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Fuzzy Techniques for Artificial Snow Cover Optimization in the Ski Areas. Case Study: Obârșia Lotrului (Southern Carpathians, Romania)

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Abstract: This paper focuses on the environmental conflicts induced by insufficient continuous snow cover on the ski areas in Romania. The case study aims envisions the area of Southern Carpathians, Latoriței Mountains, belonging to the group of Parâng Mountains. The area chosen to develop and improve the artificial snow system was conducted for in the proposed ski area, Obârşia Lotrului. This fulfilled a necessary condition (geomorphological and climatic) for the development of the ski domain. The methodology focuses on two main stages phases. In the first stage phase, based on the GIS, the areas that have shown problems in terms of continuity of the snow layer and its thickness were identified, while the second phase, there is a supposed optimization based on Fuzzy logic for the installation of artificial snow. The corresponding thickness of snow for a longer period of time can lead to a higher socio-economic efficiency, as well as the increase of the use duration of the respective ski area, and also a prevention mechanism to environmental conflicts that may arise. The proposed study supports civil society by optimizing artificial snow machines through a positive impact on water resources allocated to a ski area in order to maintain a continuous snow cover.

Keywords: fuzzy logic; optimization; ski area; environmental conflicts; Southern Carpathians; Romania

1. Introduction

The sustainability of the space, particularly the mountainous one, has become a major challenge for the last two decades, especially within the context of global changes in the environment. The elements and the anthropic activities are intensely affected by more and more visible outcomes, such as the accelerated glacier and snow melting, the intensification of ciclicity, and intensity of extreme phenomena.

Winter sports constitute some of the most affected activities that are specific to the mountainous space by the restrainment of the period when they can be practiced. This is a direct consequence of global warming, which leads to accelerated snow melting, and diminished solid precipitations.

In order to establish a balance in efficiently using the resources of the mountainous spaces, there is a need to develop new solutions for analysis and control on the relation between the natural and anthropic elements.

Therefore, the Fuzzy analysis that we propose may become a genuine and highly useful instrument for the economic environment, directly linked or related to winter sports, in view of a sustainable development of the new ski resorts or for their efficient management.

The interest in the topic addressed in this study concerns the issues regarding winter sports in Romania, as most of ski areas are not recording over 1500 m optimum altitude. Even if there are 92 ski areas in Romania, only eight of these are situated between 1500 to 1800 m [1].

The uniformity of snow cover (minimum 30 cm) on the surface of the ski slopes is required for the practice of the winter sports in good conditions. Though the geomorphological character of each ski domain can be identified, according to its characteristics, the areas where snow has deficiencies in recording the minimum thickness for good practice of the winter sports. Along with the geomorphological factors, the climatic factors represent another category of defining the areas where the snow cover will not have a continuous nature.

In recent years, interest in efficient snowmaking systems in ski areas has become increasingly powerful, and many studies are being conducted by researchers worldwide. According to the results obtained from the query of the Web of Science database (WoS), using the keywords "ski area", 851 ISI articles have been published in recent years. Most of these address areas such as environmental sciences (193 articles), sport sciences (114 articles), geology (87 articles), and geography (30 articles). The following figure illustrates the most relevant research areas of the articles published in ISI journals and the number of published papers according to year. It can be observed that recently, the number of published ISI articles have significantly increased, the year of 2013 representing the apogee in terms of interest for this domain (Figure 1).

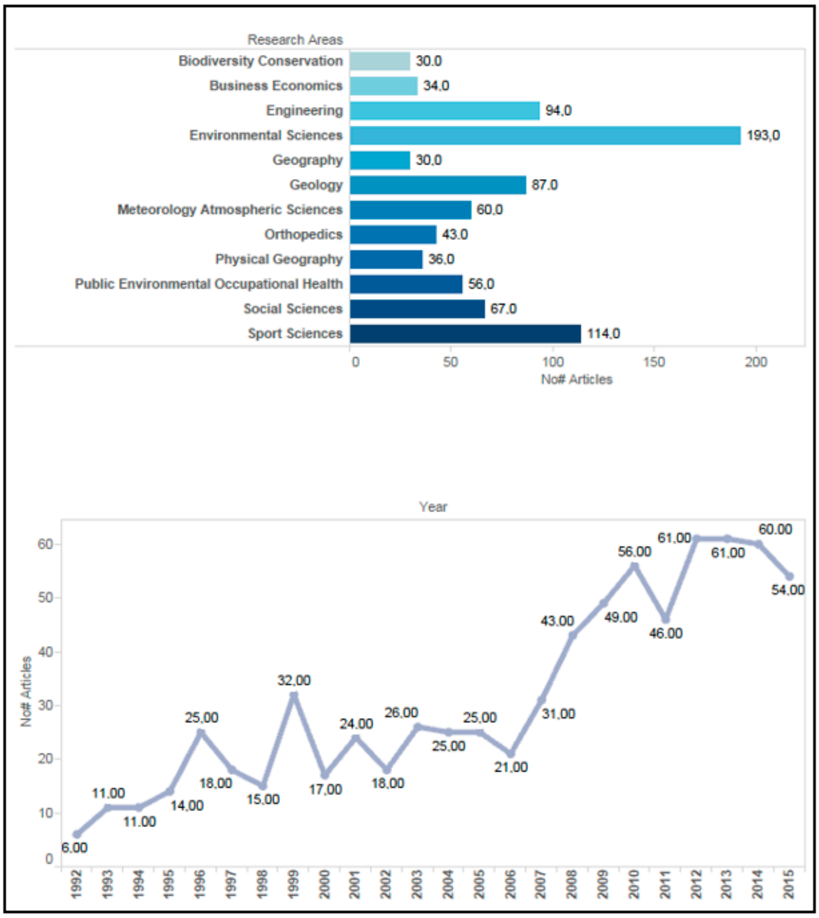

Figure 1. The research areas and the evolution of the published articles in the field.

In terms of geographical distribution of the authors, most of the articles came from the USA, followed by Austria, Canada, Switzerland, and Germany. Only 11 ISI articles were published by Romanian authors. These articles refer to issues related to GIS assessment of a winter sports resort location [2], landslide susceptibility assessment in urban development [3], the resolution of land-use conflicts [4], snow avalanche risk assessment [5,6], and mountain tourism [6]. The risk assessment can be done by identifying and monitoring the (key risk indicators) KRIs [7,8]. The study conducted by Dezsi et al. (2015) focuses on the impact of tourism infrastructure on the development of an area, using a spatial analysis model for predicting the optimum location of a ski resort. The research conducted by Mihai et al. (2014) approached an analysis for mitigating the potential natural hazards that are influenced by an urban extension of a resort in areas covered by landslides, the article's results showing the consequences of landslides using an urban development scenario. Magnier's (2016) [9] approach showed that sharing the water resource in a specific mountain environment could be a risky situation in the moment when a particular lake or hillside collector permits the water supply for production of snow and drinking water.

In the study realized by Tudor et al. (2014), four cases of land-use conflicts in terms of the resolution performance and factors of influence were analyzed using the Analytic Network Process. Voiculescu, Popescu (2011), Voiculescu, Ardelean (2012), Voiculescu et al. (2012), and Voiculescu, Onaca (2013) analyze the ski areas (the hazards that affect inclusively) in the Carpathians (Bucegi, Banat Mountains, the Mic, Tarcului Mountain), and also their development perspectives. The features of the ski slopes from the Carpathians Mountains are analyzed by Lesenciu et al. (2013).

The exploitation of tourism potential in Romania was analyzed by Nistor et al. (2010), in which the research offering new approaches for promoting the Romanian tourist products [10]. Popescu, Petrisor (2010) approached the accessibility in the mountainous space in Romania by using GIS and possibilities of superior capitalization, taking into consideration their insufficient valorization. As a consequence, the analyzed region is included into the group of regions with reduced infrastructure and accessibility. In 2008, Sandric used a Bayesian approach with error propagations for hazards assessments [11].

Internationally, the studies published on ski areas were approaching aspects regarding snow management and snowpack models [11]. Within this study, an assessment of the snow cover in ski resorts during all seasons was realized, and the model provided simulation of the snowpack. Professor Buhler and his co-authors studied the mapping snow depth in alpine terrain using unmanned aerial systems [12], while Deems [13] also studied the mapping starting zone snow depth with a ground-based lidar in order to predict snow avalanche. The awareness programs for snow avalanches were analyzed by [14].

The influence of ski infrastructure on the local development and environmental sustainability was analyzed by Cuka in 2015 [15], starting from the incidence factors of the tourism development.

According to the results generated by the WoS database query by keywords "ski", "area", and "Fuzzy logic", only one ISI article was published using this computational intelligence technique. This article was published in 2004 [16] and addresses a natural hazards risk analysis using a Monte Carlo simulation and the Fuzzy set theory.

The Fuzzy analysis spatially highlights the favourable ski areas with snow supplement, but also the unfavourable ones with snow deficit. Additionally, the analysis provides information regarding the differences between the two types. One can accurately measure the ski areas by applying the fuzzy analysis, and also collect information concerning the cost-benefits analyses and economic profitability of such type of investment.

In a concrete manner, the Fuzzy instrument underlines the favourable conditions to build ski areas while avoiding situations when ski areas can be used only for a reduced time period in one year due to snow shortage.

The Fuzzy analysis is successfully used in several geographic fields, particularly in the ones with impact on anthropic elements, but scientific papers using the Fuzzy analysis for establishing the sustainability of the ski area have not been identified in specialized literature so far. Significant analyses in the fields of urban-rural [1,2], concerning the environmental planning [3,4], The Fuzzy Cognitive Map related to the functional transformation of the urban space, the transformations of the European landscape [5,6], the ecological benefits [7], and the assessment of regional functions [8] were identified instead.

The Fuzzy analysis is made in strict connection with landscaping features, certification, maintenance, exploitation of the ski slope, and trails for leisure regulated by Government Decision no. 263/2001, and also by Order of the Minister of Turism no. 491/2001 for approving the rules regarding ski areas.

Romania is consistently affected by the outcomes of global warming in mountainous spaces, as there are ski resorts erroneously placed where skiing cannot be practiced any day per year, or other ski areas where the shortened time frame for practicing ski leads investments to economic failure. Consequently, The Fuzzy instrument can be used inclusively in the region of medium height mountains (under 3000 m) in temperate climate, where the impact of global warming on ski areas is emphasized. Price (ed.) (2000) stresses the necessity to develop the tourist infrastructure in the mountainous space, the ski slopes inclusively.

Case Study

The area selected for this study represents an "unexplored" one from the Southern Carpathians, in this case, the Latoritei Mountains of the Parang Mountains, Figure 2. The Obârşia Lotrului resort, which will support the ski area, is the perfect setting for this development. In addition to these favorable aspects (geomorphological and climatic factors) for the development of Obârşia Lotrului resort, Vidra resort, which is situated near Obârşia Lotrului, also indicates the suitability of the area for the development of the ski domain. The most common forms and types of tourism practiced in this area are hiking, recreation and recreation, and tourism related to winter sports.

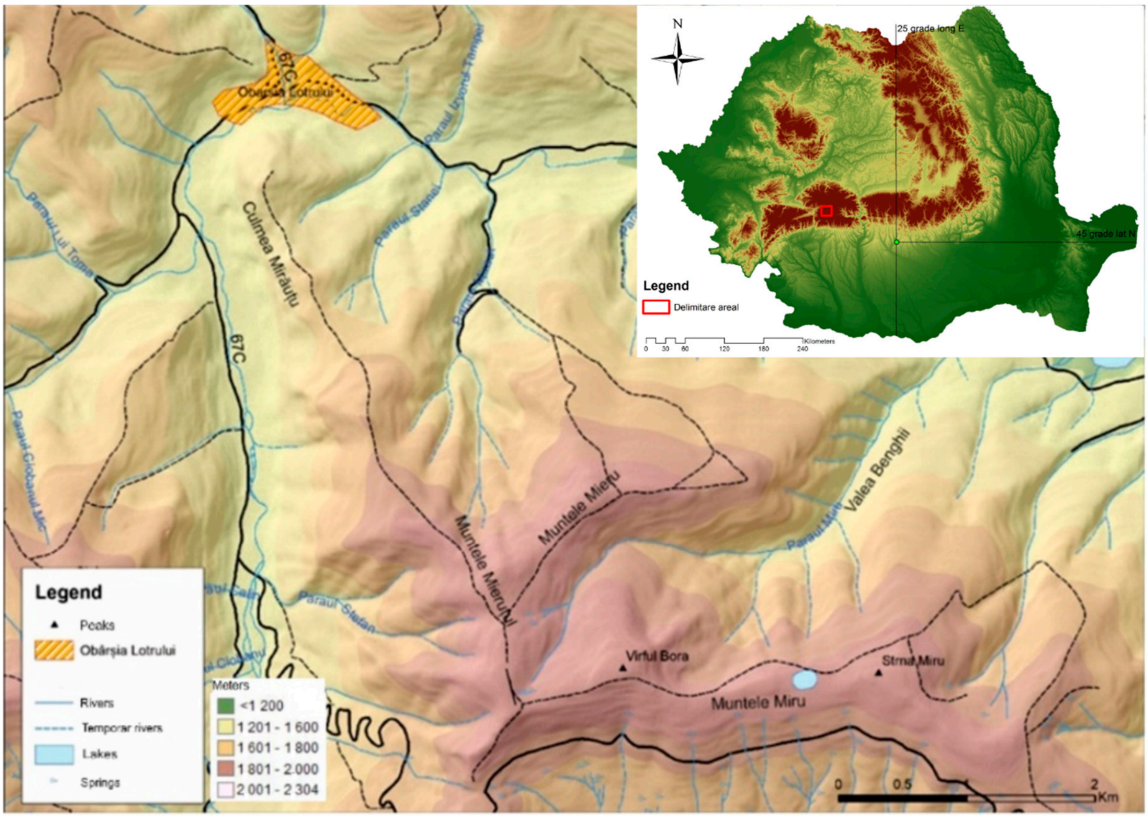

Figure 2. The study area: Obârșia Lotrului (Southern Carpathians, Romania).

The specific feature of the analyzed area is given by the fact that it is situated in the interference area between the alpine domain and the forest domain, and from the altitudinal point of view, it is overlapped with the hypsometric steeps between 1200 m and 2000 m which, from the microclimate perspective, leads to some large variations. This aspect has direct and imported consequences on the the main parameters variation, which contribute to the sustainable exploitation of a ski domain. Thus, the amount of solid precipitation, the duration and thickness of the snow cover, and the solar radiation are elements which require a deep analysis, especially in the current context of climate change.

The studied surface is approximate 565.0 ha. The area between Mount Miru and Obârşia Lotrului has 103 ha, lying between the north of the Lotru valley and south of the Latoritei valley.

2. Materials and Methods

The chosen area will be achieved using the relationship between the incidence degree of sun rays on the topographic surface and the hypsometry, geodeclivity, the slopes, and solid precipitation. The study was conducted over two stages consisting in analysis models. The first model of analysis will be made using the GIS program and the second part of the model will be made using Fuzzy logic.

The methodology used in this study aims, in the first part, the identification of the areas where the snow cover has deficiencies in recording the minimum necessary thickness.

The methodological approach may have a new character for the modern techniques of analysis and modeling a set of data generated and used in several stages (Figure 3). The suitability map can be a strategic decision tool for both the development of the tourist infrastructure and their management. The suitability map is the result of the integrated analysis of all the defining, restrictive, and favorable factors for the implementation of the investment objectives.

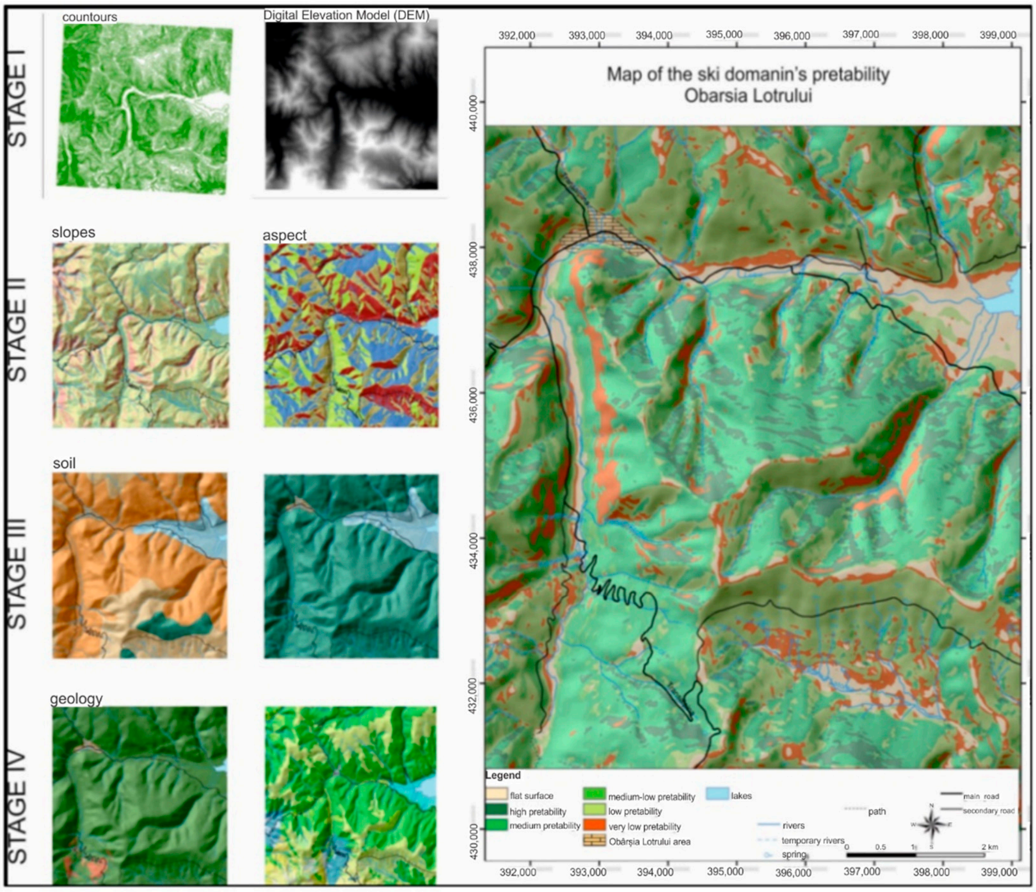

Figure 3. Map of ski domain's pretability suitability.

For this, the raster multiplication technique was used and was realized and reclassified in intervals of values the following maps: the exposure slopes map, the geodeclivity map, and the hypsometric map (see table of values). Afterward, the raster operation resulted in a map, which was reclassified into three classes of favorability of the snow cover. The minimum favorability class is defined by the following parameters: an altitude lower than 1200 m, southern, southeast, or southwest exposure, and geodeclivity between 5 and 15 degrees (Table 1).

Table 1. Classification of geomorphologic factors, according to the favorability.

No.	Exposure	Favorability	Geodeclivity	Favorability	Altitude	Favorability
1.	N	high	5–15	small	< 1200	small
2.	N-E		15–25	average	1200–1600	average
3.	E	average	25–35		> 1600	high
4.	S-E	small	35–45	high		
5.	S					
6.	S-V					
7.	V	average				
8.	N-V	high				

Within the second phase of the methodology, the development of the Fuzzy logic system was simulated using MATLAB programming language. Building the Fuzzy logic system took four steps: establishing the input variables and the related Fuzzy sets, the Fuzzy rule base identification, the establishment of the Fuzzy inference operators, and the neural control [17,18] (Figure 4).

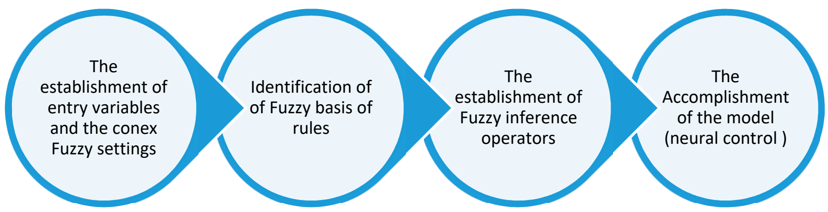

Figure 4. Fuzzy controller.

The input variables were set in the first step of the Fuzzy logic system: aspect, geodeclivity and altitude, as well as the output variable (result): the output Fuzzy range, which indicates the optimal necessary quantity of snow for winter sports. The input variables of the system are arranged according to the size of their impact on the favorability for practicing winter sports.

The variable exposure is structured in three categories: high exposure (1E), medium exposure (2E), and small exposure (3E). Geodeclivity was identified in three classes: small geodeclivity (1G), average geodeclivity (2G), and high geodeclivity (3G). Regarding the altitude, this variable was also structured in three classes: small altitude (1A), average altitude (2A), and high altitude (3A).

For the output variable, the output Fuzzy range is determined by the Fuzzy rules base and Fuzzy inference operators; as well as by the expert assessments, being divided into three categories: small (OFR1), medium (OFR2), and high (OFR3). For a complete definition of the Fuzzy set using the input variables, the following triangular membership function was established.

The Fuzzy logic uses the membership degree of an object to the crowd. So, for the three elements of the study (aspect, geodeclivity and altitude), a vector was created (Ak, Gj, Ei) where i, j, and k take values from the set {3, 2, 1}, representing the possible combinations of aspect (E) geodeclivity (G) and altitude (A). The underlying value ranges that are set at the basis of the Fuzzy controller to optimize installations of artificial snow are (Figure 5):

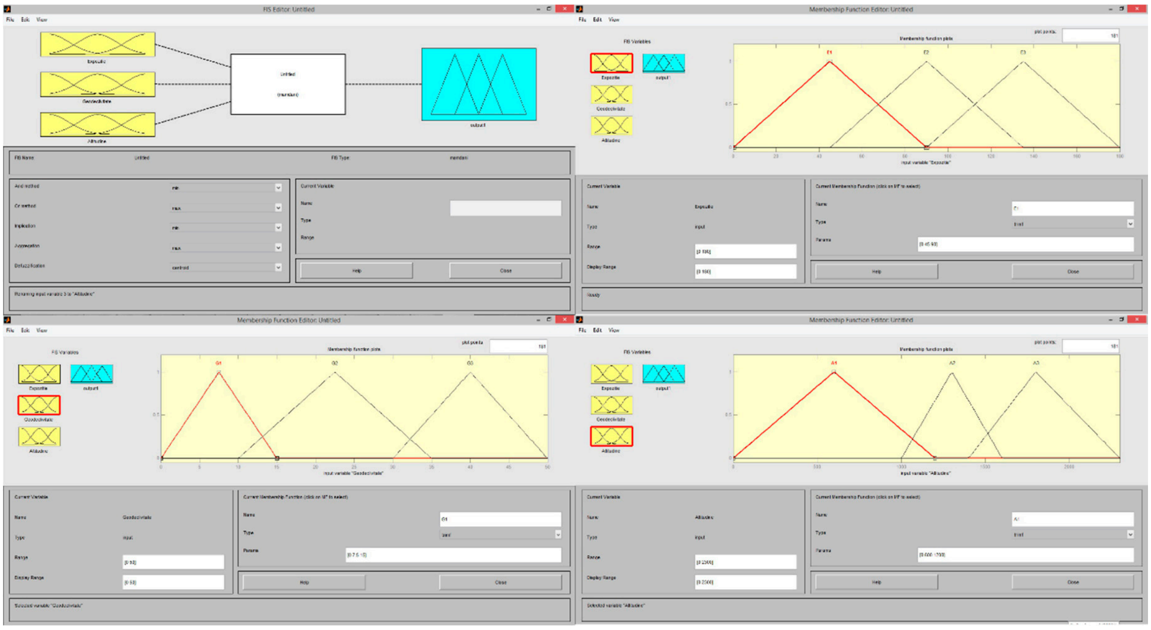

Figure 5. Setting Fuzzy intervals (variables).

For the exposure, three cases were considered, namely:

(a) exposure to N, NE, NV, with a high degree of favorability—1E;
(b) exposure n to E and V, with a medium degree of favorability—2E;
(c) exposure n to S, SW, SE, with a low degree of favorability—3E.

For geodeclivity, three situations were also considered:

(a) for values situated in the range of (5, 15) a low degree of suitability—1G;
(b) for values situated in the range of (15, 35) a medium of suitability—2G;
(c) for values situated in the range of (35, 45) a high degree of suitability—3G.

The altitude was classified in three variables, namely:

(a) below 1200 m, with a low degree of favorability—1A;
(b) in the range (1200, 1600) with a degree of medium favorability—2A;
(c) over 1600 m, with a high degree of favorability—3A.

The Fuzzy sets allow partial belonging of the elements to the set, the degree of belonging to the membership function can take any value from 0 (not belonging) to 1 (total membership). The triangular membership function for input variables is shown graphically in Figure 6.

Further were set the Fuzzy base rules base that depend on two conditions, namely "if" and "then", established by the experts based on the factors influencing the output variable. The number of Fuzzy base rules are equal to $3^3 = 27$. The output Fuzzy range will be divided into three classes: small (OFR1), medium (OFR2), and high (OFR3) (Figures 7–9).

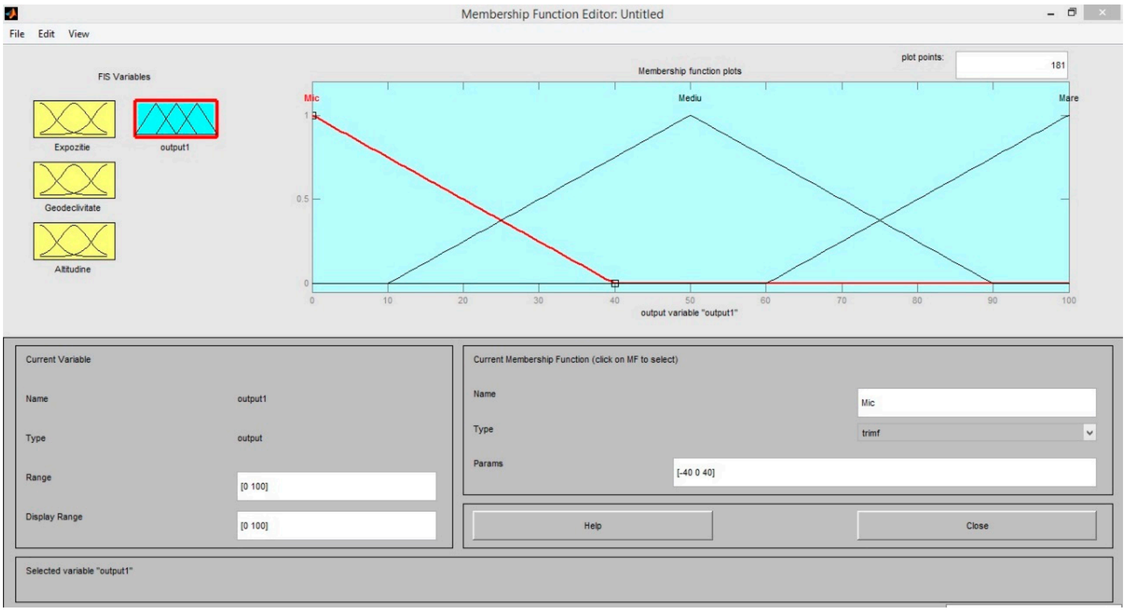

Figure 6. Output Fuzzy range.

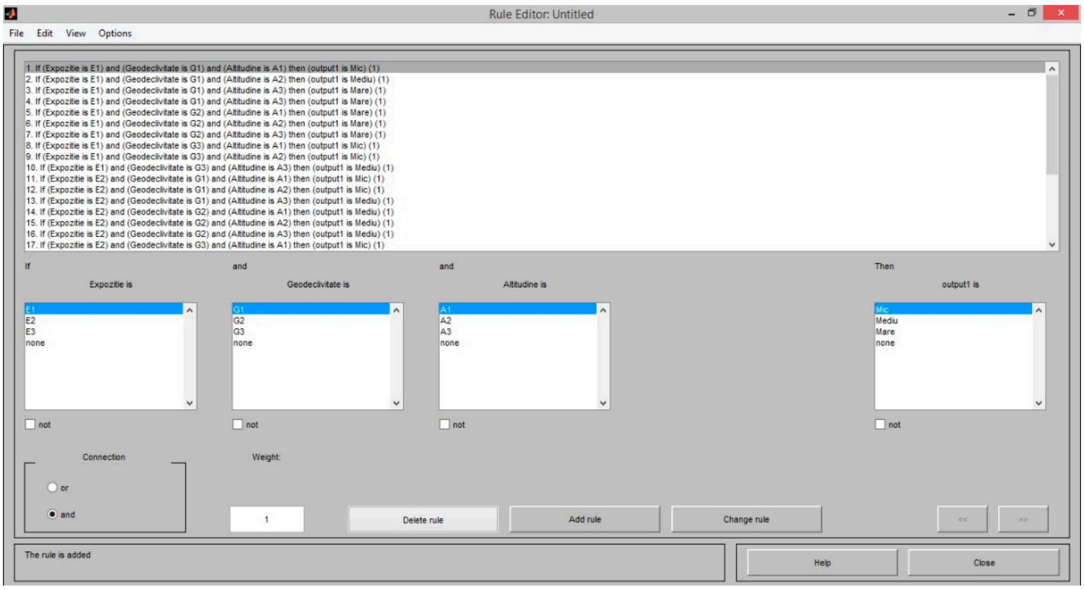

Figure 7. Establish the Fuzzy rules.

After computing the values and establishing the rules of the Fuzzy model, by introducing the parameters (exposure, geodeclivity and altitude), were generated the results of the estimated required amount of snow for an area of 100 m identified in a low suitability area. The results of the Fuzzy analysis were divided into three spheres of influence for model certification: small influence up to 45%, average influence from 46% to 60%, and high influence over 60% (Table 2).

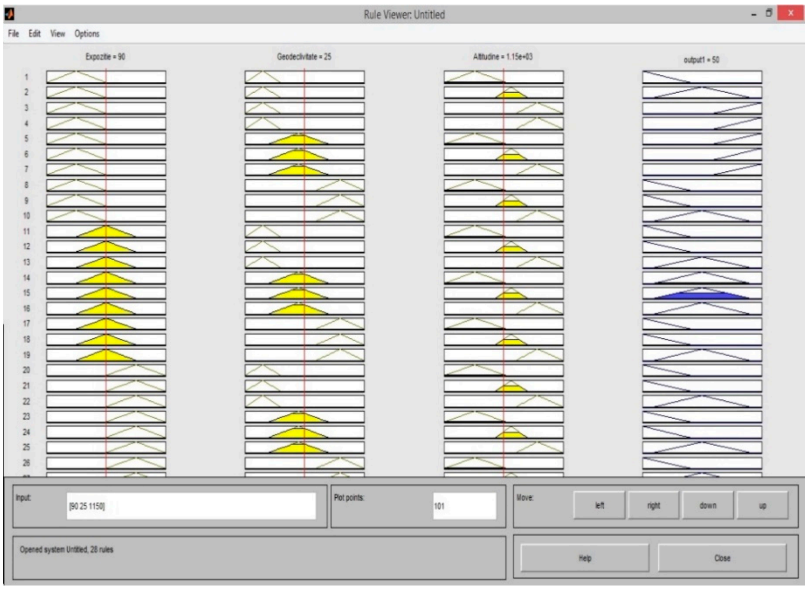

Figure 8. Entering values in Fuzzy regulator.

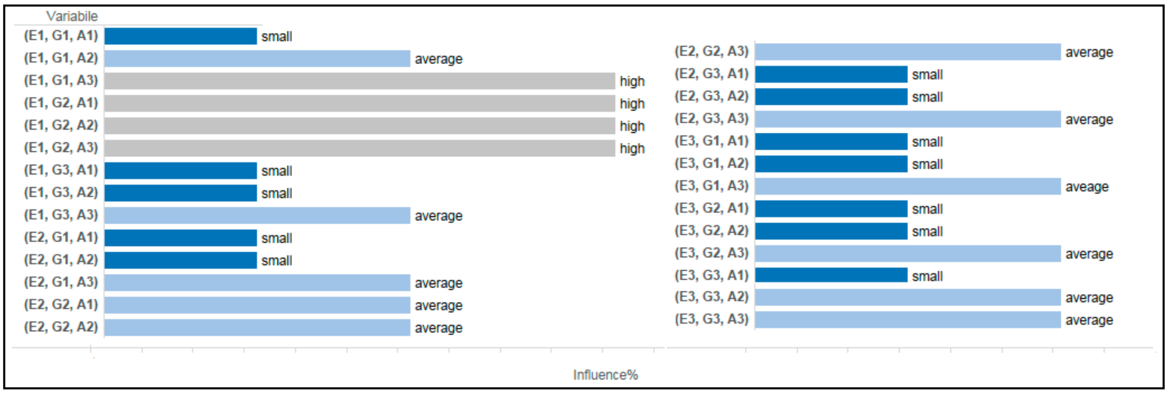

Figure 9. The (E, G, A) vector and the possible combinations.

Table 2. The Fuzzy Rules Set.

Variable	Influence	Influence %
(E1, G1, A1)	small	45
(E1, G1, A2)	average	60
(E1, G1, A3)	high	100
(E1, G2, A1)	high	100
(E1, G2, A2)	high	100
(E1, G2, A3)	high	100
(E1, G3, A1)	small	30
(E1, G3, A2)	small	30
(E1, G3, A3)	average	60
(E2, G1, A1)	small	30
(E2, G1, A2)	average	60
(E2, G1, A3)	average	60
(E2, G2, A1)	average	60
(E2, G2, A2)	average	60
(E2, G2, A3)	average	60
(E2, G3, A1)	small	30
(E2, G3, A2)	small	30

Table 2. *Cont.*

Variable	Influence	Influence %
(E2, G3, A3)	average	60
(E3, G1, A1)	small	30
(E3, G1, A2)	small	30
(E3, G1, A3)	average	60
(E3, G2, A1)	small	30
(E3, G2, A2)	small	30
(E3, G2, A3)	average	60
(E3, G3, A1)	small	30
(E3, G3, A2)	average	60
(E3, G3, A3)	average	60

The de-Fuzzyfication procedure allows calculating a scalar value, reflecting a more explicit value for the output variable. This scalar value is derived from the information associating to the Fuzzy output variable [15].

3. Results

Establishing the critical sectors regarding the thickness and the duration of the snow cover are important for the efficient exploitation of the ski domain and for a sustainable management of water and energy resources. Moreover, the analysis offers useful information for not only the current climate context, but also information that can be used in a context in which the climatic parameters change as a consequence of global climate changes.

The analysis carried out by raster operations (Figure 10) revealed seven areas with a low thickness of snow (Figure 11), areas that were analyzed using Fuzzy logic for the optimization of the artificial snow system. These seven areas were simulated using Fuzzy logic (Table 2), the resulting indicators falling in the ranges of influence.

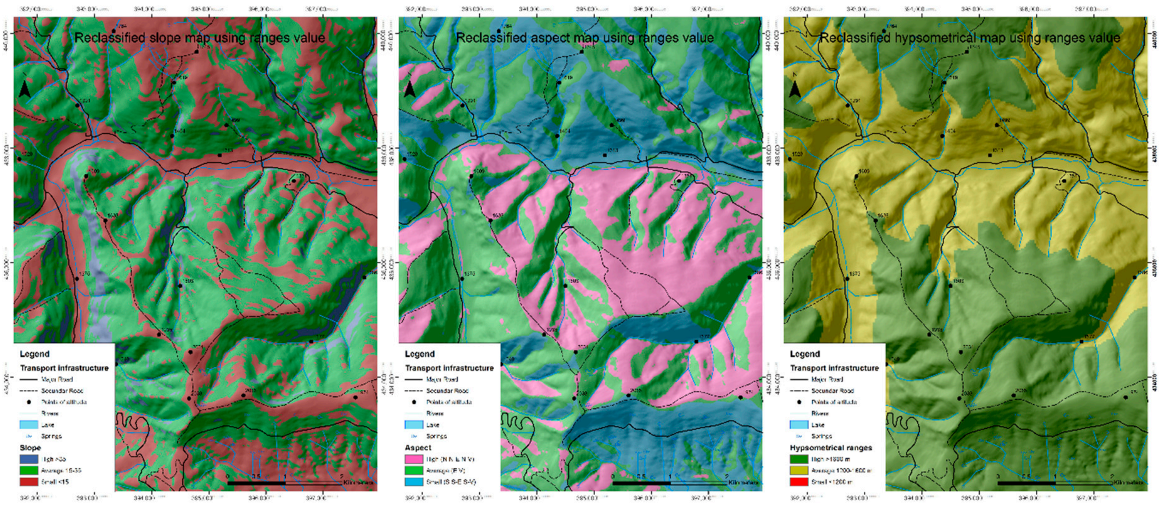

Figure 10. Classification of geomorphologic factors according to the favorability.

So, after entering the values and generating the result, it was obtained for sector no. 1 that the actual amount of snow is 42.9% from the optimum quantity and 56.1% is required. The optimum (100%) snow volume is 750 m^3, so for 42.9% of volume is required 428.25 m^3 of artificial snow. This Fuzzy analysis aims the optimization of the artificial snow making systems by achieving energy savings and resizing the water supply for the ski area (Table 3).

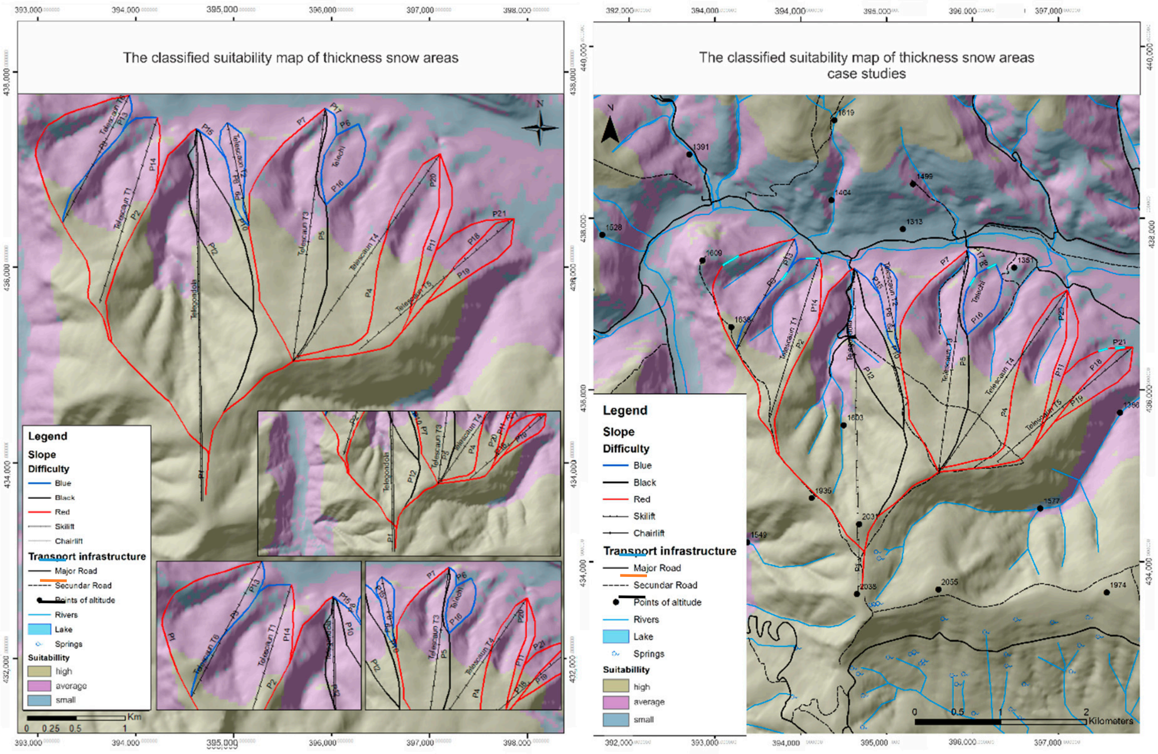

Figure 11. Map of thickness snow areas.

Table 3. Simulation Results using MatLab.

	Aspect	Geodeclivity	Hypsometry	Amount of Snow per Sector (%)	Volume of Required Snow (m^3)
1	154	9	1521	42.9	428.25
2	28	11	1435	51.5	363.75
3	106	10.3	1399	17.6	618
4	33	6.7	1390	50	375
5	81	11	1340	35	487.5
6	16	7.4	1403	50.2	373.5
7	51	12.4	1365	51.5	363.75

4. Discussion

Responsible management of energy and water resources should be a top priority for the ski domain administrator, both economically and environmentally.

The average favorability class is characterized by an average altitude of 1200–1600 m, East or West exposure, and geodeclivity between 15 and 35 degrees. The areas with high favorability are those located over 1600 m altitude, with north aspect and a geodeclivity above 35 degrees (the geodeclivity above 35 degrees can be assigned for low favorability, because the skiers exercise with greater pressure on snow). To identify the necessary volume of snow, the ski slopes were divided into 100 m sectors, which allowed the calculation of the volume of snow, representing an ideal of 750 cubic meters. After the identification of the areas, seven sectors with low favorability were taken into account and were introduced in the Fuzzy model for improving the installation of artificial snow.

The Fuzzy controller aims to identify the snow layer optimum according to the area deficiencies. The Fuzzy controller is based on geomorphologic and climatic parameters that directly affect the continuous snow cover that must be at least 30 cm high in optimal conditions for winter sports.

Fuzzy analysis is an authentic anticipatory tool, useful both in the design phase of a ski domain as well as in the operationalization of the project for correlating and adapting resources depending on the spatial and temporal contexts.

Fuzzy analysis can also highlight the sensitivity areas by identifying the boundary between efficiency-financial inefficiency, capitalization of energy, and water resources.

Regarding the approach in the area of skiing, there is a late start into using these fuzzy computing methods. The mention that should be made is that similar studies in which the classification and use of fuzzy systems have been applied [17,18] were oriented to the way of determining avalanches and the predictability of these phenomena, with the determination of areas in which they are predisposed. An attempt should be made to address the fuzzy methodology in the ski areas [19], but with more emphasis on the mathematical computing apparatus and methodology and less on the technical and geographical terrain.

5. Conclusions

Keeping an optimum snow cover at least 30 cm thick is a principal aspect for practicing winter sports. A ski area stands out by the variety and difficulty degrees that depend on their configuration for ski slopes, plus the average number of days for practicability of winter sports.

Throughout the ski slopes, several sectors can be identified where the geomorphological factors may arise due to disruptive snow cover, or where they can have a thickness under 30 cm. Identifying areas was based on the methodology of favorability relief for developing ski areas. Following this support methodology, we were able to identify the geomorphological parameters that were put into the Fuzzy controller in the second phase. By setting intervals of membership and rules for Fuzzy controller, the snow need was identified.

The methodology addressed in two stages and manages to capture the optimum quantity of water to optimize the artificial snow facilities. Though the optimization of artificial snow facilities are produced significant savings in terms of electricity consumption, but the most important aspect is to give the skiers an ideal surface for winter sports.

The Fuzzy analysis represents a veritable work tool both for the investors and experts who carry out the feasibility studies regarding the development of a ski domain due to the fact that the analysis offers a clear picture of the sensitive areas to the climatic variations, induced either by the local particularities of the area or by the impact of the global climatic changes overall.

Through this type of Fuzzy analysis, the predictability related to the efficient management of financial resources but also of energy and water resources is created, which is particularly important in the current context of sustainable environmental management.

Starting from the applied methodology and the results of the present study, in the future we can take into consideration to test this approach for other areas with different geomorphological conditions from the Carpathian area. The strengths of the approach are represented by the possibility of the identification and optimization of the water requirement for maintaining the minimum thickness of the snow layer along the slopes, while the limitations of the applied method are represented by the small number of methodological tests in this specific field of research.

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