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The Waterfalls of Belasica: An Integrated Study of Geomorphology, Hydrology, Ecology, and Tourism

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Abstract

The Belasica mountain range, located in southeastern North Macedonia, exhibits significant geomorphological and hydrological diversity, with waterfalls as prominent natural features. This study examines the geomorphology, hydrology, ecological value, and sustainable tourism potential of the Smolare, Koleshino, Gabrovo, Djavolski, Kochulski, and Prstenski waterfalls. Field measurements, hydrometric data, GIS mapping, and ecological surveys were integrated to evaluate physical characteristics, seasonal flow variability, and anthropogenic impacts. Findings reveal that tectonic structures, lithological resistance, and erosive processes shape waterfall morphology, while surrounding mixed forests enhance biodiversity and visitor experience. Visitor surveys (n=100) indicate high satisfaction, particularly for natural beauty and hiking opportunities. Recommendations for sustainable tourism development, including trail maintenance, educational activities, and infrastructure improvement, are proposed to ensure conservation and promote geo-tourism. These findings underscore Belasica's potential as a geoheritage site contributing to ecological, educational, and socio-economic benefits.

Keywords: Belasica, waterfalls, geomorphology, hydrology, ecology, geotourism, sustainable development

Introduction

Belasica Mountain, spanning North Macedonia, Greece, and Bulgaria, is one of the most geomorphologically and hydrologically diverse regions in the Balkan Peninsula (Durgutović et al. 2019). Its geological composition, combined with tectonic activity and abundant precipitation, has led to the formation of numerous waterfalls with scientific, aesthetic, and touristic significance (Aleksova 2025). These waterfalls serve as indicators of geological evolution, hydrological processes, and climate variability.

This study aims to:

1. Analyze the geomorphological and hydrological characteristics of Belasica waterfalls.
2. Assess their ecological and tourism value.
3. Provide recommendations for sustainable development within the regional eco-tourism framework.
4.

2. Geographic Setting

Belasica extends approximately 60 km west-east, with its highest peak, Tumba (1881 m), at the tri-border point of North Macedonia, Greece, and Bulgaria. The mountain slopes toward the Strumica Valley, forming a dense network of short, dynamic streams, including the Lomnica, Smolare, and Bashiboska rivers, which

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have carved steep ravines and gorges leading to prominent waterfalls (Iliev et al. 2015).

The climate is predominantly moderate-continental with Mediterranean influences, yielding high annual rainfall (up to 1200 mm) and seasonal variability in streamflow. Bedrock consists primarily of metamorphic schists, gneisses, and quartzites, interspersed with tectonic fractures facilitating vertical water flow (MZSPP 2018).

Methodology

1 Field Research

- Photographic documentation of slopes, riverbeds, and surrounding landscapes.
- Measurement of waterfall height using digital altimeters and laser devices (accuracy ±0.1 m).
- GPS-based recording of precise geographic coordinates.
- Assessment of trail infrastructure, accessibility, and anthropogenic impact.

2 Comparative Analysis

Field data were compared with existing literature and indexed journals, including UNWTO reports on sustainable tourism and regional geographical studies (Petrovska 2015; Dimitrov 2012).

3 Geo-Hydrological Analysis

- Assessment of waterfall watercourses, heights, flow, and seasonal variability.
- Evaluation of tectonic and erosive processes and plunge pool characteristics.
- GIS-based cartographic documentation.

4 Ecological Assessment

- Identification of dominant tree species and protected flora.
- Assessment of trail infrastructure and ecological conditions.
- Recommendations for conservation and sustainable management.

5 Data Synthesis

- Compilation into comparative tables and diagrams for waterfall height, width, flow, and tourism indicators.
- Maps indicating waterfall locations, access trails, and infrastructure.

Belasica is a mountain that stretches along the borders of North Macedonia, Greece, and Bulgaria. With its steep slopes descending into the valleys of the Vardar and Struma rivers and the surrounding basins, the mountain represents an important geomorphological feature. The waterfalls within its terrain have formed as a result of tectonic processes, river erosion, and the geological structure of the mountain (Aleksova 2025; Vasilevski 1999). They are significant not only as natural attractions but also as indicators of ecosystem health.

Geomorphological and Hydrological Characteristics

Waterfalls are stunning natural features … that not only provide visual beauty, but also play a crucial role in the balance of the ecosystem and the well-being of society (Ramón & Caballero, 2022, 588 polodelconocimiento.com).

The Belasica waterfalls predominantly exhibit **tectonic structures**, with well-defined faults and associated erosional forms (MZSPP 2018). Morphology is shaped by tectonic fractures, lithological resistance, and fluvial processes, resulting in vertical drops, plunge pools, and cascade series.

Waterfall	Altitude (m a.s.l.)	Height (m)	Pool Dimensions (L/W/D m)	Type	Avg Flow (m^3/s)	Geological Formation
Smolare	600	39.5	5 / 11 / 0.7	Tectonic	0.35	Gneiss–schist
Koleshino	610	19	4 / 6 / 0.5	Tectonic	0.28	Schist–quartzite
Gabrovo	580–600	5–10	3 / 5 / 0.4	Erosional	0.14	Schist
Djavolski	570	10	2 / 3 / 0.5	Structural	0.16	Quartzite
Kochulski	650–700	2–8	2 / 3 / 0.3	Mixed	0.22	Metamorphic rocks
Prstenski	660	3–5	1.5 / 2 / 0.2	Erosional	0.18	Schist–gneiss

Table 1. Distribution of Waterfall Heights and Average Flow (illustrative)

5. Ecological and Tourism Analysis

Waterfalls are located in mixed deciduous forests dominated by beech (Fagus sylvatica), oak (Quercus spp.), and maple (Acer spp.), supporting endemic species and wetland ecosystems (Markov 2016; Durgutović et al. 2019).

Established trails, observation platforms, and minimal-impact infrastructure facilitate recreational and educational activities.

Criterion	Weight	Smolare	Koleshino	Gabrovo	Djavolski	Kochulski	Prstenski
Accessibility	0.20	5	5	3	2	2	1
Aesthetic value	0.20	5	4	4	4	4	3
Ecological integrity	0.20	5	4	5	5	5	5
Scientific importance	0.15	4	4	4	4	5	5

Criterion	Weight	Smolare	Koleshino	Gabrovo	Djavolski	Kochulski	Prstenski
Recreational potential	0.15	5	4	3	3	3	3
Cultural relevance	0.10	3	4	3	4	2	2
Total Index	1.00	4.6	4.3	3.8	3.7	3.5	3.2

Table 2. Tourism Valorization Indicators

6. Visitor Survey Results

Surveyed 100 respondents to evaluate visitor demographics, motivations, and satisfaction.

Gender	Number	%			
Male	48	48			
Female	52	52	**Age Group**	**Number**	**%**
			<18	5	5
			18–30	40	40
			31–45	30	30
			46–60	20	20
			60+	5	5

Table 3. Visitor Demographics

Visit Frequency: First visit 35%, 2–3 times 40%, 4–5 times 15%, >5 times 10%.
Visit Companions: Alone 15%, Friends 50%, Family 25%, Tourist group 10%.
Motivations: Natural beauty 80%, Photography/social media 60%, Hiking/sports 50%, Relaxation 40%, Education/scientific 20%.
Satisfaction: 87% satisfied or very satisfied, 90% would recommend.

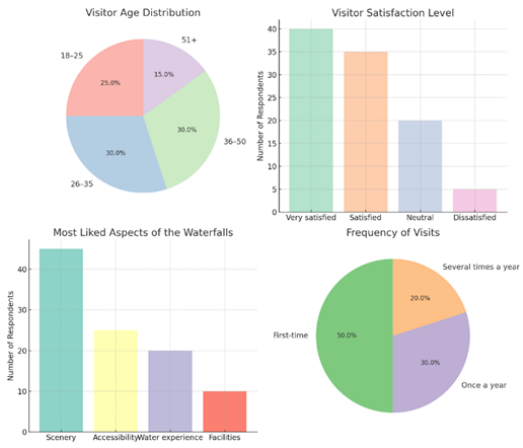

Chart 1. Results of the research

Discussion

Visitor satisfaction is influenced by natural aesthetics, trail accessibility, and infrastructure. Young and middle-aged adults dominate the visitor profile.

Infrastructure improvements, educational activities, and interpretive signage are recommended to enhance engagement, repeat visits, and sustainable tourism development. Belasica waterfalls provide ecosystem services, recreational opportunities, and educational value (Gimel Falls 2017).

Recommendations for Improvement

Priority	**Area**	**Recommendation**	**Expected Effect**
High	Infrastructure	Improve trails, rest areas, signage	Enhanced safety & comfort
Medium	Educational content	Information panels, workshops	Increased understanding
Medium	Activities	Guided tours, photo points	Deeper engagement
High	Service quality	Staff training, information access	Greater satisfaction
Low	Marketing	Social media promotion	Increased awareness

Table 4. Recommendations for Improvement

Conclusion

The waterfalls of Belasica represent significant natural phenomena that reflect the complexity of geomorphological and hydrological processes in the region. They not only enhance the visual and aesthetic value of the landscape but also play a crucial role in maintaining the ecological balance of local ecosystems,

influencing soil moisture, groundwater dynamics, and creating specific micro-ecological conditions conducive to the development of endemic flora and fauna.

The conservation and sustainable management of these natural resources yield substantial scientific, ecological, and social benefits. Firstly, they facilitate scientific research and systematic monitoring of natural processes, contributing to a better understanding of ecosystem dynamics and the impacts of climate variability. Secondly, the waterfalls serve as natural laboratories for educational purposes, fostering awareness among students and the general public regarding the importance of preserving natural heritage. Thirdly, effective integrated management within the framework of sustainable tourism provides economic benefits to local communities without compromising ecological integrity.

Future research may focus on detailed hydro-geomorphological analyses of the waterfalls, the impact of seasonal variations on their hydrology, and the development of sustainable management strategies that combine scientific education with local tourism. Overall, the waterfalls of Belasica are natural assets of multidimensional value, whose preservation and promotion enhance awareness of natural heritage and provide a foundation for sustainable regional development, while encouraging future generations toward scientific exploration and ecological responsibility.

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