

QUANTITATIVE GIS EVALUATION OF SKI SLOPES: CASE STUDY SKI CENTER BJELAŠNICA

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Abstract: The subject of research in this paper is a quantitative analysis of the ski slopes at the Bjelašnica Ski Center. Bjelašnica is a mountain in Bosnia and Herzegovina, very attractive and visited by domestic and foreign tourists, especially in winter. It is one of the Olympic mountains of Bosnia and Herzegovina, where the XIV Olympic Winter Games were held in 1984. The aim of the research is to present the procedure for quantitative analysis of ski slopes in geographic information systems. The paper analyzes slopes, aspects, altitudes, lengths, determines ski slopes difficulties, and creates topographic profiles for 6 ski slopes. For the purpose of comparing the results, ski slopes on Bjelašnica were selected, where some of these parameters have already been calculated. The analysis was done in geographic information systems by integrating remote sensing data. Quantitative analysis is done primarily to help skiers gain insight into the terrain itself, its steepness, and the difficulty of the trail, in order to better prepare for the experience that awaits them. Ski resort management also needs this information to ensure safety on the trail, improve management, and to assess their ecological impact on the environment. A small number of ski resorts in Bosnia and Herzegovina have conducted a quantitative analysis of ski slopes. Quantitative data on ski slopes improves the tourist offer of ski centers, and it is essential for them to have it.

Keywords: ski slopes, quantitative analysis, Bjelašnica Ski Center, Bosnia and Herzegovina, geographic information systems

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INTRODUCTION

The subject of research in this paper is the ski slopes at the Bjelašnica ski center, which includes quantitative analysis and evaluation of ski slopes using geographic information systems. The aim of the research is to geospatially analyze six selected ski trails on Bjelašnica (out of a total of eight), to determine the altitudes of the starting and ending points, their lengths, aspect, slope angles, configurations and difficulty levels, which will contribute to their increased safety, attractiveness and economic sustainability. Analytical procedures in geographic information systems encompass spatial and attributive data to answer various questions and solve real-world problems (Hadžimustafić, 2023).

Also, the paper present a geospatial analysis, which can be applied to other ski centers and their ski slopes. Using GIS, researchers can create spatial analyses that help make decisions about developing and maintaining ski resorts, identifying the highest quality ski slopes, optimizing ski areas, improving infrastructure, strengthening ski tourism, and preserving the area's natural resources. GIS is a powerful set of tools for collecting, storing, searching as needed, transforming, and displaying spatial data from the real world (Burrough, 1986). A quantitative analysis of the trails on Bjelašnica has been previously conducted, and these values will be used to compare the results obtained through GIS analysis.

The research area is Mount Bjelašnica. It is one of the four Olympic mountains in Bosnia and Herzegovina, where the XIV Winter Olympic Games were held in 1984. Mount Bjelašnica represents a significant geomorphological resource for the development of tourism in our country (Fig. 1.).



Fig. 1. Bjelašnica Ski Center (*Photo: Edin Hadžimustafić*)

The Bjelašnica Olympic Center includes one skiing destination, Babin Do, whose slopes are among the top of European ski slopes. The Babin Do ski resort has eight ski slopes and five children's slopes, three cable cars and five ski lifts, which lead to the very top of Bjelašnica at 2,067 m. For skiers, this mountain beauty offers 14,000 m of slopes for alpine skiing (Olympic centers Bjelašnica-Igman). A meteorological station was built on the highest peak (2,067 m) in 1894, which is also the highest permanently inhabited point in Bosnia and Herzegovina.

Since 2005, the Bjelašnica area, together with Igman, Treskavica and the Rakitnica Canyon, has been declared an area of special significance for the Federation of Bosnia and Herzegovina, with the aim of preserving biological, landscape and geomorphological diversity (Sivac, Hrelja, 2022).

Mountains in Bosnia and Herzegovina, including Bjelašnica, are attractive and visited by tourists. Extraordinary natural beauty, geodiversity, landscape diversity, rivers and lakes, rich forests, even rainforests, preserved biodiversity, ski resorts, a network of mountain trails, remote mountain villages with a rich gastronomic and (ethno)cultural offer, are some of the attractions that attract domestic and foreign tourists (Mešanović, Hadžimustafić, 2025).

Mountain tourism is one of the most attractive forms of tourist movement, and the most widespread continental recreational form. Mountain tourism is a specific form of tourism that focuses on activities in mountainous areas, such as hiking, skiing and ecotourism. These activities provide opportunities for enjoying nature, as well as for physical activity and relaxation. This type of tourism contributes to the preservation of natural resources and biodiversity, while simultaneously providing economic benefits to local communities.

The most common forms of tourist valorization of mountain areas are: mountaineering and other recreational activities, whitewater adventure activities, and snow recreation. Snow recreation activities include cross-country skiing, alpine skiing, heliport, snowboarding, sledding, bob, biathlon, etc. Such recreation is mostly limited to higher mountain areas in the snowy winter tourist season (Temimović et al., 2017).

In the tourist valorization, three parts of the mountain are particularly valued: peaks, slopes and foothills. Peaks are valued for their adrenaline and the desire of mountaineers and alpinists to conquer them. Slopes allow for hiking and various skiing activities, while tourist settlements are mainly formed at the foothills of attractive mountains (Mešanović, Hadžimustafić, 2023).

Staying in the mountains has many benefits for the human body and mind. Fresh mountain air improves lung function and increases the amount of oxygen in the body. Movement and spending time in nature strengthen the cardiovascular system, increasing an individual's strength and endurance, which leads to better overall physical health (Mešanović, Hadžimustafić, 2025). The mountain climate has a beneficial effect on the human body, it increases the number of red blood cells, it is suitable for asthmatics, anemic people, people who do a lot of intellectual work, staying in fresh and clean air has a beneficial effect on people who replace the urban environment with a natural environment (Hadžimustafić, Mešanović, 2024).

MATERIALS AND METHODS

Study area

Bjelašnica is a high mountain located in the central part of Bosnia and Herzegovina and belongs to the Dinaric Mountain system. It is located about 25 km southwest of Sarajevo, the capital of Bosnia and Herzegovina (Fig. 2.). Bjelašnica represents a large Dinaric plateau stretching from northwest to southeast, over a length of 22 km.

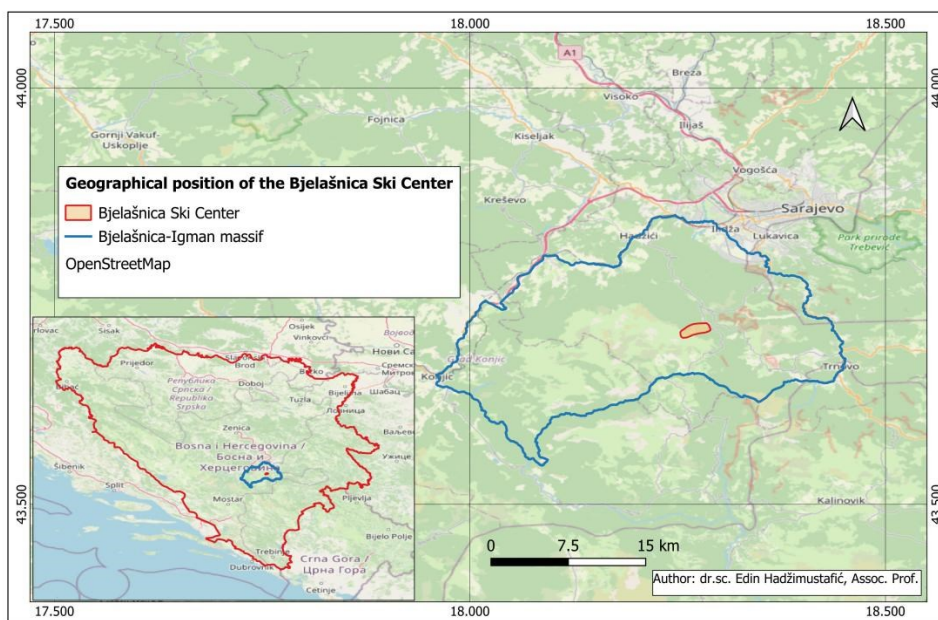


Fig. 2. Geographical position of the Bjelašnica Ski Center (*Source: created by authors*)

Bjelašnica borders the Igman mountain in the north, but since they form the same mountain massif with Bjelašnica, they can be considered as one unit. Bjelašnica and Igman Mountain are bounded from the north by the Sarajevo Field, the Zujevina River and the Željeznica; to the east is the border from Sarajevo polje from the river Željeznica across Hojta, through the canyon of the river Rakitnica; to the west is the border from the river Zujevina across Ivan-sedlo and the river Trešanica, the right tributary of the Neretva. From the south, it is bordered by the river Rakitnica and Neretva (Mihić, 1984).

The geological structure of Bjelašnica is dominated by limestone and dolomite. In geomorphological terms, it has a karst and glacial relief, represented by plateaus, valleys, fields, sinkholes, pits and caves. According to geomorphological regionalization, it is located in the Macroregion of the High Central Dinarides (Lepirica, 2009).

Bjelašnica is divided into High and Low. The Bjelašnica Ski Center is located in the extreme northeastern part of High Bjelašnica. From the highest northeastern ridge of Bjelašnica, where the highest peak of the Observatory is located (2,067 m), towards Babin dol, a slope with ski trails stretches. The slopes of the Ski Center are built of Triassic limestones that genetically belong to the covered karst.

This area has a mountain climate, and the highest peaks have characteristics of an alpine climate. For the period 1961-1990. the average annual air temperature was 1.2°C (FHMZ). The annual amount of rain and snow precipitation is, on average, more than 2,000 mm, depending on the altitude. Snow remains for three to six months. Snow cover greater than 10 cm usually lasts 160 days a year, from late November to May (Sivac et al., 2024).

In hydrological terms, the area is a watershed between the Black Sea and Adriatic basins, which, due to the karst terrain, is characterized by the absence of significant surface flows. Botanical research on Bjelašnica has been extensive and the mountain has beech forests, beech and fir forests, with very little spruce. Also, on Bjelašnica we find forests of mountain pine (Balijan, 2017).

For quantitative analysis of ski slopes in geographic information systems, vector and raster data models were used. The ski slopes were taken from the OpenStreetMap (OSM) website. The relief of the slopes of the Bjelašnica ski center was analyzed using the global SRTM Digital Elevation Model with a spatial resolution of 30 m (USGS). Data analysis was carried out in geographic information systems, QGIS 3.34.3 software. All geographic data models were reprojected into a

single Gauss-Kruger coordinate reference system, which is the reference for the area of Bosnia and Herzegovina.

Ski trails on OSM are shown in segments, for which quantitative parameters have been calculated. These segments do not reflect the real situation, because these parts of the trail were not selected according to the uniformity of the slope on them. Therefore, it was necessary to first connect the segments of individual trails, and then continue their analysis.

The first step is to download tracks, or their segments (if the track is made up of several parts), and connect them into one whole. This gives a complete path from one part, from beginning to end, which made it possible to calculate its length. After that, the ski slope, or rather the line that represents it, is divided into a series of points at equal distances (in our case, every 20 m). After obtaining the points, a longitudinal topographic profile of the entire ski track was made. The topographic profile shows the slope angles of the track, so it can be used to distinguish parts that have a similar slope, that is, to determine the boundaries where the slope changes rapidly. For those parts with a uniform slope, points that were previously formed are selected. These parts of the ski slope, represented by points with a similar slope angles, are exported to separate files. The points are connected into lines in order to later determine their lengths and display the weights. These files also need to be saved.

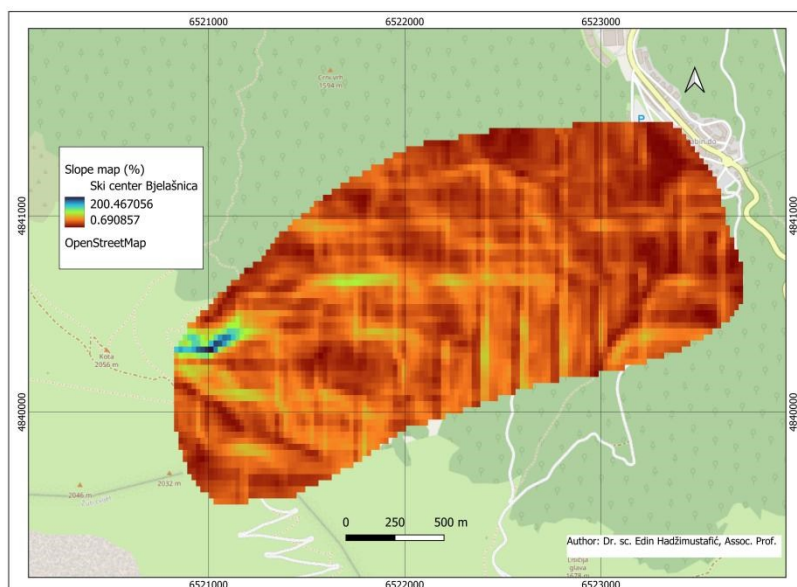


Fig. 3. Slope angle map of Bjelašnica ski center (*Source: created by authors*)

For slope angles and aspect analysis Digital Elevation Model of Bjelašnica ski center was used. The slope angles expressed in percentages are DEM (Fig. 3.). It served as the basis for determining the statistical parameters of the tracks and their parts. From the same digital elevation model, slope orientations were derived, which were later used to analyze the aspect of ski slopes (Fig. 4.).

The points that were previously extracted are assigned slope and aspect values from the raster. These obtained values are saved in Microsoft Excel where further statistical analysis was performed. Calculated statistical values are: minimum, maximum, average and standard deviation. The average slope value also indicates the difficulty of the ski slope.

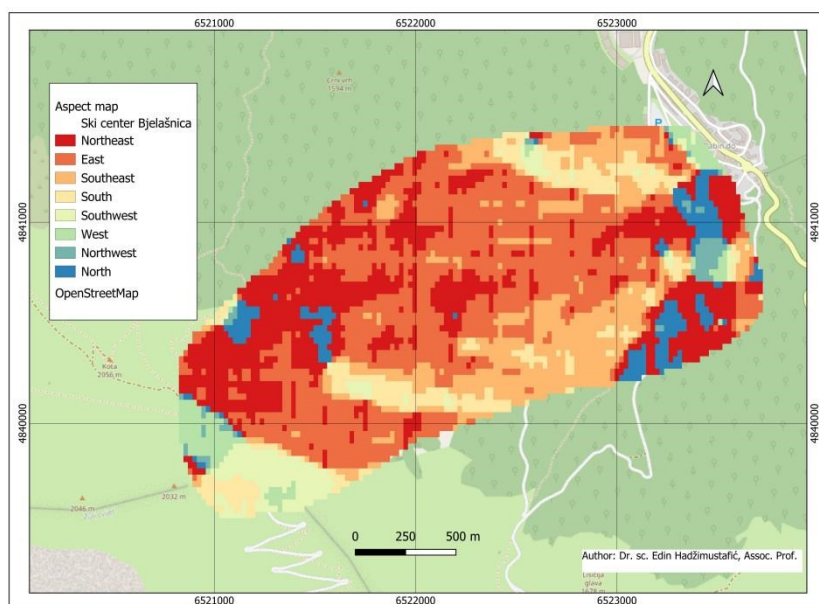


Fig. 4. Aspect map of Bjelašnica ski center (*Source: created by authors*)

The difficulty of ski slopes in the Alps is classified using color codes: Green for beginners, Blue for intermediate, Red for difficult and Black for expert slopes. Slope from 0 - 20%, has a green ski track. Maximum slope of 20 - 30%, blue ski track. Slope from 30 to 45%, red track and slope over 45%, black ski track (Fig. 5.).

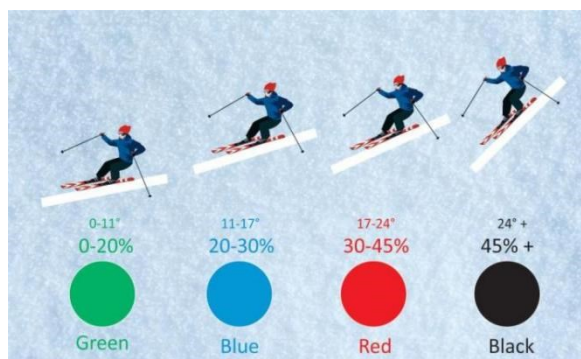


Fig. 5. Color codes for determining the difficulty of ski slopes (*Source: created by authors*)

In order to provide a clearer visualization of the ski trails and their difficulty, 3D terrain models were created to display them. They highlight the difficulty of the trails in colors that correspond to the specified classification.

RESULTS AND DISCUSSION

At the Bjelašnica Ski Center, a quantitative analysis of six ski slopes was conducted: ski slope “Downhill”, ski slope “Slalom and giant slalom”, ski slope “Štinji Do”, ski slope “Vučko”, ski slope “Kolijevka” and Training ski slope. Altitudes, lengths, slope angles, aspect were analyzed, slope difficulties were determined, and topographic profiles of all six trails were created. When determining trail weights, most trails were divided into individual segments with the same weights. This clearly and precisely highlights the difficulty of the trails, which is necessary for skiers visiting the ski center for the first time. Green slopes have the lowest gradient, for absolute beginners with no experience. Injuries are very rare. Blue slopes are wide, with gentle slopes, ideal for beginner skiers, the risk of injury is reduced. Medium-difficult slopes or red slopes require much more skill and experience from skiers. They have steeper sections and various obstacles. Experienced skiers ski on difficult or black slopes. They are steep, with increased slopes and sudden changes in the terrain. The risk of injury is very high. The management of ski centers must take care to inform skiers about the difficulty of ski slopes, or the potential risks they carry, in order to increase safety and reduce possible injuries.

We could not find on the official web portals that the difficulty of the trails by segment is shown on a map. There is only a general division of trails by difficulty, coded in colors. For the entire trails, as well as individual sections, a statistical

analysis was performed with calculated values: minimum, maximum, average and standard deviation.

The data obtained could only be compared for the Ski slope “Downhill” and the official “Downhill” track on the website of the Ski Center Bjelašnica - Igman (Ski Center Bjelašnica - Igman). A slightly different methodology was used for the other slopes and they could not be compared.

Ski slope “Downhill”

The “Downhill” ski slope was built for the competition at the XIV Winter Olympic Games. The total length of the “Downhill” ski slope is 2,840 m. According to official data from the Bjelašnica - Igman Ski Center, the length of this slope is 2,830 m (Ski Center Bjelašnica - Igman). The slope starts at the highest peak of Bjelašnica at 2,067 m and ends in Babin Do at 1,270 m. The configuration of the slope is shown by a topographic profile (Fig. 6.).



Fig. 6. Longitudinal profile of Ski slope “Downhill” (*Source: created by authors*)

The average slope angle of the “Downhill” ski slope is 33%, which matches the official data (Ski Center Bjelašnica - Igman). It is divided into four parts with lengths calculated from the initial part of the slope to the final one. The first part is 470 m long, with an average slope of 48%, which places it in the Black category of ski slope difficulty. The second part continues the previous one, with a length of 500 m and an average slope of 19%, or the Green category of ski slope difficulty. The third part of the slope is the longest, with 1,380 m and an average slope of 37%, which places it in the Red category of ski slope difficulty. The final part of the slope, with a length of 490 m and an average slope of 22%, places it in the Blue category of ski slope difficulty.

The average aspect of the upper Black category part of the ski slope is 24°, which is a northern aspect. The second part or Green category of ski slope difficulty, has an average aspect of 77°, which is an eastern aspect. The third part of the ski slope, has

a northeastern aspect with a value of 67° . The final part of the ski slope, with a difficulty of Blue category, has an eastern aspect or 84° .

Tab. 1. The results of the quantitative analysis of the “Downhill” ski slope

Piste segment	First	Second	Third	Fourth
Length (m)	470	500	1380	490
Statistical analysis				
Min	8.62	1.34	13.13	6.78
Max	79.32	43.35	70.69	39.66
Average	48.23	18.71	37.39	21.62
StDev	18.72	10.26	12.78	10.55
Ski piste difficulty	Black	Green	Red	Blue

Source: authors

The total length of the trail, divided into parts by difficulty, is shown on the 3D model of the Bjelašnica ski center (Fig. 7.).

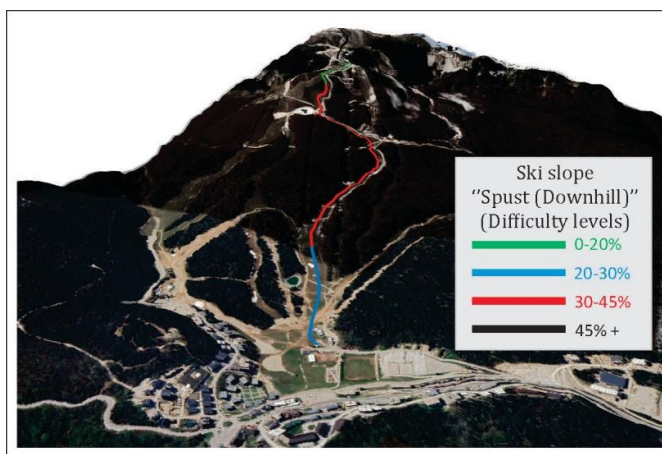


Fig. 7. 3D model of difficulty levels of Ski slope “Spust (Downhill)” (*Source: created by authors*)

Ski slope “Slalom and giant slalom”

The ski slope “Slalom and giant slalom” was used for slalom races and giant slalom at the XIV Winter Olympic Games. The length of the “Slalom and giant slalom” ski slope is 1,520 m. It starts at an altitude of 1,871 m and ends at 1,372 m. The path is shown with a longitudinal topographic profile, where its slope is clearly visible, as well as the height difference between the starting and ending points (Fig. 8.).

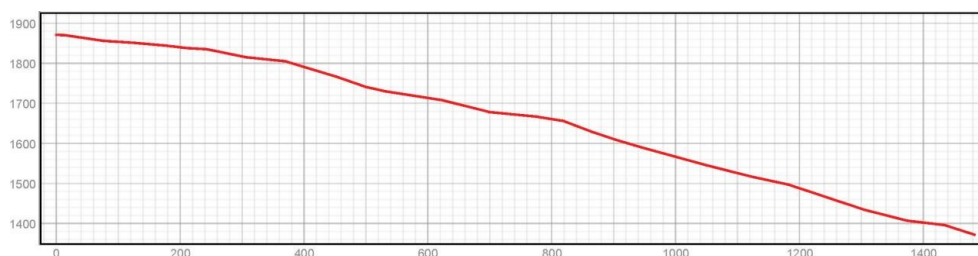


Fig. 8. Longitudinal profile of Ski slope “Slalom and giant slalom” (*Source: created by authors*)

A statistical analysis was performed on two segments of the ski slope. The first or upper part has a length of 385 m and an average slope of 24%, which places it in the Blue category of ski slope difficulty. The second or lower part of the ski slope has a length of 1,135 m and an average slope of 40%. According to the difficulty of the slope, it falls into the Red category.

The first part of the ski slope is oriented towards the northeast with an average aspect value of 60° . The second part of the ski slope has an average aspect value of 88° , which is the east direction.

Tab. 2. The results of the quantitative analysis of the “Slalom and giant slalom” ski slope

Piste segment	First	Second
Length (m)	385	1135
Statistical analysis		
Min	4.59	16.42
Max	51.88	75.09
Average	24.12	40.16
StDev	10.15	14.49
Ski piste difficulty	Blue	Red

Source: authors

The ski slope “Slalom and giant slalom” is shown on the 3D model of the ski center Bjelašnica, with its two segments (Fig. 9.).

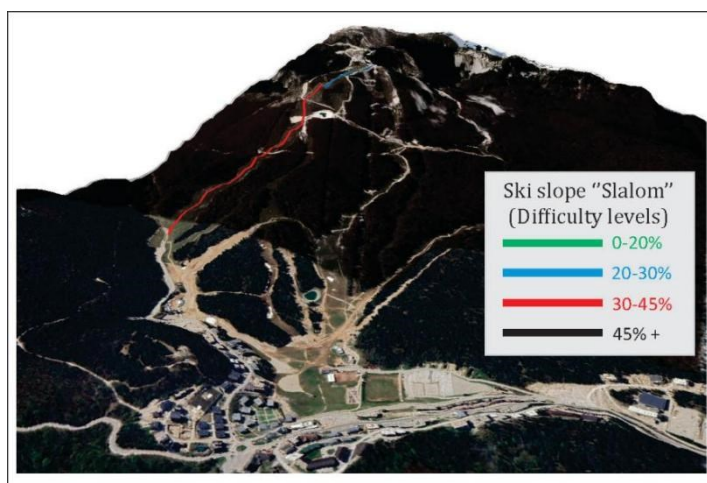


Fig. 9. 3D model of difficulty levels of Ski slope “Slalom and giant slalom”
(Source: created by authors)

Ski slope “Štinji Do”

The ski slope “Štinji Do” continues the previous ski slope “Slalom”. It is the shortest track with a length of 985 m. According to Temimović, E. and Muratović, M., (2015), the length of this track is 1,047 m. The beginning of the ski trail is at 1,372 m, and the end is in Babin Do at 1,271 m. The total length and slope angle changes of the ski track are shown on the longitudinal profile (Fig. 10.).

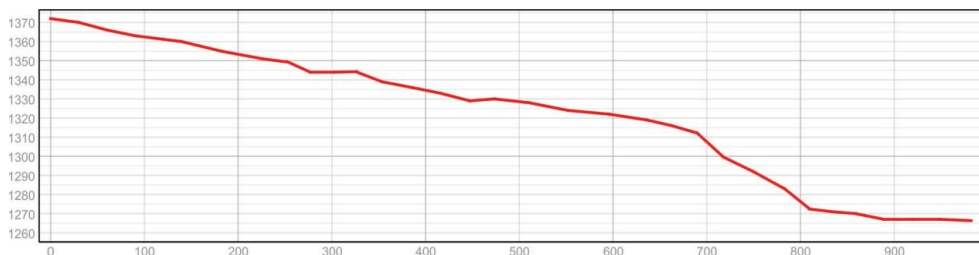


Fig. 10. Longitudinal profile of Ski slope “Štinji Do” (Source: created by authors)

The ski slope “Štinji Do” has an average slope angle of 15%, and according to the difficulty of the trail, it is classified as Green category. The average aspect of the ski slope is 96°, oriented towards the east.

Tab. 3. The results of the quantitative analysis of the “Štinji Do” ski slope

Statistical analysis	
Min	3.05
Max	39.36
Average	15.30
Mode	9.33
StDev	9.15
Ski piste difficulty	Green

Source: authors

A 3D model was created for this slope, for a clearer visualization of the track and its surroundings (Fig. 11.).

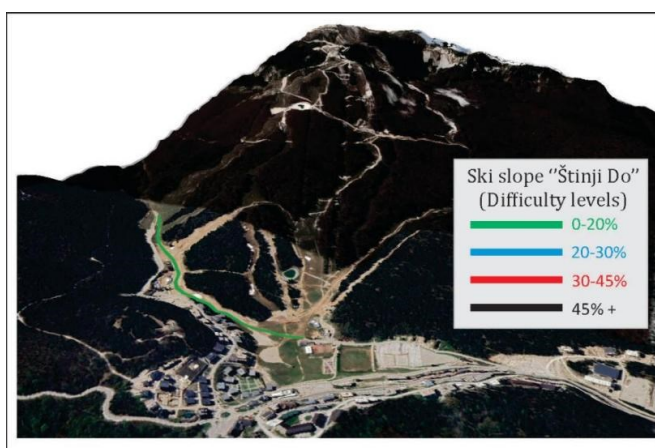


Fig. 11. 3D model of difficulty level of Ski slope “Štinji Do” (*Source: created by authors*)

Ski slope “Vučko”

Ski slope “Vučko” was named after the official mascot of the XIV Winter Olympic Games. It has a length of 1,988 m, starting at 1,868 m and ending at 1,268 m in Babin Do. The appearance of the slope, its configuration and any changes in slope angles are shown on the longitudinal profile (Fig. 12.).

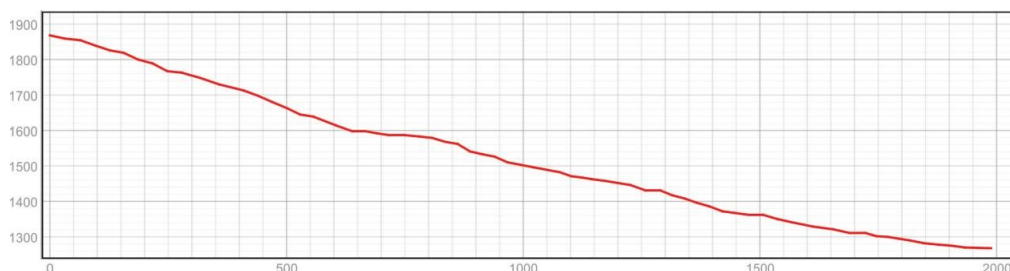


Fig. 12. Longitudinal profile of Ski slope “Vučko” (*Source: created by authors*)

The trail is divided into two parts according to gradients or difficulty. The first or upper part is 640m long, with an average slope angle of 44%, which according to the weight puts it in the Red category. The second or lower part of the trail with 1,345m and an average slope angle of 27%, according to the difficulty of the trail, is classified as Blue. The first part of the ski slope is oriented towards the northeast with an aspect value of 37°. The second part of the ski slope has an eastern aspect with value of 73°.

Tab. 4. The results of the quantitative analysis of the “Vučko” ski slope

Piste segment	First	Second
Length (m)	640	1345
Statistical analysis		
Min	17.82	5.53
Max	76.44	60.58
Average	44.61	27.65
Mode	35.63	18.68
StDev	13.08	11.13
Ski piste difficulty	Red	Blue

Source: authors

In order to visualize the track more clearly, its 3D model was created (Fig. 13.).

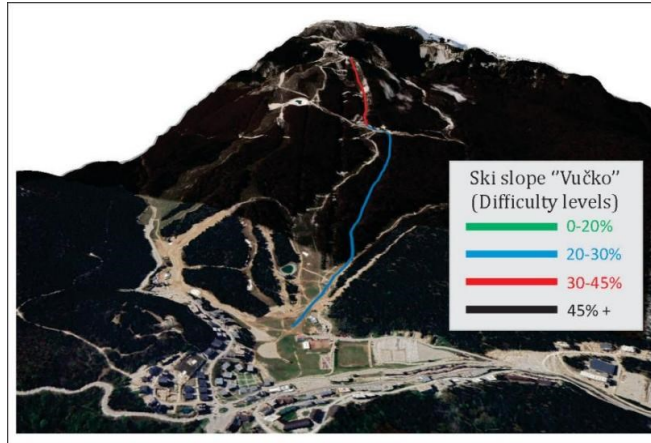


Fig. 13. 3D model of difficulty levels of Ski slope “Vučko” (Source: created by authors)

Ski slope “Kolijevka”

The ski slope “Kolijevka” has a length of 2,423 m. It starts at 1,861 m and ends at 1,268 m. The appearance of the track, with its length and slope angles, is shown in a longitudinal profile (Fig. 14.).

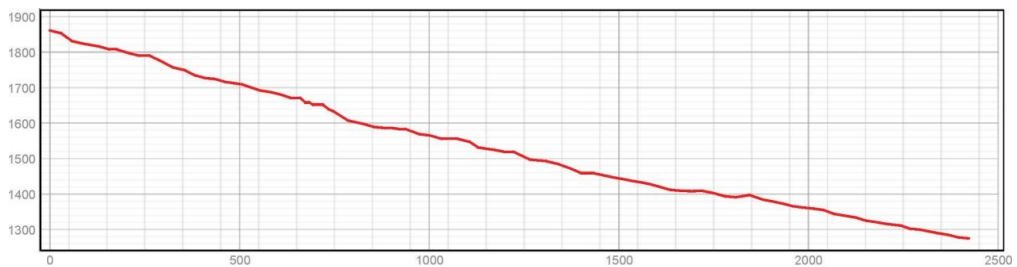


Fig. 14. Longitudinal profile of Ski slope “Kolijevka” (Source: created by authors)

Ski slope “Kolijevka” has a uniform slope angle of 29%, which can also be seen on its longitudinal profile. According to the ski slope difficulty, it is classified as Blue. Ski slope “Kolijevka” has an average aspect of 95°, that is, it is oriented on average towards the east.

Tab. 5. The results of the quantitative analysis of the “Kolijevka” ski slope

Statistical analysis	
Min	7.60
Max	62.19
Average	29.03
Mode	44.10
StDev	10.34
Ski piste difficulty	Blue

Source: authors

A 3D model of the Ski slope “Kolijevka” was also made, so that the length, slope angles and relief can be visually analyzed (Fig. 15.).

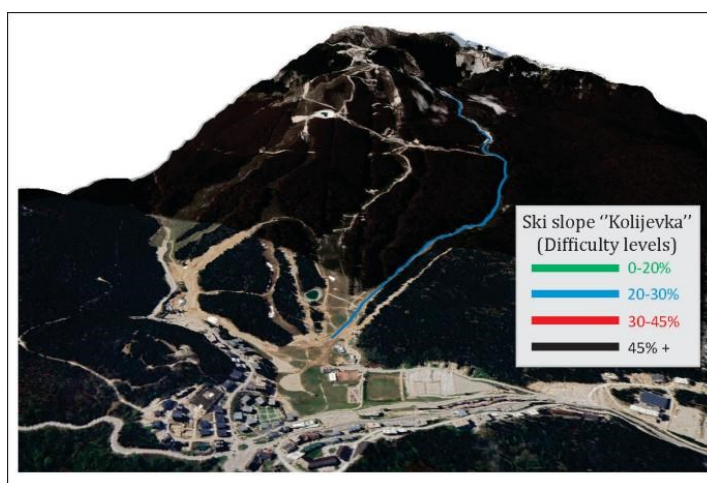


Fig. 15. 3D model of difficulty levels of Ski slope “Kolijevka” (*Source: created by authors*)

Training ski slope

Finally, the Training ski slope, which has a length of 1,593 m, was analyzed. It starts at 1,615 m and ends at 1,268 m. The longitudinal profile shows the configuration of the terrain, its slope angles and length (Fig. 16.).

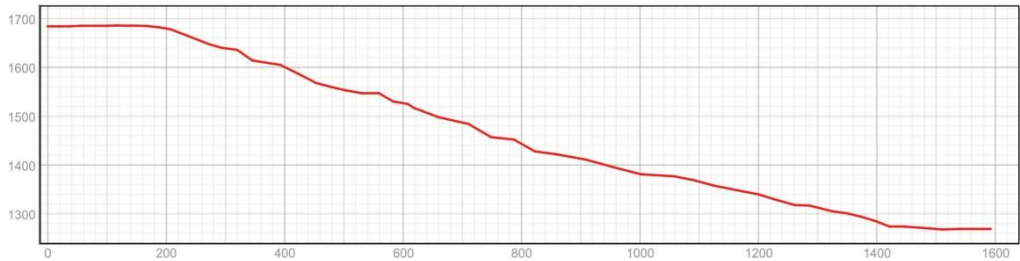


Fig. 16. Longitudinal profile of Training ski slope (*Source: created by authors*)

The training ski slope is divided into three parts. The statistical analysis conducted determined that the average slope of the initial part of the slope angle is 30%, so the ski slope difficulty is in the Blue category. The middle part of the slope has an average slope angle of 34%, the ski slope difficulty is in the Red category. And the lower part of the slope has the smallest slope of 19.6%, which places it in the Green category of ski slope difficulty, although this value is on the very border between the Green and Blue slopes. The upper and middle parts of the Training ski slope are oriented towards the east with average aspect values of 85° and 70°, respectively. The lower or final part of the ski slope has a northeast aspect with a value of 63°.

Tab. 6. The results of the quantitative analysis of the Training ski slope

Piste segment	First	Second	Third
Length (m)	375	935	305
Statistical analysis			
Min	11.47	14.70	5.53
Max	61.56	61.56	38.93
Average	29.92	34.51	19.63
Mode	11.47	26.72	25.83
StDev	14.81	11.76	10.50
Ski piste difficulty	Blue	Red	Green

Source: authors

A 3D model of the Training Ski slope was also made, so that the length, slope angles and relief can be visually analyzed (Fig. 17.).

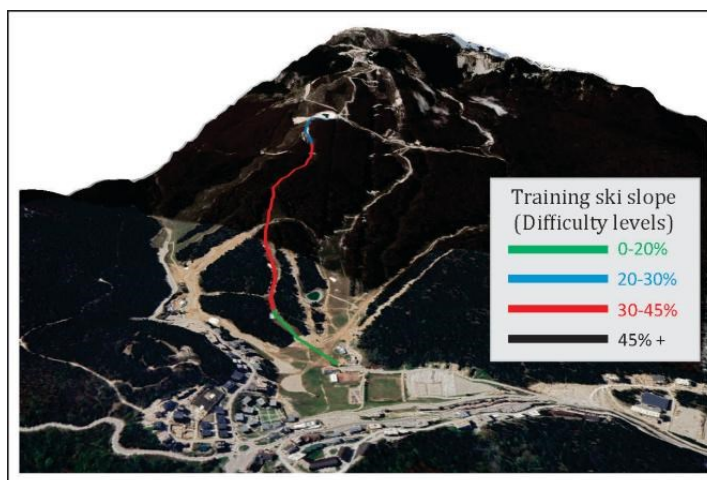


Fig. 17. 3D model of difficulty levels of Training ski slope (*Source: created by authors*)

In terms of sustainable trail management, ski slopes should be designed and maintained in a way that minimizes the impact on the human environment. This includes the use of natural materials for the construction of ski slopes, as well as the preservation of local flora and fauna. The preservation of natural trails and mountain landscapes contributes to the preservation of the ecosystems themselves, which is of huge importance for the biodiversity of the area and the health of mountain areas.

CONCLUSION

Bjelašnica Mountain is very attractive and has been valorized as a tourist destination. Its attractiveness began after the XIV Winter Olympic Games. It is home to a ski center with eight ski slopes, six of which are analyzed in this paper. A quantitative analysis was conducted in geographic information systems. This method gives good and very precise results. It can be applied to any ski slope, anywhere in the world. A digital elevation model with a spatial resolution of 30 m was used in this paper. The accuracy of the results would increase if a digital elevation model with a better resolution were used.

Finally, to conclude in general, skiers should choose ski slopes correctly according to their own skills and experience, which is crucial for skiing safety. Likewise, one should adhere to the rules of skiing and be aware of the conditions on the ski slopes, the most important of which are the current weather conditions and snow depth. Also, the difficulty of the slopes plays a significant role in shaping the experience of

individual visitors or entire families, affecting their safety and security, the level of enjoyment of the skiers and their confidence.

This paper represents a contribution to the development of ski tourism in Bosnia and Herzegovina. It can also help in making decisions about the development and maintenance of ski centers, improving infrastructure, strengthening winter tourism and preserving the natural resources of the area.

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