A GIS-BASED MULTI-CRITERIA ANALYSIS OF OPTIMAL SKI RESORT LOCATIONS IN SARAJEVO CANTON

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Abstract: This research was aimed to employ a GIS-based multi-criteria analysis (MCA) to identify optimal ski resort locations within Sarajevo, where the XIV Winter Olympic Games were held in 1984. Utilizing a MCA within a geographic information system (GIS), four key geomorphological parameters were analyzed: elevation, slope, aspect and terrain roughness. Elevation and slope were prioritized as primary criteria, while aspect and terrain roughness served as secondary criteria. Additionally, climatic data, including snow cover depth and average air temperatures, were considered to provide a comprehensive assessment of the region's suitability for ski resort infrastructure. Using a digital elevation model (DEM), these parameters were first standardized and then weighted according to their significance in ski resort suitability. The combined analysis facilitated the identification and visualization of the most suitable locations for ski resorts on mountains such as Bjelašnica, Treskavica and Jahorina. The integration of multiple criteria within GIS provided a comprehensive and objective approach to spatial planning and tourism development. The robustness of the results was confirmed through systematic analysis, demonstrating the method's reliability in supporting informed decision-making processes. This research underscores the importance of detailed geomorphological and climatic analysis in the sustainable development of tourism.

Key words: GIS, Multi-Criteria Analysis (MCA), Ski Resort Location, Sarajevo, Spatial Planning, Tourism Planning

INTRODUCTION

Tourism significantly contributes to the global economy, by providing opportunities to enhance local communities, protect the environment and improve quality of life. Geographic

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Information Systems (GIS), which facilitate in-depth spatial analyses and strategic decision-making, have become integral to tourism planning in recent years. It provides a strong basis for recognizing potential and overcoming challenges in the development of tourism, by incorporating a range of datasets, including environmental, socioeconomic and infrastructure aspects (Khattab & El-Sayed, 2021; Lawelai, 2024). This technology enables precise site selection and the development of sustainable tourism policies that balance economic objectives with environmental preservation. An example of GIS application can be found in Sarajevo Canton, located in the central part of Bosnia and Herzegovina, which represents a region with significant tourism potential that could greatly benefit from such planning approaches. Its mountains – Bjelašnica, Igman, Trebević, Jahorina and Treskavica – are renowed for their geomorphological conditions for winter sports. Furthermore, their historical role as hosts of the XIV Winter Olympic Games in 1984 adds cultural and symbolic significance. Despite these advantages, Sarajevo's tourism resources remain underutilized, pointing to the need for a systematic approach to developing it's tourism infrastructure.

GIS technology offers a solution by integrating spatial parameters such as elevation, slope, terrain roughness and climatic data into a detailed analytical models. When combined with MCA, GIS serves as a powerful tool for evaluating spatial suitability, providing important insigths for informed tourism development planning. This combination enables evidence-based decision-making, ensuring that tourism development aligns with sustainability objectives and addresses environmental challenges (Malczewski, 2006; Lawelai, 2024). For instance, GIS is instrumental in analyzing factors like snow cover depth and temperature fluctuations, which are pivotal for ski resort viability (Berard-Chenu et al., 2022).

Climate change poses significant challenges for winter tourism, particularly through the variability in snowfall patterns and increasing temepratures. In Sarajevo Canton, these impacts are evident in reduced snow reliability in lower elevations and increased dependency on artificial snowmaking. To address these challenges, this research utilizes GIS-based MCA to develop sustainable solutions.

The increasing unpredictability of snowfall and rising temeperatures trends threaten the sustainability of ski resorts, necessitating innovative solutions such as artificial snowmaking and climate-adaptive designs (Berard-Chenu et al., 2021; Mikloš et al., 2018). GIS-based tools provide insights for assessing these risks and developing mitigation strategies, thereby ensuring resilience of tourism development. This research was focused on the usage of GIS and MCA methodologies to evaluate tourism planning within Sarajevo Canton, emphasizing the importance of sustainability principles integration in that process. Sustainable tourism in this context ncludes the preservation of natural features, but also reduction of ecological footprint and the promotion of socio-economic development within local communities (Khattab & El-Sayed, 2021; Lawelai, 2024).

This research uniquely integrates geomorphological parameters, such as elevation and terrain roughness, with climatic data, including snow cover and temperature, to provide a strong basis for sustainable ski resort planning in Sarajevo Canton The results of this research intend to support policymakers, but also investors, in formulating tourism planning strategies that harmonize natural conservation with economic profit, thus enabling long-term benefits of mountain tourist destinations. This research therefore offers a systematic approach to understanding and addressing the complexities of tourism development, as it provides practical recommendations for improving Sarajevo Canton's tourism infrastructure while considering the impacts of climate variabilities and regional disparities.

LITERATURE REVIEW

The integration of Geographic Information Systems (GIS) combined with MCA has become an important method in tourism planning. It helps solve various challenges such as site selection, sustainable development and resource optimization.

GIS analyses, based on MCA model, have been widely recognized as a powerful tool for addressing complex challenges in land-use planning and resource management. Rikalović et al. (2014) emphasize GIS-MCDA's utility in industrial site selection, showcasing its adaptability to spatial decision-making challenges. Lokhande et al. (2017) and Aksoy & San (2019) extend this framework to landfill site selection, highlighting its ability to integrate diverse criteria for informed planning. Their research has demonstrated the efficacy of GIS and MCA in industrial and landfill site selection. However, application to ski resort planning remains limited, particularly in integrating climatic and geomorphological data. Ahmadi et al. (2014) highlighted the rapid evolution of GIS-based MCA in solving urban planning problems and managing conflicting multi-objectives, such as ecological conservation versus tourism expansion. Similarly, Vuković (2022) illustrated the utility of GIS and MCA in ecotourism development, showcasing their ability to evaluate resources and develop strategic plans that balance environmental and economic priorities.

Phua and Minowa (2005) emphasized the adaptability of GIS-based MCA in forest conservation planning, which has been extended to tourism infrastructure development. Boers and Cottrell (2007) applied these methods to identify sustainable tourism pathways by overlaying social and environmental datasets, enabling planners to create sustainable trail systems that align with carrying capacity and visitor preferences.

GIS-based MCA has also proven invaluable in cultural and ecotourism contexts. Sivac et al. (2023) developed a methodological framework for evaluating cultural tourism sites in Foča, Bosnia and Herzegovina, ranking attractions based on accessibility, amenities and ancillary services. Their research was conducted to show an example of how GIS can optimize resource allocation and provide actionable insights for enhancing tourism offerings.

In ecotourism, Ahmadi et al. (2014) utilized GIS and MCA to identify site suitability in Iran, integrating physical and environmental criteria to optimize land-use strategies. Ebrahimi et al. (2019) further explored ecological carrying capacity in Iran, demonstrating the importance of aligning tourism development with environmental sustainability by balancing visitor numbers and ecological preservation.

Accessibility plays a crucial role in successful tourism planning. Zhu et al. (2006) applied GIS and MCA to evaluate housing and tourism infrastructure in Singapore, focusing on accessibility to public transport and amenities. Their findings underscore the importance of integrating accessibility models into tourism development strategies to ensure connectivity and convenience for visitors.

Similarly, Ólafsdóttir and Runnström (2009) examined ecological sensitivity for tourism development in Iceland, emphasizing the importance of preserving fragile environments while developing tourism infrastructure. Their research reinforces the necessity of environmentally conscious planning to maintain the integrity of natural landscapes.

Climate considerations have emerged as critical factors in tourism planning. Mailly et al. (2013) integrated climatic variables such as wind speed and temperature into MCA frameworks to evaluate favorable climates for tourism. This approach highlights the role of GIS in climate-responsive tourism planning, ensuring resilience to environmental changes and optimizing visitor experiences. Selçuk (2013) also applies GIS-MCDA to avalanche hazard mapping in Turkey, addressing geomorphological risks - a methodology highly relevant to ski resort planning.

Recent advancements in GIS technology have facilitated digital and web-based applications in tourism. Noviansyah (2023) demonstrated the development of GIS platforms for halal tourism, enabling users to locate attractions and facilities through mobile apps. These innovations reflect the growing emphasis on interactive GIS solutions to enhance tourism management and accessibility. By combining spatial analysis with decision-making models, these tools enable a balanced approach to economic development and environmental conservation. Research by Sivac et al. (2023), Ahmadi et al. (2014) and Vuković (2022) underscores the transformative potential of GIS and MCA in optimizing resource allocation, enhancing cultural tourism and fostering sustainability.

Despite the extensive use of GIS and MCA in tourism planning, limited studies have simultaneously integrated geomorphological and climatic parameters in the context of ski resorts. This research is focused on addressing this gap by combining these parameters to provide actionable insights for Sarajevo Canton's winter tourism

RESEARCH AREA

Sarajevo Canton, located in central Bosnia and Herzegovina, spans 1,276.9 km², with diverse geomorphological and climatic characteristics that are highly relevant for tourism development, particularly winter sports. The canton is characterized by its mountainous terrain, including the Sarajevo Valley and the surrounding mountains: Bjelašnica, Igman, Trebević and Treskavica. These mountains, especially Bjelašnica and Treskavica, showcase significant geomorphological features such as karst formations, glacial deposits and five glacial lakes on Treskavica, including Veliko and Bijelo Lake. These features not only define the Sarajevo's natural appeal but also serve as a solid basis for developing tourism infrastructure like ski resorts and eco-tourism initiatives.

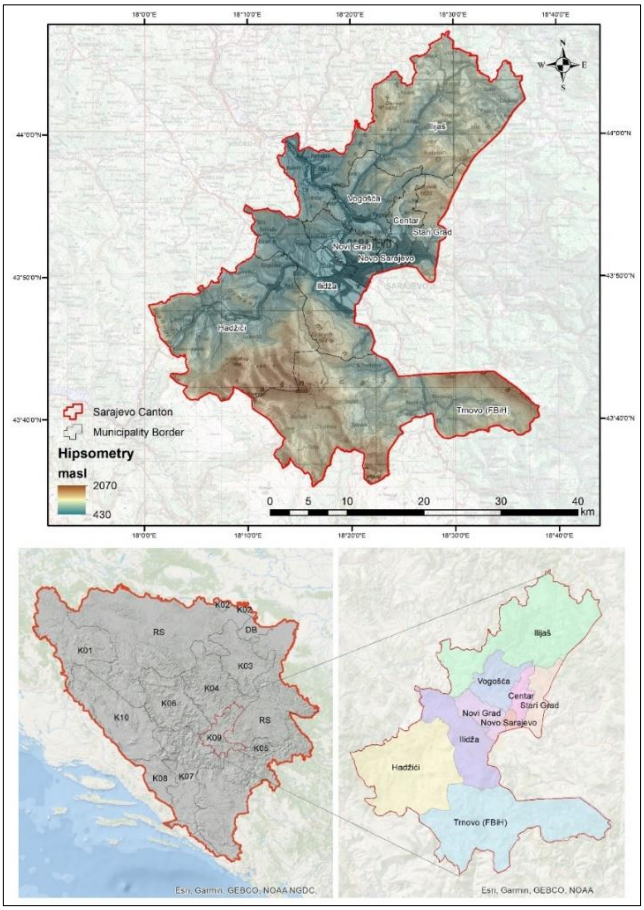

Fig. 1: Geographic and administrative position of Sarajevo Canton in Bosnia and Herzegovina

(Source: Geo-database of GIS Center of Department of Geography, University of Sarajevo – Faculty of Science, adapted by the authors using ArcGIS [GIS software] Version 10.6.1.)

Sarajevo's elevation ranges from 500 to over 1,500 meters, with approximately 10% of the area lying above 1,500 meters, primarily in the southern regions. This relief variation significantly influences the area's climatic diversity. Lower altitudes are characterized by Cfb climate type, with warm summers (but no dry season) and moderate precipitation evenly distributed throughout the year, while higher altitudes experience colder and snowier conditions, classified under the Df climate type (humid boreal or snow forest climate) in the Köppen system. The classification within this climatic type is determined based on the thermal and pluviometric regimes, alongside the accompanying values of other climatic elements (Drešković, 2011). The lower elevations, including the Sarajevo Valley, are characterized by a temperate continental climate with an average annual temperature of 9.7°C and annual precipitation of 935.0 mm. These climatic conditions, combined with the geomorphological ones, create ideal conditions for winter tourism, particularly skiing. The valley's topography, however, can slow down air circulation during winter thermal inversions, contributing to air pollution, which negatively impacts tourism development both directly and indirectly. (Gekić et al., 2022)

Bjelašnica, one of the most prominent mountains in the research area, represents it's potential for winter sports. The mountain receives significant snowfall, with snow cover exceeding 10 cm typically lasting 160 days annually, from late November to May. These characteristics were a crucial factor in its selection as a venue for the 1984 Winter Olympics, stabilizing its reputation as a premier location for skiing and other winter sports.

The historical significance of Sarajevo Canton, highlighted by its role as host of the 1984 Winter Olympics, provides a unique cultural and symbolic foundation for tourism. However, recent climatic trends, such as temperature inversions and snow variability, highlight the need for adaptive and climate-resilient planning.

Sarajevo Canton's transitional climate, situated between subtropical and temperate zones, provides a mix of conditions suitable for diverse tourism activities. Higher altitudes offer cold, snowy winters essential for ski resorts, while the temperate conditions of lower elevations support year-round activities. The area also experiences approximately 1,800 hours of annual sunshine, enhancing its appeal for outdoor recreation. However, climate change poses significant challenges, including fluctuations in snow reliability and temperature inversions, particularly in the Sarajevo Valley. This area is especially susceptible to air pollution, influenced primarily by its geomorphological and climatic features, as well as emissions from individual heating systems and traffic. These factors must be accounted for in tourism planning to ensure the region's resilience and long-term viability.

The geomorphological and climatic features of Sarajevo Canton provide a strong basis for using GIS-based analyses in tourism planning. Key spatial parameters such as elevation, slope, terrain roughness, snow cover and temperature can be integrated into a MCA framework to identify optimal sites for ski resorts and other tourism infrastructure.

This approach ensures that development aligns with the natural characteristics of the region while addressing environmental and climatic challenges. For example, the glacial and karst features of Bjelašnica and Treskavica offer unique opportunities for eco-tourism and educational programs, complementing the Sarajevo's winter sports facilities.

MATHERIALS AND METHODS

The methodology applied in this research outlines the systematic approach used to identify optimal ski resort locations within Sarajevo Canton using GIS and MCA. ArcGIS software was selected for its strong capabilities in data collection, integration, analysis and visualization of spatial data.

Initially, the research focused on data preparation, using DEM to derive critical geomorphological parameters such as elevation, slope, aspect and terrain roughness. These datasets were compiled from topographic maps, high-resolution satellite imagery and field surveys to ensure comprehensive coverage and accuracy across the research area. Standardization of parameters was used to ensure consistency and comparability across diverse datasets. Each parameter underwent normalization within predefined ranges suitable for ski resort suitability analysis.

Primary criteria included elevation and slope, which significantly influence snow quality and skiing conditions, while secondary criteria like aspect and terrain roughness impact wind. For each criterion, specific scales were defined to reflect the most optimal, optimal and unfavorable conditions for ski resorts. The weighting scheme was informed by expert consultations and validated against established frameworks, such as the U.S. Ski & Snowboard Association guidelines (2022) and Marinović-Uzelac's spatial planning criteria (2001), ensuring relevance to skiing infrastructure requirements.

The classification of these layers was performed using ArcMap. Elevation was classified according to the suitability for ski resorts. Following the guidelines set by Marinović-Uzelac (2001), the most optimal locations were defined as those with elevations between 1600 and 1800 meters, as these elevations typically provide the most favorable snow conditions and terrain features for skiing. Locations above 1800 meters were also considered optimal due to their potential for better snow quality and extended skiing seasons. All other elevations were deemed unfavorable for ski resort development.

Slope was categorized based on its relevance to skiing conditions. The analysis utilized slope classifications similar to those applied by the U.S. Ski & Snowboard Association (2023), where slopes between 14 and 22 degrees were considered most optimal for skiing due to their ideal gradient for various skiing activities. Slopes ranging from 3 to 14 degrees were deemed optimal, while slopes outside these ranges were classified as unfavorable.

The classification of aspect involved differentiating between various exposures to sunlight and prevailing winds. Most optimal aspects were those facing north (0 to 22.5 degrees and 337.5 to 360 degrees), as these orientations typically experience less direct sunlight and more consistent snow conditions. Slope aspects within the ranges of 22.5 to 67.5 degrees (northeast) and 292.5 to 337.5 degrees (northwest) were classified as optimal, while all other aspects were considered unfavorable due to less favorable snow preservation conditions.

Terrain roughness was evaluated using criteria adapted from the U.S. Ski & Snowboard Association (2023). The most optimal roughness values were those between 30 and 100 meters, indicating moderate terrain variation suitable for diverse skiing experiences. Roughness values between 100 and 296 meters were considered optimal, while terrain with roughness outside these ranges was deemed unfavorable due to excessive roughness impacting skiing quality and safety.

With standardized parameters, MCA was applied to integrate and evaluate these criteria collectively. MCA enabled the synthesis of multiple factors into a single evaluative framework, facilitating the identification of the most suitable locations for ski resorts. Weighting criteria were assigned based on their relative importance in determining the suitability of ski resort site selection. This process involved assigning numerical weights to each criterion to reflect their influence on optimal skiing conditions and site attractiveness. Validation was conducted using sensitivity analysis by altering weights for each criterion. This process revealed minimal variation in final results, confirming the robustness of the applied methodology. The weights were derived from established guidelines (e.g., Marinović-Uzelac, 2001) and consultations with tourism planning experts. Elevation and slope were assigned higher weights (0.4 each), due to their critical influence on skiing conditions while aspect and terrain roughness were assigned lower weights (0.1 each) but still considered essential for comprehensive analysis. These weights reflect the relative importance of each parameter in the context of assessing locations for ski resorts. The combination of standardized and weighted layers was performed using the *Raster Calculator* tool, where the weights were applied to the respective layers and the results were combined into a single layer that displayed the overall score for the optimal ski resort location for each spatial unit. The final result is represented by an equation that synthesizes and integrates all relevant criteria into a weighted summation framework:

$$\boldsymbol{OL_{SR}} = \sum_{\{i=1\}}^{n} (\boldsymbol{X_i} \cdot \boldsymbol{W_i})$$

where:

- $\boldsymbol{X_i}$ signifies the normalized or standardized value corresponding to the $\boldsymbol{i}$-th criterion, explicitly detailed as follows:
    - $\boldsymbol{E_i}$ for elevation
    - $\boldsymbol{S_i}$ for slope

    - A_i for aspect
    - TR_i for terrain roughness
- W_i denotes the corresponding weight applied to the i-th criterion, ascribed to:
    - W^E for elevation,
    - W^S for slope,
    - W^A for aspect and
    - W^{TR} for terrain roughness.

Using ArcGIS, the standardized and weighted parameters were combined through *Raster Calculator* to produce a suitability map for ski resorts. The GIS-based approach allowed for detailed spatial analysis and visualization of the most favorable locations based on the integrated criteria. The final output was a composite map highlighting the optimal areas for ski resort development, categorized into most optimal, optimal and unfavorable locations. MCA integrated the weighted parameters to objectively evaluate potential ski resort locations. The final values were classified using the Jenks natural breaks classification method, which creates class breaks to best group similar values together while maximizing the differences between classes. The Jenks natural breaks algorithm, much like K-means clustering, assigns data to one of *K* groups such that within-group variance is minimized. This method resulted in three categories related to ski resort location conditions: 0–0.298 (unfavorable), 0.299–0.651 (optimal), and 0.652–1 (most optimal). By synthesizing multiple criteria into a unified analytical framework, MCA facilitated the identification of sites that best met the predefined criteria for ski resort development in Sarajevo Canton. Sensitivity tests varied criterion weights and input parameters to ensure the consistency and quality of findings, thereby confirming the method's suitability for informing decision-making processes.

FINDINGS AND DISSCUSSION

The research was conducted to provide a detailed analysis of the spatial distribution of optimal and most optimal values for each geomorphological parameter within Sarajevo Canton, focusing on elevation, slope, aspect and terrain roughness. These parameters were systematically evaluated and visualized to identify the most suitable areas for ski resort development. Furthermore, the analysis was augmented with climatic data, including snow cover depth and average air temperatures, to ensure a comprehensive and holistic assessment of the region's potential for ski resort infrastructure. Using Fig. 2, which illustrates the suitability of elevation, slope, aspect and terrain roughness, the research resulted in geovisualisation of the most favorable locations for ski resort infrastructure.

The elevation parameter is critical in determining suitable locations for ski resorts due to its influence on snow cover and climatic conditions. The elevation suitability map (Fig. 2.1) categorizes locations into:

- Most Optimal Locations (1600 - 1800 meters): These regions represent the ideal elevation range for ski resorts. They represent only 4,31% of total research area, emphasizing the scarcity of high-suitability zones. However, locations within this range ensure a reliable snow cover while maintaining accessibility. This elevation range is crucial as it balances the need for adequate snowfall and the logistical considerations of resort construction and maintenance.
- Optimal Locations (Above 1800 meters): These areas cover only 2,50% of total area. They are suitable for skiing, but present challenges such as increased difficulty in access and potential harsh weather conditions. However, they still offer reliable snow conditions, making them viable options for ski resort locations.
- Unfavorable Locations (Below 1600 meters): Areas below indicate unsuitability for ski resort development due to insufficient snow cover and less favorable climatic conditions.

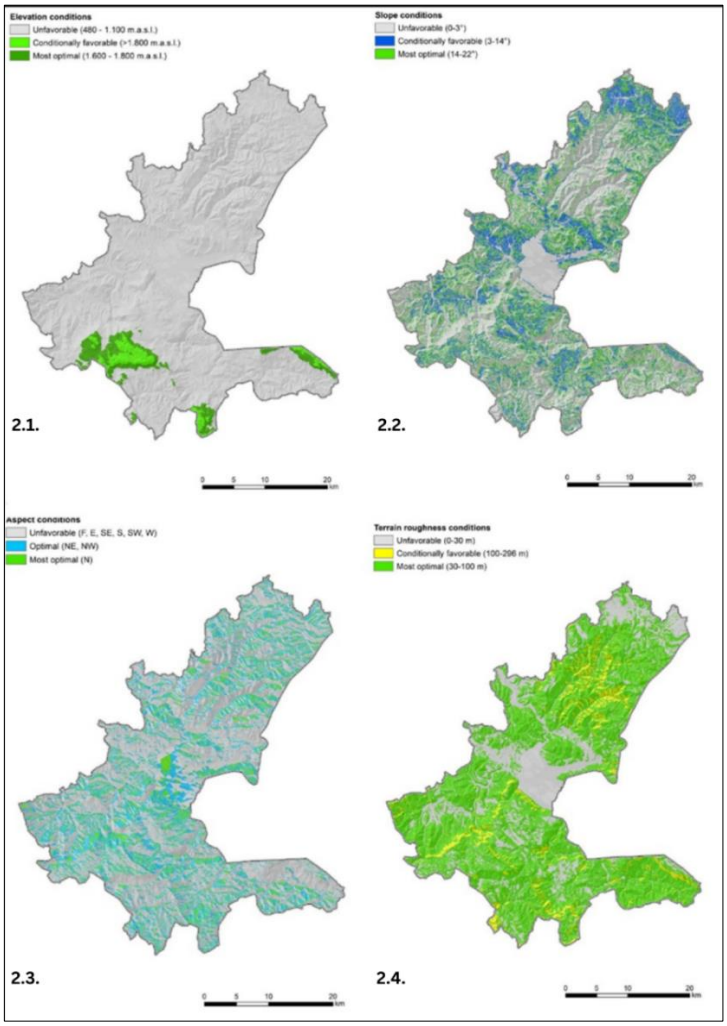

Fig. 2: Suitability analysis of geomorphological parameters for ski resort development in Sarajevo Canton: Elevation (2.1), Slope (2.2), Aspect (2.3) and Terrain roughness (2.4)
(Source: Geo-database of GIS Center of Department of Geography, University of Sarajevo – Faculty of Science, adapted by the authors using ArcGIS [GIS software] Version 10.6.1.)

Slope gradient is another fundamental parameter influencing the suitability of ski resort locations, as it impacts the quality and safety of skiing activities. The slope map (Fig. 2.2) classifies the terrain as:

– Most Optimal Locations (14-22°): These slopes provide a good balance between challenge and safety, catering to a wide range of skiing abilities and preferences, therefore these ideal for skiing activities. They participate with 24,66% in total research area.

- Conditionally Favorable Locations (3-14°): Less steep slopes cover 21,19% of total area. They may not offer the same level of excitement; therefore, they may not meet the needs of experienced skiers, but they are suitable for beginner skiers and alternative winter sports activities.
- Unfavorable Locations (0-3° and >22°): These areas either lack sufficient incline for skiing or are too steep, posing significant safety risks and operational challenges.

Aspect, or the direction a slope faces, significantly impacts snow retention and quality, due to varying sun exposure. The aspect conditions map (Fig. 2.3) classifies slopes based on their orientation:

- Most Optimal Locations (North-facing, 337.5-22.5°): North-facing slopes cover 12,56% of total area. Those slopes are optimal due to reduced direct sunlight exposure, which helps preserve snow quality and prolongs the skiing season.
- Optimal Locations (North-East and North-West, 22.5-67.5° and 292.5-337.5°): These slopes cover 25,95% of total research area. They also benefit from favorable snow retention conditions but may receive slightly more sunlight compared to purely north-facing slopes, making them slightly less optimal.
- Unfavorable Locations (Other Directions): These areas are more exposed to sunlight, leading to quicker snowmelt and less favorable conditions for skiing.

Terrain roughness affects the feasibility of ski resort infrastructure development and the overall skiing experience. The terrain roughness conditions map (Fig. 2.4) categorizes the terrain as follows:

- Most Optimal Locations (30-100 meters): Moderate terrain variations create ideal conditions for skiing, while fascilitating infrastructure development. These participate with a large percent (67,89%) in total research area.
- Conditionally Favorable Locations (100-200 meters): These areas cover 7,52% of total area. They may pose challenges for development but are still usable with careful spatial planning.
- Unfavorable Locations (0-30 meters and >200 meters): Extremely smooth or rugged terrains either lack the necessary terrain features for skiing or are too rugged for safe and practical resort development, therefore those are less suitable due to safety concerns and construction difficulties.

Climatic factors, particularly temperature and snow cover depth, play a pivotal role in determining the viability of ski resorts. This research included data on temperature from a 30-year period (1992–2022) recorded at the Bjelašnica meteorological station.

By examining such an extensive temporal range, the research was aimed to identify precise climatic patterns critical for assessing long-term viability. For snow cover depth, data spanning the period 2015–2022 were analyzed, as this parameter has only been systematically recorded in meteorological yearbooks since 2015. The results revealed that snow cover depths from December to March consistently ranged between 66.75 cm and 183.125 cm, providing stable conditions for skiing activities. Average temperatures during the same months varied from -5.8°C in February to -3.7°C in March, which aligns with favorable conditions for snow retention and quality. Conversely, snow cover during the remaining months was negligible, typically ranging from 0 to 10 cm, making these periods unsuitable for winter tourism planning. Dual approach to analyzing long-term temperature trends and recent snow cover data ensures a solid framework for understanding the climatic prerequisites for sustainable ski resort development in Sarajevo Canton. The synthesis of geomorphological and climatic parameters (Fig. 3) provides a comprehensive overview of Sarajevo Canton's potential for ski resort development. By integrating elevation, slope, aspect, terrain roughness and climatic data, three mountains—Bjelašnica, Jahorina and Treskavica were identified as the most optimal locations for the construction and development of ski resorts. Each mountain is characterized by its unique attributes, influencing its suitability for ski resort infrastructure and diversification of tourism activities. The classification of suitability conditions depicted in Fig. 3 was derived using the Jenks natural breaks method, which optimally groups similar values while maximizing differences between classes. The most optimal locations constitute 2.17% of the total area of Sarajevo Canton, while optimal locations account for 36.99%, highlighting significant potential for targeted tourism development. The following provides a concise overview of the key characteristics of these mountains, with a particular focus on their suitability for winter tourism infrastructure development and implications for sustainable tourism planning

Bjelašnica is identified as one of the most optimal locations for ski resort development in Sarajevo Canton. The mountain's elevation, ranging up to 2,067 meters, falls within the ideal range for ski resorts, ensuring reliable snow cover and extended skiing seasons. The terrain features slopes with gradients between 14° and 22°, which provide the perfect balance between skiing challenge and safety. Additionally, the predominance of north-facing slopes ensures reduced sunlight exposure, enhancing snow preservation and quality. Bjelašnica's historical significance as a venue for the men's alpine skiing events during the 1984 Winter Olympics reinforces its identity as a winter sports destination. Recent investments in modern ski lifts and hospitality facilities have enhanced its infrastructure, attracting both domestic and international tourists. Despite its well-established ski amenities, the mountain remains relatively tranquil, offering a serene environment that appeals to those seeking less commercialized settings. Beyond winter sports, Bjelašnica supports diverse activities such as hiking and mountain biking, making it a year-round destination.

Jahorina, located southeast of Sarajevo, represents another highly favorable site for ski resort development. This mountains peak elevation of 1,916 meters supports consistent snow cover, while its extensive ski trails and moderate slopes cater to skiers of all levels. The slopes of Jahorina feature gradients within the optimal range (14°–22°), complemented by northeast and northwest aspects, which enhance snow retention and prolong the skiing season. As a host of the women's alpine skiing events during the 1984 Winter Olympics, Jahorina has solidified its reputation as a premier winter sports destination. Modern infrastructure, including advanced ski lifts, well-maintained trails and family-friendly amenities, positions it as a highly commercialized resort with wide appeal. Jahorina's extensive offerings, such as hiking and biking in the summer, ensure that it remains a year-round tourist attraction.

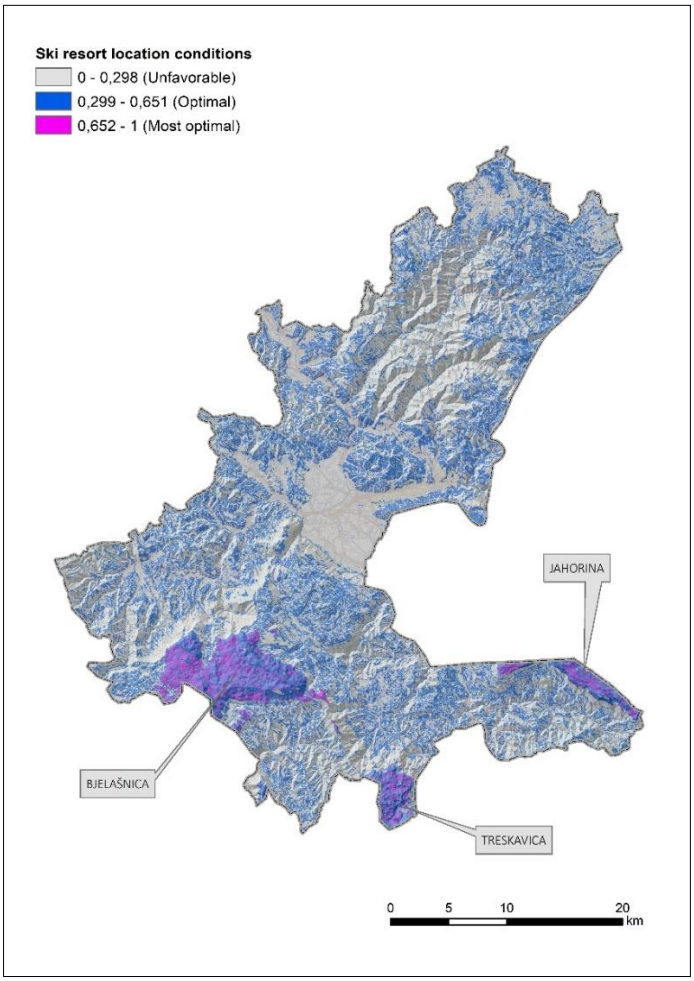

Fig. 3: Synthesized suitability map for ski resort locations in Sarajevo Canton
(Source: Geo-database of GIS Center of Department of Geography, University of Sarajevo – Faculty of Science, adapted by the authors using ArcGIS [GIS software] Version 10.6.1.)

Treskavica, although lacking the infrastructure of Bjelašnica and Jahorina, is a mountain with significant potential for diversifying tourism. Its remarkable features, such as glacial lakes and diverse biodiversity, make it an ideal destination for eco-tourism and adventure activities. While Treskavica's elevation and terrain meet many of the criteria for ski resort development, several factors limit its immediate feasibility. The absence of ski infrastructure on Treskavica is partly due to landmine contamination in certain areas, a legacy of the war that afflicted Bosnia and Herzegovina during the 1990s. Additionally, this lack of development can be attributed to the presence of relatively well-established ski resorts in its immediate vicinity. Additionally, the mountain's physical-geographical determinants align more closely with eco-tourism and conservation goals, offering opportunities for hiking, camping and nature exploration. Treskavica's landscapes provide an alternative to the highly commercialized settings of Bjelašnica and Jahorina, appealing to visitors seeking authentic outdoor experiences.

The synthesis map (Fig. 3) points to the fact that Bjelašnica and Jahorina are the most suitable locations for ski resort development, with both areas combining favorable geomorphological and climatic conditions. Bjelašnica's higher elevation and challenging terrain make it particularly attractive to advanced skiers, while Jahorina's extensive ski runs and modern infrastructure cater to families and tourists of all skill levels. In contrast, Treskavica's lack of ski infrastructure limits its immediate suitability for skiing but underscores its potential as a leading eco-tourism destination. The comparative analysis highlights the complementary roles of these mountains in Sarajevo Canton's tourism strategy. Bjelašnica and Jahorina can continue to expand as flagship winter sports destinations, while Treskavica offers a unique opportunity to diversify the region's tourism offerings through sustainable eco-tourism initiatives.

Compared to similar studies in the French Alps (Berard-Chenu et al., 2022), Sarajevo Canton demonstrates competitive geomorphological advantages but faces greater climatic variability. For instance, snow cover on Bjelašnica, averaging 160 days annually, contrasts with declining trends in similar regions globally, underscoring its resilience.

CONCLUSION

The results of this research point to the effectiveness of integrating GIS-based MCA in identifying optimal locations for ski resort development within Sarajevo Canton. By systematically evaluating geomorphological parameters—elevation, slope, aspect and terrain roughness, alongside essential climatic data such as snow cover and temperature, the research provides a solid framework for informed decision-making in tourism and regional planning.

The synthesis map highlights Bjelašnica, Jahorina and Treskavica as the most optimal areas of interest, with Bjelašnica and Jahorina standing out as the most suitable locations for ski resort infrastructure due to their optimal terrain and climatic conditions. Treskavica, while lacking ski infrastructure, presents significant potential for eco-tourism development, emphasizing the importance of preserving its natural environment.

The findings of this research provide a detailed plan for policymakers, emphasizing the integration of spatial data and multi-criteria analysis to guide sustainable investments in tourism infrastructure, ensuring resilience amid climate variability. Investments in the established ski resorts of Bjelašnica and Jahorina could enhance their competitiveness and solidify Sarajevo Canton's reputation as a premier winter tourism destination in Southeast Europe. The construction of new and potential reconstruction of existing infrastructure would improve accessibility and expanding amenities would not only attract more tourists but also stimulate local economies and foster sustainable regional development. Conversely, Treskavica's unique natural and ecological characteristics position it as an ideal candidate for eco-tourism initiatives. Targeted efforts in conservation and sustainable planning could further emphasize the potential of this mountain from a tourism perspective, while preserving its biodiversity and natural heritage. Such approach aligns with global trends toward environmentally responsible tourism, catering to a growing segment of eco-conscious travelers. Adopting a dual tourism strategy, focusing on the continued growth of ski tourism in Bjelašnica and Jahorina and developing Treskavica as an eco-tourism hotspot ensures a balanced and sustainable framework for tourism in Sarajevo Canton. This strategy accommodates diverse tourist preferences while addressing environmental sustainability, creating opportunities for both economic advancement and cultural preservation. By using the strengths of these three mountains, Sarajevo Canton can optimize its tourism potential while safeguarding its natural resources for future generations.

The methodology applied in this research demonstrates the value of integrating spatial analysis with MCA, offering a replicable model for similar studies in other regions. The use of GIS tools enabled precise visualization and evaluation of spatial and environmental factors, fostering objective, data-driven decision-making. Importantly, the inclusion of climatic data highlights the need for adaptive planning to address the challenges posed by climate change, ensuring the long-term viability of ski resorts. Policymakers should prioritize infrastructure upgrades on Bjelašnica and Jahorina, focusing on improving accessibility and sustainable amenities. Additionally, targeted conservation efforts on Treskavica could position it as a leading eco-tourism destination.

Future research should incorporate additional parameters, such as proximity to transportation networks, urban centers and complementary tourist attractions, to refine the analysis further. Furthermore, future research should incorporate socio-economic factors and stakeholder input to refine findings. Expanding the scope to include socioeconomic factors and stakeholder input could enhance the applicability of the findings and support more

comprehensive regional tourism strategies. By continuing to integrate advanced analytical tools and sustainable practices, Sarajevo Canton can serve as a model for other regions seeking to balance economic development with environmental protection.

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