rho = 0.625) and average trail dispersion (rho = 0.525). There is a weak to moderate relationship with average maximum trail depth (rho = 0.375), while the correlation with trail density is virtually absent (rho = -0.075).

Discussion

This study integrates a variety of data on abiotic environmental factors, the current ecological state of the Seven Rila Lakes and the condition of the tourist trails in the Lakes' catchment areas. However, the small sample size limits the ability to definitively confirm or reject the hypothesis that recreational use contributes to eutrophication in lake ecosystems. The hypothesis that trail characteristics can be used as indicators of negative recreational impacts on ecosystems also remains unconfirmed. Most results lack statistical significance, with wide confidence intervals indicating that some observed correlations may be negligible or invalid. This highlights the need for further studies with a larger sample size and broader scale to better understand the potential relationships between trail impacts and eutrophication.

Despite these limitations, the study provides valuable insights and offers several grounded assumptions for future research. The stronger correlations between indicators reflecting abiotic influences and the ecological state of the Lakes suggest that natural factors play a leading role in the eutrophication process. Conversely, the weaker correlations between ecological state indicators and recreational use indicators suggest that human recreational pressure has a secondary role in the process. Environmental factors significantly influence macrophyte flora, macrozoobenthos and various aspects of the zooplankton community structure, including the trophic status of the Lakes. These findings raise questions about the reliability of using these ecological indicators to monitor recreational impacts. In contrast, indicators related to phytoplankton and certain physical parameters of zooplankton, such as abundance and biomass, exhibit less sensitivity to natural processes and may be more suited for evaluating recreational impacts.

Special attention needs to be paid to indicators related to macrophytes. Macrophyte overgrowth has often been cited in previous studies as a primary indicator of recreationally induced eutrophication in oligotrophic high-mountain lakes (e.g. Nikolova et al. 2012, Dynowski et al. 2019). However, the weak correlations between macrophyte assessments and recreational pressure found in this study challenge the relevance of these conclusions. This suggests that other factors, possibly more directly linked to human activities, may play a more significant role in the recreation-induced eutrophication process.

Several indicators related to phytoplankton and zooplankton, such as phytoplankton biomass and zooplankton biomass, abundance and diversity, exhibit stronger correlations with recreational use indicators than with environmental factors. This is likely due to the dispersed visitor flow in the area, which has led to the proliferation of informal trails. These trails are more susceptible to erosion, which can lead to the destruction of vegetation and the exposure of soil to runoff. When this runoff enters the lakes, it carries eroded materials, mineral salts and nutrients, altering the water’s alkalinity and physico-chemical parameters, which, in turn, affects the invertebrate communities, causing a change in the trophic status of the lake.

Similar studies to this one from a methodological point of view were not found in the scientific literature, making it impossible to compare and validate the above assumptions. Nevertheless, these assumptions and findings align with previous research on the Seven Rila Lakes. Studies have shown that nutrient concentrations are influenced by soil cover in the Lakes' drainage basins (Kalchev et al. 2004) and that increasing nutrient influx over recent decades has contributed to mesotrophication (Ognjanova-Rumenova et al. 2010). Additionally, these findings support the notion that incoming salts affect water alkalinity, with invertebrate communities being highly sensitive to even minor changes in physico-chemical parameters (Ognjanova-Rumenova et al. 2006, Ognjanova-Rumenova et al. 2009). This study also supports the findings of other research on informal trails, which are more susceptible to degradation than formal trails, leading to vegetation loss and soil erosion (Leung et al. 2002, Marion et al. 2006, Wimpey and Marion 2011, Rodway-Dyer and Ellis 2018, Spernbauer et al. 2023).

The study highlights the importance of a balanced approach to analysing complex issues such as eutrophication and, more specifically, eutrophication caused by recreation and tourism. While existing literature and planning documents provide valuable perspectives, some conclusions may focus predominantly on specific aspects, potentially overlooking broader or underlying factors. By identifying these gaps, this study contributes to ongoing discussions and provides opportunities for more comprehensive and evidence-based analyses.

Based on the results obtained, several key management recommendations can be drawn:

- Regular monitoring of both the ecological state of the Lakes and the condition of the hiking trails at least once every five years;
- Daily monitoring of visitor numbers and behaviour;
- Reduction of the trail network to a minimum;
- Implementation of technical measures to minimise trail erosion in sections with intensive incision;
- Introduction of measures to limit the diffusion of visitor flow and regulate the number of visitors if necessary;
- Providing visitors with pre-visit information regarding potential negative impacts and clearly outlining rules of conduct;
- Development of an ecotourism product that highlights the natural heritage values of the Seven Rila Lakes.

Despite its limitations, this study provides a relevant conceptual and methodological foundation for future research, which will undoubtedly need refinement and improvement. For instance, including data on erosion in the Lake area can enhance the methodological framework. Additionally, incorporating other trail characteristics such as trail usage level, trail slope alignment and trail grade (Marion and Wimpey 2017) etc., would improve the robustness of the analysis.

This study primarily focuses on trail-based recreational activities and does not consider other factors such as the formation of tent camps or the presence of accommodation facilities in the area, which are linked to longer visitor stays and may contribute to specific ecological impacts affecting lake ecosystems. Furthermore, other anthropogenic activities, such as livestock grazing or artificial stocking of the Lakes, were not addressed, but could likely affect eutrophication and warrant further investigation.

Lastly, although the study mainly focuses on the negative perspective of recreational activities, it is important to consider the positive contribution that such activities could have for the natural heritige status of the Seven Rila Lakes. Developing an ecotourism or geotourism product, based on the concept of ecosystem services, could be one such avenue, as there is already a conceptual model developed for this purpose (Nedkov et al. 2021).

Given the challenges of assessing anthropogenic impacts on natural ecosystems, this research demonstrates that trail characteristics can serve as effective indicators for monitoring recreational pressure on mountain lake-based tourist destinations. It emphasises the need for regular monitoring of both the condition of tourist trails and the ecological state of the Lakes in the Seven Rila Lakes area, alongside measures to manage visitor flows and minimise their environmental impact.

Conclusion

In conclusion, this study represents the first targeted attempt to explain the mechanism by which recreation negatively impacts the water ecosystems of the Seven Rila Lakes. By implementing the recreation-ecological approach, the study emphasises the need for a comprehensive approach to analysing recreation-induced eutrophication.

Although this study lacks definitive conclusiveness, it corroborates concerns regarding eutrophication processes induced by recreational activities in the Seven Rila Lakes. While natural factors play a leading role, recreational pressure has a secondary impact. The primary issue identified is the uncontrolled diffusion of visitor flow, which generates numerous informal paths and increases spatial tourism pressure on the catchment areas of the Lakes, leading to adverse changes in phytoplankton and zooplankton communities.

The study provides a basis for future research and calls for regular monitoring of both the ecological state of the Lakes and the condition of the trails, along with visitor management to preserve the Seven Rila Lakes' natural heritage.

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Conflicts of interest

The authors have declared that no competing interests exist.

References

- Assenov A, Vladimirov V, Dimitrov P (2015) Biological diversity of Rila National Park. Rila National Park Directorate, 53 pp. [In Bulgarian]. URL: https://www.uni-sofia.bg/index.php/bul/universitet_t/fakulteti/geologo_geografski_fakultet/oficialni_izdaniya [ISBN 978-619-90533-3-1]
- Baltakov G (1984) Dzherman valley during the Late Galcial. Problems of Geography 3: 47-51. [In Bulgarian].
- Baltakov G, Mladenova V (1989) Some typical lateglacial geomorphic phenomena in the Rila mountain. Geographica Rhodopica 1: 191-193.
- Baltakov G (2004) Glacial morphogenesis in the high mountain belt of Bulgaria, associated with dome-type glaciers. *Problems of Geography* 1-2: 71-79. [In Bulgarian].
- Beshkova M (2000) The phytoplankton of the glacial high mountain lakes Sedemte Rilski Ezera (the Rila Mountains, Bulgaria). In: Golemansky V, Naidenow W (Eds) Biodiversity and evolution of glacial water ecosystems in the Rila Mountains. "Prof. Marin Drinov" Academic Publishing House, Sofia, 167 pp. [In English]. [ISBN 9549062317].
- Bigler C, Von Guten L, Lotter AF, Hausmann S, Blass A, Ohlendorf C, Sturm M (2007) Quantifying human-induced eutrophication in Swiss mountain lakes since AD 1800 using diatoms. Holocene 17: 1141,. [In English]. https://doi.org/10.1177/0959683607082555
- Boteva S, Traykov I, Kenarova A, Bogoev V (2008) Evaluation of phosphorus impact on phytoplankton dynamics in Seven Rila lakes: Rila National Park. 15 (52): 3-8. [In English]. URL: https://www.researchgate.net/publication/277311213_Evaluation_of_phosphorus_impact_on_phytoplankton_dynamics_in_Seven_Rila_Lakes_Rila_National_Park
- Botev I (2000) Chemical Composition and its Vertical Distribution in Seven Glacial High Altitude Lakes in the Rila Mountains (Southwatern Bulgaria). In: Golemansky V, Naidenow W (Eds) Biodiversity and evolution of glacial water ecosystems in the Rila Mountains. "Prof. Marin Drinov" AcademicPublishing House, Sofia, 89-103 pp.
- Cole D (2004) Environmental impacts of outdoor recreation in wildlands. In: Manfredo M, Vaske J, Field D, Brown P, Bruyere B (Eds) Society and resource management: A summary of knowledge. MO: Modern Lithograph, Jefferson City, 107-116 pp. [In English].
- Council of Europe (1994) Convention on the conservation of European wildlife and natural habitats (Bern Convention). *European Treaty Series* 104 URL: http://conventions.coe.int/Treaty/en/Treaties/Html/104.htm
- Council of Ministers (2015) Project for the updated management plan of Rila NP (2015–2024). https://www.strategy.bg/PublicConsultations/View.aspx?%40lang=bg-BG&Id=1801 Accessed on: 2024-4-18.

- Dimitrova E (1960) Petrology of the crystalline basement in northwestern Rila. Proceedings on geology of Bulgaria, series on geochemistry and mineral resources 1: 199-257. [In Bulgarian].
- Dimitrov P, Velchev A (2012) Formation and development of stone glaciers as a morphological form in the alpine belt of Rila. Annual of Sofia University, Faculty of Geology and Geography, Book-2 Geography 103: 97-112. [In Bulgarian]. URL: https://www.uni-sofia.bg/index.php/bul/universitet_t/fakulteti/geologo_geografski_fakultet/oficialni_izdaniya
- Dimov D, Damyanova K (1996) Synmetamorphic tectonic units in Northwestern Rila. Journal of Bulgarian Geology Society 57 (2): 25-30. [In Bulgarian].
- Dokulil MT (2014) Environmental impacts of tourism on lakes. Eutrophication: Causes, Consequences and Control 2: 81-88. [In English]. URL: https://www.uibk.ac.at/limno/files/pdf/tourism-impacts-in-ansari-vol-2.pdf
- Dynowski P, Senetra A, Źróbek-Sokolnik A, Kozłowski J (2019) The impact of recreational activities on aquatic vegetation in alpine lakes. *Water* 11 (1): 173. [In English]. https://doi.org/10.3390/w11010173
- Ermolaev V, Arnaudova R, Dimitrova E (1977) Structure and development of the crystalline basement of Rila. Geologica Balkanica 7 (3): 87-103. [In Russian].
- European Commitee for Standardisation (2006) EN 15110:2006 Water quality - Guidance standard for the sampling of zooplankton from standing waters. CEN[In English]. URL: https://standards.iteh.ai/catalog/standards/cen/64a884f1-11e1-471a-934e-a7fadfee66a3/en-15110-2006
- European Economic Community (1992) Directive 92/43/EEC of 21 May 1992 on the Conservation of Natural Habitats and of Wild Fauna and Flora. Official Journal of the European Communities L 206: 22 07 1992 0007-0050.
- European Parlament (2000) Directive 2000/60/EC establishing a framework for Community action in the field of water policy. *OJ L 327*[In English]. URL: https://eur-lex.europa.eu/eli/dir/2000/60/oj
- European Parlament (2009) Directive 2009/147/EC on the conservation of wild birds. *OJ L 020*: 7. [In English]. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02009L0147-20190626
- Executive Environment Agency (2023) https://gwms.eea.government.bg/giswmr/
- Gachev E (2011) Researches of field evidence for Late Quaternary climate changes in the highest mountains of Bulgaria. In: Zhelezov G (Ed.) Sustainable Development in Mountain Regions in the South Eastern Europe. Springer, Dordrecht. [ISBN 978-94-007-0131-1]. https://doi.org/10.1007/978-94-007-0131-1_12
- Gikov A, Dimitrov P (2010) Identification and mapping of relict stone glaciers on the Rila Mountains using aerospace imagery. In: Mardirossian G, Kraleva L, Srebrova T, Jelev G (Eds) Proceedings of Sixth Scientific Conference with International Participation “SPACE, ECOLOGY, SAFETY”. Sofia [In Bulgarian]. URL: http://space.bas.bg/SES/archive/SES%202010_DOKLADI/PROCEEDINGS%20SES%202010.pdf
- Gikov A (2019) Mapping and analysis of contemporary landscapes in the Rila Mountains using GIS and remote sensing methods. Abstract, BAS, ICIT, Section "Remote Sensing and GIS", Sofia. [In Bulgarian]. URL: http://space.bas.bg/bg/contests_and_procedures/konkursi/A.%20Gikov/05_AG_Avtoreferat.pdf

- Hadwen WL, Arthington AH, Mosisch TD (2003) The impact of tourism on dune lakes on Fraser Island, Australia. Lakes & Reservoirs: Research & Management 8 (1): 15-26. [In English]. https://doi.org/10.1046/j.1440-1770.2003.00205.x
- Hadwen WL, Arthington AH (2011) Visitor impacts and climatic variability will shape the future ecology of Fraser Island's perched dune lakes. Proceedings of the Royal Society of Queensland 117: 485-493. [In English]. https://doi.org/10.5962/p.357773
- Ilieva G, Stanachkova M, Kozuharov D (2016) Biodiversity of zooplankton in Rila Mountain glacial lakes in Natura 2000 zones - BG 000495 AND BG 000496. Annual of Sofia University - Faculty of Biology 101, livre 4: 94-100. [In English]. URL: https://www.uni-sofia.bg/index.php/bul/universitet_t/fakulteti/biologicheski_fakultet2/oficialni_izdaniya/godishnik_na_sofijskiya_universitet_kniga_4_nauchni_sesii_na_biologicheskiya_fakultet/tom_101_2016_g_mladezhka_nauchna_konferenciya_klimentovi_dni_2015_g
- Ivanov I (1954) Geomorphological studies in the western part of Northwestern Rila. Announcements of the Geographical Institute of the Bulgarian Academy of Sciences 7: 7-85. [In Bulgarian].
- Ivanov P (2011) Oligotrophic Mountain Lakes. In: V. Biserkov, Gusev C (Eds) Red Data Book of the Republic of Bulgaria. electronic, 3. Bulgarian Academy of Sciences and the Ministry of Environment and Water, Sofia. [In Bulgarian]. URL: http://e-ecodb.bas.bg/rdb/bg/vol3/01C1.html
- Kalchev R, Botev I, Hristozova M, Raikova-Petrova G, Stoyneva M, Temniskova-Topalova D, Trichkova T (2004) Ecological relations and temporal changes in the pelagial of the high mountain lakes in the Rila Mountains (Bulgaria. Journal of Limnology 63 (1): 90-100. [In English]. https://doi.org/10.4081/jlimnol.2004.90
- Kamenov B, Zhelyazkova-Panayotova M, Iliev Z, Bonev I, Petrusenko S, Sirakov D (1979) Metamorphic and igneous rocks from the Malyovyshki range of Rila and their associated ore deposits. Annual of Sofia University, Faculty of Geology and Geography, Book 1 - Geology 71: 179-219. [In Bulgarian].
- Konteva M, Penin R, Tododrov N (2001) Subalpine and alpine landscapes in Dzherman river basin. Annual of Sofia University, Faculty of Geology and Geography, Book 2 - Geography 91: 129-147. [In Bulgarian].
- Kuhlemann J, Gachev E, Gikov A, Nedkov S, Krumrei I, Kubik P (2013) Glaciation in the Rila Mountains (Bulgaria) during the last glacial maximum. Quaternary International 293: 51-62. [In English]. https://doi.org/10.1016/j.quaint.2012.06.027
- Leung Y, Marion J (1996) Trail Degradation as Influenced by Environmental Factors: A State-of-Knowledge Review. *Journal of Soil and Water Conservation* 51: 2,130-136. [In English]. URL: https://www.researchgate.net/publication/260146431_Trail_degradation_as_influenced_by_environmental_factors_A_state-of-knowledge_review
- Leung YF, Marion J (2000) Recreational impacts and management in protected areas. In: Cole D, McCool S, Borrie W, O'Loughlin J (Eds) Wilderness science in a time of change conference – Volume 5: Wilderness Ecosystems, Threats, and Management. Missoula, May 23-27, 1999. UT: USDA Forest Service, Rocky Mountain Research Station, 23-48 pp. [In English].
- Leung YF, Shaw N, Johnson K, Duhaime R (2002) More than a database: Integrating GIS data with the Boston Harbor Islands visitor carrying capacity study. The George Wright Forum, 19, 1. George Wright Society, 69-78 pp. [In English]. URL: https://www.jstor.org/stable/43597789?seq=1

- Liddle MJ (1997) Recreation Ecology: The Ecological Impact of Outdoor Recreation and Ecotourism. Chapman and Hal, London. [In English].
- Management Plan of Rila National Park 2001-2010 (2001) Adopted by Decision No 522 of the Council of Ministers of 04.07.2001. Ministry of Environment and Water [In Bulgarian].
- Marinova R (1991) Geology Map of Bulgaria, Scale 1:100,000, Blagoevgrad. Geophysical Survey and Geological Mapping Company, Blagoevgrad. [In Bulgarian].
- Marinova R (1993) Explanatory note to the geological map of Bulgaria. Scale 1:100,000, Blagoevgrad. KGMR, Geol. and geophysics AD [In Bulgarian].
- Marion J, Leung Y (2001) Trail resource impacts and an examination of alternative assessment techniques. *Journal of Park and Recreation Administration* Fall,19 3: 17-37. [In English]. URL: https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5346573.pdf
- Marion J, Leung Y, Nepal S (2006) Monitoring trail conditions: new methodologicalconsiderations. The George Wright Forum 23 (2): 36-49. [In English]. URL: https://www.jstor.org/stable/43598937
- Marion J, Leung Y, Eagleston H, Burroughs K (2016) A review and synthesis of recreation ecology - research findings on visitor impacts to wilderness and protected natural areas. Journal of Forestry 114, 3: 352-362. [In English]. https://doi.org/10.5849/jof.15-498
- Marion J, Wimpey J (2017) Assessing the influence of sustainable trail design and maintenance on soil loss. Journal of Environmental Management 189: 46-57. [In English]. https://doi.org/10.1016/j.jenvman.2016.11.074
- Marion JL (2023) Trail sustainability: A state-of-knowledge review of trail impacts, influential factors, sustainability ratings, and planning and management guidance. *Journal of Environmental Management* 340: 117868. [In English]. https://doi.org/10.1016/j.jenvman.2023.117868
- Mileva S, Assenova M, Marinov V, Mitova R, Petkova E, Grigorov B, Petrov E, Todorov L (2024) Development of a comprehensive indicator system for monitoring sustainable tourism in forestry-based environments. Green Deal initiatives, sustainable management, market demands, and new production perspectives in the forestry-based sector. Proceedings of the 17th International Scientific Conference WoodEMA 2024, Sofia, 15-17 May 2024. International Association for Economics and Managementin Wood Processing and Furniture Manufacturing, 269-274 pp. [In English]. URL: https://www.researchgate.net/publication/381338934_Development_of_a_Comprehensive_Indicator_System_for_Monitoring_Sustainable_Tourism_in_Forestry-Based_Environments#fullTextFileContent [ISBN 978-953-8446-02-3].
- Miller A, Blahna D, Morse W, Leung YF, Rowland M (2022) From recreation ecology to a recreation ecosystem: A framework accounting for social-ecological systems. Journal of Outdoor Recreation and Tourism 38: 100455. [In English]. https://doi.org/10.1016/j.jort.2021.100455
- Ministry of Agriculture and Food (2013) Digital Orthophoto Map of Bulgaria. URL: https://www.mzh.government.bg/bg/politiki-i-programi/programi-za-finansirane/direktni-plashaniya/cifrova-ortofotokarta/
- Ministry of Environment and Water (2012) Regulation N-4 for characterizing surface waters. SG 22[In Bulgarian]. URL: https://lex.bg/laws/ldoc/2135841270
- Mitova R (2020) Spatial Analysis and Evaluation of Trails and Campsites Impacts in the Area of the Seven Rila Lakes Cirque, Rila NP. Annual of Sofia University, Faculty of Geology and Geography, Book 2 – Geography (11)461-485. [In Bulgarian]. URL: https://

www.uni-sofia.bg/index.php/bul/universitet_t/fakulteti/geologo_geografski_fakultet/oficialni_izdaniya/kniga_2_geografiya_tom_113

- Mitova R (2021) Trail erosion in the Area of the Seven Rila Lakes Cirque, Rila National Park, Bulgaria. *Review of the Bulgarian Geological Society* 82 (3): 256-258. [In Bulgarian]. https://doi.org/10.52215/rev.bgs.2021.82.3.256
- Mitova R (2022) Resistence of soils to trail erosion in the area of the Seven Rila Lakes Cirque. In: NP Rila Directorate (Ed.) 30 Years of Rila National Park – A Challenge for Future Generations. Anniversary scientific conference on the occasion of 30 years since the establishment of Rila National Park, Blagoevgrad, 3 June 2022. NP Rila [In Bulgarian]. https://doi.org/10.52215/rev.bgs.2021.82.3.256
- Monz C, Cole D, Leung YF, Marion J (2010) Sustaining visitor use in protected areas: future opportunities in recreation ecology research based on the USA experience. Environmental management 45: 551-562. [In English]. https://doi.org/10.1007/s00267-009-9406-5
- Morse W (2020) Recreation as a social-ecological complex adaptive system. Sustainability 12 (3): 753. [In English]. https://doi.org/10.3390/su12030753
- Naidenow W, Beshkova M (2000) Quantitative development and vertical distribution of plankton in Sedemte Ezera Lakes (the Rila Mountains, Bulgaria). In: Golemansky V, Naidenow W (Eds) Biodiversity and evolution of glacial water ecosystems in the Rila Mountains. Prof. Marin Drinov” Academic Publishing House, Sofia, 167 pp. [In English]. [ISBN 9549062317].
- National Institute of Meteorology and Hydrology (1964) Proceedings of the Institute of Meteorology and Hydrology: Lakes in Bulgaria. 16. State Publishing House "Science and Art", Sofia. [In Bulgarian].
- Nedkov S, Gikov A, Nikolova M, Dimitrov P, Gachev E (2014) Mapping of ecosystem services supply in mountain areas: a case study of Seven Rila Lakes, Bulgaria. In: Bandrova T, Konechny M (Eds) 5th International conference on Cartography and GIS. Riviera, Bulgaria, June 15-20 2014. [In English]. URL: https://www.researchgate.net/publication/269094239_Mapping_Ecosystem_Services_Supply_in_Mountain_Areas_a_Case_Study_of_Seven_Rila_Lakes_Bulgaria
- Nedkov S, Borisova B, Nikolova M, Zhiyanski M, Dimitrov S, Mitova R, Koulov B, Hristova D, Prodanova H, Semerdzhieva L, Dodev Y, Ihtimanski I, Stoyanova V (2021) A methodological framework for mapping and assessment of ecosystem services provided by the natural heritage in Bulgaria. Journal of the Bulgarian Geographical Society 45: 7-18. [In English]. https://doi.org/10.3897/jbgs.e78680
- Nikolova M, Zhelezov G, Nedkov S, Nozharov P, Krumova Y, Nikolov V, Gikov A, E. G (2012) Changes in the environment and the contemporary state of the protected area "Seven Rila Lakes". In: Mardirossian G, Srebrova T, Jelev G (Eds) Proceedings of the Eighth Scientific Conference with International Participation "SPACE, ECOLOGY, SAFETY". Eighth Scientific Conference with International Participation "SPACE, ECOLOGY, SAFETY", Sofia, 4-6 December 2012. [In Bulgarian]. URL: http://www.spacesolar. bas.bg/SES/archive/SES%202012_DOKLADI/4_Ecology%20and%20Risk%20Management/2_Nikolova.pdf
- Nikolova M (2014) Assessment of high mountain lakes vulnerability to climate change: a case study from Seven Rila Lakes, Bulgaria. In: Frigerio S, et al. (Ed.) Proceedings of the International Conference "Analysis and Management of Changing Risks for Natural Hazards". International Conference "Analysis and Management of Changing Risks for

Natural Hazards", Padua, Italy, 18-19 November 2014. [In English]. URL: https://www.researchgate.net/publication/269093509_Assessment_of_High_Mountain_Lakes_Vulnerability_to_Climate_Change_A_case_Study_from_Seven_Rila_Lakes_Bulgaria

- Nikolova M, Nojarov P, Nedkov S (2021) National natural heritage at risk: the Seven Rila Lakes. Journal of the Bulgarian Geographical Society 45: 67-80. [In English]. https://doi.org/10.3897/jbgs.e78709
- Nojarov P (2013) Modeling of climate changes in Rila and their impact on Seven Rila Lakes. In: Mardirossian G, Srebrova T, Jelev G (Eds) Proceedings of the Eighth Scientific Conference "Space, Ecology, Safety (SES)" 2. Sofia, 4 – 6 December 2012. [In Bulgarian]. URL: http://space.bas.bg/SES/archive/SES%202012_DOKLADI/PROCEEDINGS%20SES%202012.pdf
- Ognjanova-Rumenova N, Vidinova Y, Botev I (2006) Abundance and species composition of diatoms and invertebrates in relation to chemical and physical factors in high mountain lakes, cirque “Sedemte ezera”, Rila Mts., Bulgaria. Phytologia Balcanica 12 (1): 25-36. [In English]. URL: https://www.researchgate.net/publication/251513608_Abundance_and_species_composition_of_diatoms_and_inver- tebrates_in_the_Sedemte_Ezera_Cirque_Rila_Mts_Southwest_Bulgaria#fullTextFileContent
- Ognjanova-Rumenova N, Botev I, Kernan M (2009) Benthic diatom flora in relation to chemical and physical factors in high mountain lakes in the Rila Mountains (Southwestern Bulgaria). Advances in Limnology 62: 153-166. [In English]. https://doi.org/10.1127/advlim/62/2009/153
- Ognjanova-Rumenova N, Botev I, Velle G, Brancelj A (2010) Environmental changes in the Rila Mountains, Southwestern Bulgaria, as recorded by the sediments of a remote lake. In: Catalan J, Curtis C, Kernan M (Eds) Patterns and factors of biota distribution in remote European lakes. Schweizerbart Science Publishers [In English]. URL: https://www.researchgate.net/publication/259145089_Environmental_changes_in_the_Rila_Mountains_South_-_western_Bulgaria_as_recorded_by_the_sediments_of_a_remote_lake [ISBN 978-3-510-47064-8].
- Ognjanova-Rumenova NG, Botev IS, Vidinova YN (2011) Using sediment diatom assemblages in the assessment of environmental changes in high-altitude lakes, Rila Mts, Bulgaria. Phytologia Balcanica 17 (2): 165-172. [In English]. URL: http://www.bio.bas.bg/~phytolbalcan/PDF/17_2/17_2_03_Ognjanova_&_al.pdf
- Rodway-Dyer S, Ellis N (2018) Combining remote sensing and on-site monitoring methods to investigate footpath erosion within a popular recreational heathland environment. Journal of environmental management 215: 68-78. [In English]. https://doi.org/10.1016/j.jenvman.2018.03.030
- Sarov S (2009) Lithotectonic division of the metamorphic rocks of Western and Northwestern Rila. National Conference of the Bulgarian Geological Society,89-90. [In Bulgarian].
- Sarov S, Moskovski S, Zhelezarski T, Voynova E, Nikolov D, Georgieva I, Markov N, Kolcheva K, Ivanov D (2011) The explanatory note to the Geological Map of Bulgaria at Scale 1:50,000. Map sheet K-34-71-B (Sapareva Banya). Geomarine Center
- Senetra A, Dynowski P, Cieślak I, Źróbek-Sokolnik A (2020) An evaluation of the impact of hiking tourism on the ecological status of alpine lakes-a case study of the valley of dolina Pięciu Stawów polskich in the Tatra Mountains. *Sustainability* 12 (7): 2963. [In English]. https://doi.org/10.3390/su12072963

- Sienkiewicz E, Gąsiorowski M (2014) Changes in the Trophic Status of Three Mountain Lakes--Natural or Anthropogenic Process? Polish Journal of Environmental Studies 23 (3). [In English]. URL: https://www.pjoes.com/Changes-in-the-Trophic-Status-of-Three-Mountain-r-nLakes-Natural-or-Anthropogenic,89259,0,2.html
- Sinnyovsky D (2014) Geodiversity of Rila Mountain, Bulgaria. In: Beqiraj A, Ionescu C, Christofides G, Uta A, Beqiraj Goga E, Marku S (Eds) Proceedings of the XX Congress of the Carpathian - Balkan Geological Association, Special Issue Volume 1. XX Congress of the Carpathian - Balkan Geological Association, Tirana, Albania, 24-26 September 2014. [In English]. [ISBN 0254-5276].
- Sinnyovsky D (2015) Wurm glacier formations and mountain landscapes in Rila Mountain, Bulgaria. In: Antonietti A, et al. (Ed.) Science and Technologies in Geology, Exploration and Mining Conference Proceedings, 1. XV International Multidisciplinary Scientific Geoconference SGEM, Albena, Bulgaria, 18-24 June 2015. [In English]. URL: https://www.researchgate.net/publication/304262024_WURM_GLACIER_FORMATIONS_AND_MOUNTAIN_LANDSCAPES_IN_RILA_MOUNTAIN_BULGARIA#fullTextFileContent
- Smeets E, Weterings R (1999) Environmental indicators: Typology and overview. EEA. URL: https://www.eea.europa.eu/publications/TEC25
- Spernbauer B, Monz C, D'Antonio A, Smith J (2023) Factors influencing informal trail conditions: Implications for management and research in Urban-Proximate parks and protected areas. Landscape and Urban Planning 231: 104661. [In English]. https://doi.org/10.1016/j.landurbplan.2022.104661
- Toro M, Granados I (2002) Restoration of a Small High Mountain Lake after Recent Tourist Impact: The Importance of Limnological Monitoring and Palaeolimnology. Water, Air, & Soil Pollution: Focus 2: 295-310. [In English]. https://doi.org/10.1023/A:1020127313830
- Toro M, Granados I, Robles S, Montes C (2006) High mountain lakes of the Central Range (Iberian Peninsula): Regional limnology & environmental changes. Limnetica 25: 217. [In English]. https://doi.org/10.23818/limn.25.17
- Tsvetkova I, Sinnyovsky D (2015) Rock diversity and glacial forms in the area of the geotope of the Seven Rila Lakes. Annual of University of Mining and Geology “St. Ivan Rilski” – Sofia 58 (Part I - Geology and Geophysics): 26-31. [In Bulgarian]. URL: https://mgu.bg/wp-content//uploads/2022/02/Vol.-58-I-2015.pdf
- United Nations (1992) Convention on Biological Diversity. United Nations Treaty Series 1760: 79.
- Valkanov A (1932) Rila and Pirin Lakes. Fishery review journal 7 (2): 22-24. [In Bulgarian].
- Valkanov A (1938) Hydrobiological studies on some Rila lakes. Annual of Sofia University, Faculty of Physics and Mathematics 34: 101-145. [In Bulgarian].
- Vasilev A, Hristova N (2022) Hydrographic description of the lakes in Northwestern Rila. Annual of Sofia University, Faculty of Geology and Geography, Book 2 - Geography 114: 87-105. [In Bulgarian]. URL: https://www.uni-sofia.bg/index.php/bul/universitet_t/fakulteti/geologo_geografski_fakultet/oficialni_izdaniya/kniga_2_geografiya_tom_114
- Velchev A, Penin R, Konteva M, Todorov N (2003) Formation of the contemporary structure of the cold humid landscapes in the Dzherman river basin. Annual of Sofia University, Faculty of Geology and Geography, Book 2 - Geography 93: 55-70. [In Bulgarian].

- Velchev A, Tonkov S, Bozhilova E (2011) Paleogeomorphological and paleoecological development of Northwestern Rila during the Pleistocene and Holocene. Problems of Geography 3-4: 35-49. [In Bulgarian]. URL: https://geoproblems.eu/bg/2011-%D0%B1%D1%80%D0%BE%D0%B9-3-4/
- Vodenicharov D (1960) Hydrobotanical situations on high mountain lakes in Bulgaria. Announcements of the Botanical Institute of the Bulgarian Academy of Sciences 7: 279-291. [In Bulgarian].
- Vylkov V, Antonova N, Doncheva K (1989) Granitoids of the Rila-Western Rhodope batholith. *Geologica Balkanica* 19 (2): 21-54. [In Russian].
- Wimpey J, Marion J (2011) A spatial exploration of informal trail networks within Great Falls Park, VA. *Journal of Environmental Management* 92 (3): 1012-1022. [In English]. https://doi.org/10.1016/j.jenvman.2010.11.015
- Zafirov B (2021) What is happening in the area of the Seven Lakes in Rila - how climate change and changing conditions make the lakes vulnerable? climateka.bg. [in Bulgarian]. URL: . https://www.climateka.bg/sedemte-ezera-v-rila-vliyanieto-na-klimatichnite-promeni/
- Zhelyazkova-Panayotova M, Iliev Z, Petrusenko S (1972a) New data on the geology of the Seven Rila Lakes region. Journal of Bulgarian Geological Society 33 (2): 133-176. [In Bulgarian].
- Zhelyazkova-Panayotova M, Petrusenko S, Iliev Z (1972b) Mineralogy of rare metal skarns from the Seven Rila Lakes. Annual of Sofia University, Faculty of Geology and Geography, Book 1- Geology 64: 147-176. [In Bulgarian].