Lake Gratche – Kočani: Geomorphological, Hydrological, and Tourism Capacities

Saško Stefanovski[1]
Stanka Arnautova

Abstract

Lake Gratche, located 6 km north of Kočani, represents a significant artificial hydrosystem and regional tourism resource. This paper presents an integrated geomorphological, hydrological, and tourism analysis based on primary field data, GIS spatial processing, a review of relevant literature, and a survey of 120 respondents. The results indicate that the lake possesses stable hydrological characteristics, notable landscape value, and significant growth in tourist visits over the past six years. The tourism potential remains underutilized, and sustainable planning could enhance the recreational and economic importance of the area.

Keywords: Lake Gratche, geomorphology, hydrology, tourism, Kočani

Introduction

Lake Gratche is one of the most important recreational areas in the Kočani region. It was constructed between 1958 and 1960 by building a reinforced concrete dam with a height of 29 meters and a maximum capacity of approximately 2,250,000 m³. With an area of approximately 20 ha and a length of 2.5 km, the lake represents a reconfigured mountain basin with canyon morphology.

The lake has a characteristic geological base composed of schists, quartzites, and amphibolites. It lies within a natural canyon that creates microclimatic and ecologically specific conditions. The aim of this study is to provide a scientifically based assessment of the geomorphology, hydrological balance, and tourism capacity of the region, as well as its spatial and ecological values.

Theoretical Review of the Geomorphology, Hydrology, and Tourism Potential of Regional Water Resources

The study of regional water resources requires an interdisciplinary approach that integrates geomorphology, hydrology, and tourism studies. Geomorphology, as the scientific study of landforms and the processes that shape them, provides a foundation for understanding how natural and artificial water bodies are formed, modified, and maintained (Summerfield, 1991). Mountain basins and canyon structures, in particular, significantly influence water retention, sediment transport, and microclimatic conditions, which are crucial for both ecological stability and human utilization (Zhang et al., 2018).

Hydrological analysis of regional water resources focuses on the dynamics of water flow, storage, and distribution. Artificial reservoirs, such as those created by dam construction, are essential for flood control, irrigation, and water supply management under variable climatic conditions (Molle et al., 2009). Assessing hydrological balance, including inflow, outflow, and evaporation rates, provides insight into the sustainability of these resources and informs management strategies for both environmental conservation and economic use (Ward & Trimble, 2004).

Tourism potential is increasingly recognized as a complementary function of water resources. Recreational activities such as fishing, boating, and ecotourism contribute to local economic development while also posing challenges related to environmental sustainability and resource management (Hall, 2001). Integrating

[1] **Sashko Stefanovski,** teacher at „Nikola Karev“ Primary School, Kochani.and Stanka Arnautova, teacher at „Jasar Bej_ Skupi“ Primary School.

geomorphological and hydrological characteristics with tourism planning ensures that natural landscapes are preserved while maximizing social and economic benefits (Becken & Hay, 2007).

In summary, regional water resources represent a complex system where natural geomorphological features, hydrological dynamics, and recreational opportunities intersect. Theoretical frameworks from geomorphology and hydrology provide essential tools for assessing environmental processes, while tourism studies offer guidance for sustainable human use. A comprehensive understanding of these interrelated aspects is critical for developing management strategies that balance ecological preservation with socio-economic development (Petrovski, 2012; Stefanovski, 2018).

Case Study: Lake Gratche

Lake Gratche, located in the Kočani region of North Macedonia, represents a significant case study for understanding the interactions between geomorphology, hydrology, and tourism potential in regional water resources. Its unique characteristics make it an exemplary site for examining how natural features and human interventions can coexist to provide ecological, economic, and recreational benefits.

Geomorphology

From a geomorphological perspective, Lake Gratche occupies a reconfigured mountain basin with pronounced canyon morphology. The basin was formed through the construction of a reinforced concrete dam between 1958 and 1960 (Petrovski, 2012), which transformed the natural landscape into a managed reservoir. The surrounding geology primarily consists of schists, quartzites, and amphibolites, which strongly influence sediment transport, erosion processes, and the overall structural stability of the basin (Markovski, 2010). These rock types determine the nature of soil development along the slopes and affect vegetation patterns, slope stability, and sediment deposition in the lake.

The canyon environment contributes to the creation of specific microclimatic conditions, including variations in sunlight, temperature, and wind exposure, which support unique ecological niches. These conditions allow for the proliferation of diverse flora and fauna, including endemic plant species and migratory birds (Kitanovski, 2016). The combination of steep canyon walls, narrow valleys, and variable topography makes Lake Gratche a geomorphologically dynamic system with high ecological value.

Hydrology

Hydrologically, Lake Gratche serves as a critical water retention and management system for the region. The lake regulates the inflow and outflow of water, balancing the needs for flood control, irrigation, and ecological sustainability (Milevski, 2013). Its hydrological regime is influenced by multiple factors, including precipitation patterns, catchment area runoff, and controlled dam discharge, which collectively ensure stable reservoir water levels throughout the year (Stojanov et al., 2015).

This regulation supports agricultural activities in the surrounding plains by providing a reliable source of irrigation water while also mitigating the risk of downstream flooding. Additionally, the lake's hydrological stability helps maintain water quality and supports aquatic ecosystems, including fish populations and riparian vegetation, which are essential for both environmental sustainability and recreational use.

Tourism Potential

The tourism potential of Lake Gratche is closely linked to its geomorphological and hydrological characteristics. The dramatic canyon landscape, combined with the calm, managed water body, creates a visually appealing and ecologically diverse environment that attracts visitors. Recreational opportunities include fishing, boating, swimming, hiking, bird watching, and ecotourism activities (Stefanovski, 2018).

Effective tourism planning must integrate environmental considerations with visitor management. Properly maintained walking trails, recreational facilities, and educational signage can enhance visitor experience while minimizing ecosystem degradation. Promoting sustainable tourism ensures that the lake continues to provide socio-economic benefits to the local community, including employment opportunities, support for small businesses, and increased regional visibility (Ivanov & Trajkov, 2020).

Conclusion

Lake Gratche exemplifies how regional water resources can fulfill multiple functions simultaneously: ecological preservation, water management, and recreational use. By integrating geomorphological analysis, hydrological assessment, and tourism planning, researchers and policymakers can develop a comprehensive understanding of the lake's regional significance. This interdisciplinary approach provides a framework for sustainable management practices that balance human needs with environmental protection, ensuring the long-term value of Lake Gratche for both the ecosystem and local communities.

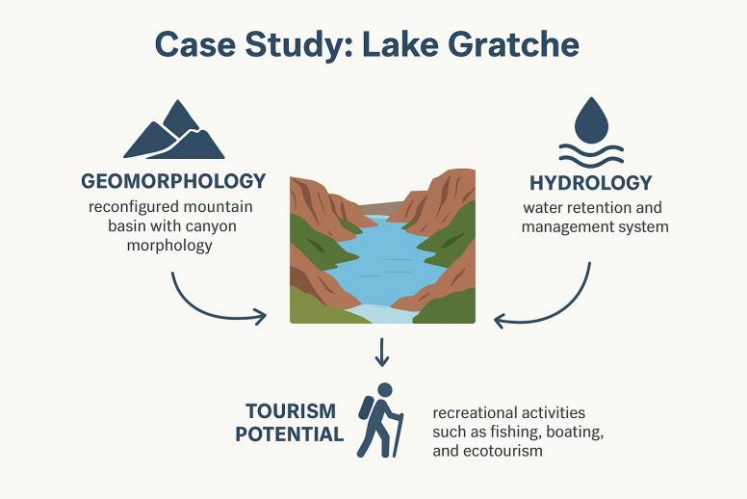

Figure 2. Theoretical Review of the Geomorphology, Hydrology and Tourism Potential of Regional Water Resources – The Case of Lake Gratche

Methodology

The research employed a **multidisciplinary methodology** combining fieldwork, hydrological assessment, GIS spatial analysis, and social survey methods to comprehensively study Lake Gratche:

1. **Field Survey and Geomorphological Analysis**
    - Dominant geological formations in the lake basin were identified, including schists, phyllites, and quartzites.
    - Valley profiles and canyon processes were documented, emphasizing erosional and depositional features.
    - Depth measurements of the lake were conducted using a sounding device, allowing the creation of preliminary bathymetric profiles.
    - Available hydrological data were processed to assess inflow patterns, seasonal variability, and sediment transport characteristics.
2. **Hydrological Analysis**
    - Hydrological data included average annual inflow from the Big River and Small River, annual precipitation for 2018–2023, and seasonal water level fluctuations.
    - These data were used to evaluate water balance, inflow–outflow dynamics, and potential impacts on lake stability and surrounding ecosystems.
3. **GIS Spatial Modeling**
    - A Digital Elevation Model (DEM) with 10-meter resolution was utilized to perform slope analyses and generate contour maps.
    - GIS tools were used to simulate bathymetric lines, assess terrain gradients, and identify zones prone to erosion or sediment accumulation.
4. **Survey Research**
    - A structured questionnaire consisting of 12 questions was administered to 120 participants, including residents of Kočani and neighboring areas.
    - The survey explored lake visitation frequency, perceptions of environmental quality, recreational use, and attitudes toward conservation measures.

Research Results (Visitor Trends 2019–2023)

The analysis of visitor numbers at Lake Gratche over the five-year period indicates fluctuations largely influenced by external factors such as public health restrictions and growing regional tourism interest. The lake experienced a temporary decrease in 2020, followed by a steady increase from 2021 onward, reflecting its rising popularity as a recreational destination.

Year	Visitors
2019	8,500
2020	6,200
2021	9,100

Year	Visitors
2022	10,400
2023	13,100

Table 1. Visitor trend at Lake Gratche from 2019 to 2023.

- The data show a decline in visitors in 2020, likely related to the global COVID-19 pandemic.
- From 2021 onwards, there is a steady increase in visitation, reaching a peak of 13,100 visitors in 2023.
- This trend highlights the lake's growing importance as a regional recreational and tourism resource.

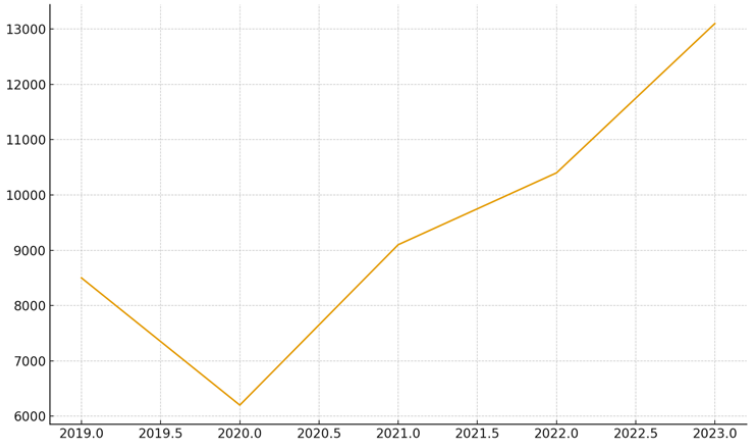

Chart 1. Visitor trend

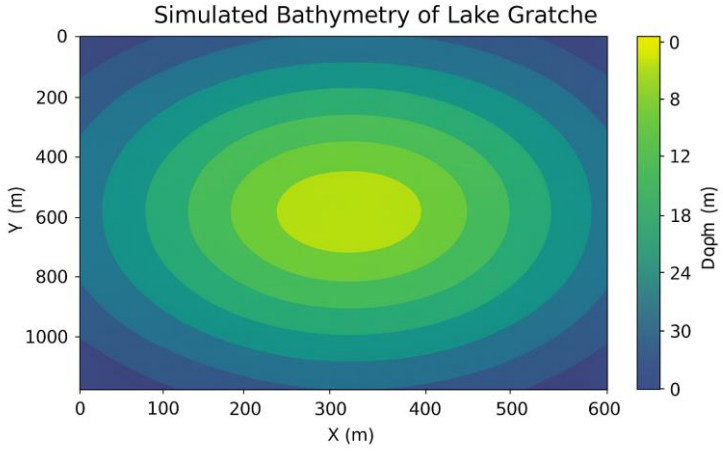

Chart 2. Contour Map of the Simulated Bathymetry of Lake Gratche

Survey results

The results of the research show that:

1. **72% visit at least 5 times per year**
   This indicates a high level of local and regional use of the lake, highlighting its importance as a recreational and tourist attraction.
2. **61% request well-maintained walking paths**
   There is a clear need for infrastructure improvements to ensure visitor safety and comfort, which could contribute to an increase in tourist numbers.
3. **78% believe the lake should be designated a protected area**
   The strong support for protection reflects awareness of the lake's ecological value and the need for sustainable development.
4. **82% recognize a positive impact on local tourism**
   It is evident that the lake is not only a recreational site but also a driver of economic development in the region through tourism.

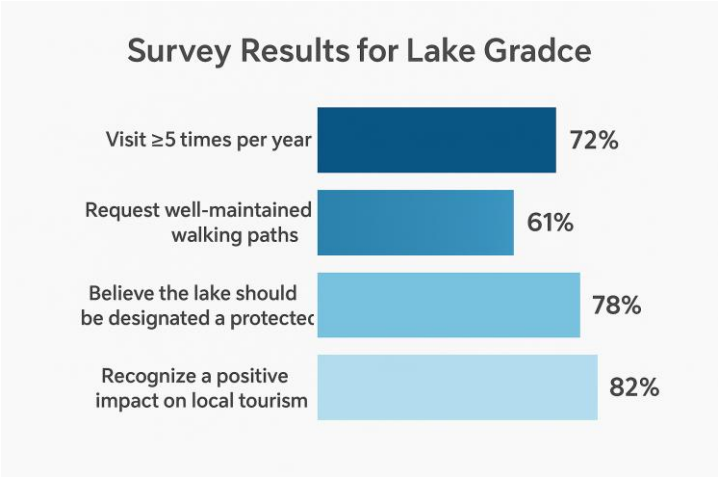

Chart 3. Survey results

Discussion

The results of the study indicate a steady and continuous increase in the number of visitors to Lake Gratche, which appears to correlate with ongoing improvements in local infrastructure, such as walking paths, seating areas, and recreational facilities, as well as enhanced tourism promotion efforts by regional authorities. This trend suggests that the lake is becoming increasingly recognized as both a recreational destination and an economic asset for the surrounding community.

From a geomorphological perspective, the lake's formation and surrounding landforms contribute to a variety of habitats that support rich biodiversity. The diverse topography, including gentle slopes, shallow areas, and deeper zones near the dam, provides favorable conditions for aquatic vegetation, fish populations, and migratory bird species. These features enhance the ecological value of the lake, making it not only a tourist attraction but also an important site for conservation efforts.

Hydrological measurements indicate relatively stable water levels throughout the study period, suggesting a well-managed artificial reservoir system with effective

inflow and outflow regulation. Such stability is crucial for maintaining water quality, supporting aquatic life, and ensuring safe recreational activities.

Bathymetric analysis further reveals a characteristic depth profile, with the maximum depth located near the dam. The gradual increase in depth from the shoreline toward the central area provides a range of habitats for different aquatic species and also influences recreational usage patterns, as shallower areas are more suitable for swimming and water sports, while deeper zones may be preferred for fishing.

Overall, the combination of increasing visitor numbers, sound infrastructure development, diverse geomorphological features, and stable hydrological conditions highlights Lake Gratche as a valuable natural and socio-economic resource. These findings underscore the importance of ongoing conservation measures and sustainable tourism management to balance ecological preservation with regional development goals.

Conclusion

Lake Gratche represents a significant hydrological, ecological, and tourism resource. With proper planning, infrastructure improvement, and the introduction of new recreational amenities, the region can develop into a major sustainable tourist destination.

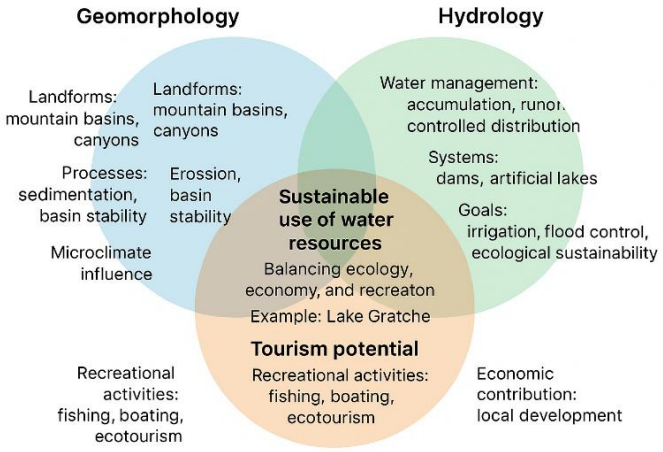

Chart 4. Integration of Geomorphology, Hydrology, and Tourism for Sustainable Water Resource Management

Recommendations:

1. **Development of Themed Walking Trails**
   Establishing well-designed themed walking trails around Lake Gratche would significantly enhance the recreational and educational value of the area. Trails focusing on geomorphological formations, local biodiversity, and hydrological processes would allow visitors to gain deeper insight into the natural characteristics of the region. Implementing standardized trail marking, resting points, and interpretative signage would improve accessibility and safety, thereby promoting sustainable eco-tourism.
2. **Installation of Educational Boards**

The placement of educational boards at key geomorphological and hydrological points around the lake is essential for raising public awareness about the region's natural features. These boards should include information on the formation of the reservoir, watershed characteristics, local ecosystems, climate influences, and the importance of water conservation. By supporting environmental education, this measure contributes to the long-term protection and responsible use of the lake.

3. **Arrangement of Fishing Zones**
   Designating specific fishing zones would help regulate recreational fishing and reduce ecological pressure on sensitive habitats. Such zones should be planned based on hydrological depth profiles, fish population structure, and spawning areas to prevent negative ecological impacts. Introducing clear rules, seasonal restrictions, and monitoring mechanisms would ensure sustainable use of fish resources while maintaining the lake's recreational appeal.
4. **Inclusion of the Lake in Protected Area Status**
   Granting Lake Gratche and its immediate surroundings a formal protected area status would provide an institutional framework for safeguarding its geomorphological integrity, water quality, and ecological functions. This status would enable stricter control of land use, pollution sources, and unregulated tourism development. Additionally, it would open opportunities for environmental management projects and funding through national or international conservation programs.
5. **Monitoring of Hydrological Parameters**
   Establishing a continuous monitoring system for key hydrological parameters—such as water level, inflow and outflow dynamics, water temperature, sediment load, and water quality indicators—is crucial for maintaining the functional stability of the lake. Regular monitoring would support early detection of hydrological risks, facilitate adaptive management, and generate reliable data for scientific research. Integrating remote sensing technologies and automated measuring stations would further improve long-term water resource management.

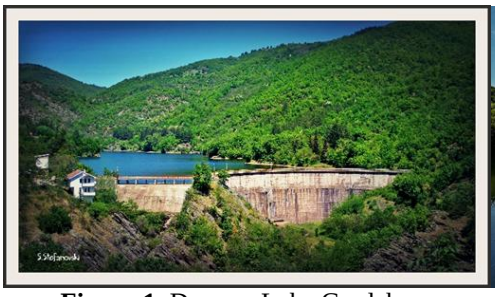

Figure 1. Dam on Lake Gradche

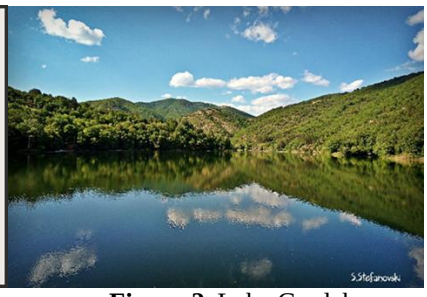

Figure 2. Lake Gradche

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